Development of a Building Energy Code for New Buildings in Thailand

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Abstract: Thailand has adopted an act for promotion of energy conservation since 1992. The law mandates issuance of ministerial regulations for energy conservation in large commercial buildings and creates an energy conservation promotion fund. A building energy code was developed and implemented on new and existing large buildings as a part of a set of bye-laws of the act. The code comprises mainly performance based requirements on building envelope system, lighting system and air-conditioning system of a building. In 2002, a project was launched with support from the Danish Agency for International Development Assistance to revise the code. A new strategic framework was adopted in setting the objective of the code development. It was decided that as the code would be implemented on a mandatory basis, it should set minimum energy performance requirements at system level for all major building systems. Life cycle costing concept was adopted as the basis for identification of suitable level of energy performance of each building system. It was then deemed that the new building energy code should be implemented on a mandatory basis on new buildings, not yet constructed, only. For existing buildings, promotion for voluntary participation on energy conservation and mandatory labeling would be the strategic direction to take. New performance indicators were developed for building envelope system and air-conditioning system. Whole building energy compliance is introduced as an alternative procedure if one or more systems of a building design cannot individually meet the respective requirements. This option adds another degree of flexibility in building design. Appropriate levels of energy performance requirements on all building systems and all building types were identified in concurrence with relevant professional institutions.

Keywords: Building Energy Code, Energy Conservation, Energy Management, Energy Performance Standards, Energy Efficiency Guideline.

1. INTRODUCTION

Energy and electricity consumption in Thailand increases significantly over the last two decades since the period of oil shortage in 1980s. From 1990, the economy expanded at a fast pace with the corresponding rise in energy consumption. With an elasticity of energy consumption growth over GDP growth of 1.12, [1] and [2], this also signifies a fast changing economy away from agriculture towards industry and services. The low and steady price of oil prevailing since late 1980s led to a steady increase in consumption of energy resources. From 1985 to the present, per capita consumption of oil and natural gas has increased five folds, while per capita consumption of electricity has increased four folds. Although urbanization in Thailand develops slowly compared to other developing countries, there has been social transformations and development in real estate sector together with changes in commercial and service sectors that result in significant increase in the number of large commercial buildings in Bangkok and all over Thailand. These large commercial buildings are all fully air-conditioned and are thus energy intensive.

The interest in energy conservation for commercial buildings arose from the situation of oil price hike and shortage. When ASEAN countries (in Southeast Asia) initiated joint activities with dialog countries in the early and mid 1980s, research and development in energy conservation in commercial buildings was a subject designated for cooperation. Experiences in USA had shown that energy conservation effort led to a decline of energy use per floor area of 11% during 1972 to 1982, [3]. An ASEAN-US cooperation program was thus adopted that later led to the development of building energy codes, [4]. A code was developed by some members of the authors of this paper in 1987 using a model provided from the cooperation program, [5].

Due to incessant effort by energy personnel in state and private sectors, a law called Energy Conservation Promotion Act (ECP Act) was promulgated in 1992. In 1995, requirements for energy conservation for large commercial buildings were made in a set of Ministerial Regulations, or By-laws of the ECP Act, its content being based on the 1987 code. However, despite the existence of the Ministerial Regulations and available funding for energy conservation activities from an Energy Conservation Promotion Fund (ECP Fund) created by the ECP Act, energy conservation effort for commercial buildings has been considered to have achieved limited success. As a part of the effort to improve the situation, the Department for Alternative Energy Development and Energy Efficiency (DEDE), requested the Danish Cooperation for Environment and Development (DANCED) for support in reviewing and adjusting the existing building energy code, with a view toward revising the relevant Ministerial Regulations. The request was approved and the project commenced in December 2001. The Asian Institute of Technology was chosen as the local lead consultant for the project. International experts were employed to guide and assist local consultants. The project was completed in early 2004 and the preparation is underway to implement the new code.

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2. DEVELOPMENT AND APPLICATION OF BUILDING ENERGY CODE IN THAILAND

Standard 90-1980 for Energy Efficient Design of New Buildings of ASHRAE, [6], was used as the main model for development of building energy code in ASEAN. The Philippines, Singapore and Thailand have adopted mandatory building energy performance requirements as parts of laws on building control or specific laws on energy conservation. Indonesia and Malaysia utilize building energy code on voluntary basis.

2.1Components of a building energy code

Studies conducted during early 1980s found that air-conditioning (for cooling) and electric lighting typically accounted for 60% and 20% respectively of the electricity consumption of a commercial building in Thailand, [7]. Furthermore, heat gain across building envelope due to external driving forces contribute 60% of the load of the cooling coils of the air-conditioning system. Such studies led to the inclusion of requirements on performance of building envelope, air-conditioning system and lighting system in the building energy code.

A measure of the performance of building envelope, called OTTV or Overall Thermal Transfer Value, has also been introduced as part of the code. Table 1 lists main requirements in the existing code.

Table 1 Requirements in the existing code of Thailand

Requirements	Application
Overall Thermal Transfer Value (OTTV)	
< 45 Wm^{-2}	new buildings
< 55 Wm^{-2}	existing building
Lighting power density	
< 16 Wm^{-2}	Office, school, hotel and hospital
< 23 Wm^{-2}	Department store
Air-conditioning systems	
System performance requirements on unitary air-conditioners	Distinct sets for new and for existing buildings
Requirements on chillers only for large air-conditioning systems	Distinct sets for new and for existing buildings

2.2 Application of Building Energy Code in Thailand

In implementing the Ministerial Regulations that embody the building energy code, dismal success has been observed. This unfortunate situation stems from the way the law was applied and the deficiency in the code itself.

Experiences Gained. Implementation of the Ministerial Regulations during the last nine years on over 1,800 buildings have taught that too much emphasis has been placed on retrofitting existing buildings. While economic and financial justification for replacement of existing equipment in existing building are unclear because the value of each equipment whose life has not expired could not be properly evaluated, the requirements of the Ministerial Regulations have been difficult to fulfilled. Disproportionate emphasis has been placed on standard items of equipment replacement or maintenance management by the authority [8]. While the cost of equipment replacement would be born by the proprietor of each building, the authority develops its own set of targets for replacement. This leads to divergence on energy efficiency improvement in a given building between the building proprietor and the consultant who conducts energy audit and whose energy audit report must be approved by the authority.

Weaknesses in the Present Building Energy Code. Some weaknesses need to be addressed and corrected. The code does not provide direct linkage between energy performance of different systems in a building to energy consumption and energy cost of the building. Moreover, the code tends to mislead industry participants to taking the code requirements as optimum targets, while the performance requirements were meant to be minimum requirements at the onset. However, the code requirements are mainly performance based. The code introduces and familiarizes building professionals to OTTV as a measure of thermal performance of building envelope, as a system performance requirement. This has helped create a knowledge base among the pool of building professionals. The detailed requirements in the existing code are also subject to review since its requirements were made based on technologies prevailing close to one decade ago.

3. FRAMEWORK OF THE NEW CODE

3.1 Concept of Standards Push and Promotion Pull

Experiences from works in improvement in energy efficiency worldwide have led to a conclusion that *mandatory requirement on energy efficiency used as a push mechanism while promotional program used as pull mechanism would be effective in achieving energy efficiency goals,* [10]. Figure 1 illustrates the point.

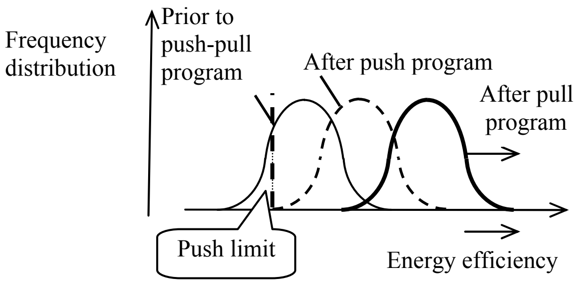


Fig. 1 Movement of distribution of energy efficiency from push and pull programs.

The mandatory requirements for energy efficiency of buildings will eliminate buildings whose energy performance cannot meet the requirements. But it is necessary to be cautions in setting such minimum performance requirements, since some conditions could disadvantage some industry participants. The minimum performance levels should be chosen so that industry participants could adjust when given a reasonable period of time. Here, it is expected the code will be a push mechanism that utilizes clear and accurate performance indicators.

3.2 Economic Basis for Energy Performance Requirement

In a normal time horizon, energy efficiency is an economic issue. It is thus rational to use economic principles to derive energy performance requirements.

Application of Life-cycle Costing Principle to New Buildings. For a building at the design stage, the choice of building construction, systems and equipment to be used is relatively free of constraint. A building developer could freely consider alternative designs, and alternative choice of systems and equipment. *It is logical that energy performance requirements or a mandatory building energy code applies to building not yet constructed.* Total cost throughout the life of a building should be used as basis for choice of building systems. *It is also logical to use life-cycle costing concept to assist in the development of energy performance requirements for new buildings or buildings not yet constructed.*

Life-cycle costing accounts for initial cost, energy cost, other operating and maintenance cost (including labor), life of each component forming the system; it is assumed that there is automatic renewal when the life of a component expires, discount rate, inflation and escalation of some cost items such as energy cost, salvage value of each component when its life is expired, and taxes, if economic consideration is required. The first two items dominate in our case. The systems in a building to be considered for setting minimum energy performance requirements are building envelope system, lighting system, and air-conditioning system. Life-cycle costing method is applicable to each system.

Existing Buildings. In an existing building, all systems and most equipment are already installed and being used. For an existing building, constraint and viability of replacement of each system and equipment in each building is unique. It is not suitable to set common mandatory requirements on energy performance for existing buildings. Energy labeling using criteria such as energy performance as well as sound management and indoor air quality could be used as criteria in a more effective pull program. Energy labeling itself can be made mandatory for existing buildings.

3.3 Features of Energy Performance of Building Systems

The new code continues to adopt system performance requirements and includes whole building energy compliance. In adopting system performance based requirements, appropriate measures or indices of performance must be identified and used.

Building Envelope System. The Overall Thermal Transfer Value (OTTV) has been introduced as an overall system performance index for building envelope in the existing code. It encompasses performance of opaque walls and windows of the whole buildings. *This index will still be used but its accuracy could be improved by adopting different indices for different types of building.* Three types of commercial buildings are distinguished as in Table 2. Parameters in the OTTV formulation embody time of use and weather information.

Lighting. Common indicator used in the present code and in all codes in the world is *lighting power density (LPD, Wm^{-2})*. This continues to be used.

Air-conditioning. Common performance indicators are performance of main equipment such as chiller.

Table 2 Usage duration and total hours per year of three groups of buildings

Building Category	Usage time	Number of hours per year
Office and education institutes	8.00-17.00	2,340
Department store and hypermarket	10.00-22.00	4,380
Hospital and hotel	24 hours	8,760

It is desirable to adopt whole system performance indicator, the coefficient of performance of the system. Existing code does not have requirement on whole system performance. As will be seen, the procedure for whole building energy compliance requires that a system performance measure or indicator be adopted for each system. *Coefficient of performance of the air-conditioning system is thus adopted.*

Whole Building Energy Performance. This is used in ASHRAE Standard 90.1-1999 for Energy Efficient Design of New Buildings, [9]. Figure 2 illustrates the concept. The following description is similar to but not exactly identical to that in Standard 90.1. It is the concept the proposed new Thai code is based.

This option allows the design of a proposed building to be assessed first with respect to the prescriptive requirements, or for system performance-based compliance. If the design passes the prescriptive or system performance-based compliance path, then the design is accepted. If the design does not pass either the prescriptive or system performance-based compliance, then it is still eligible for assessment under the whole building energy compliance path.

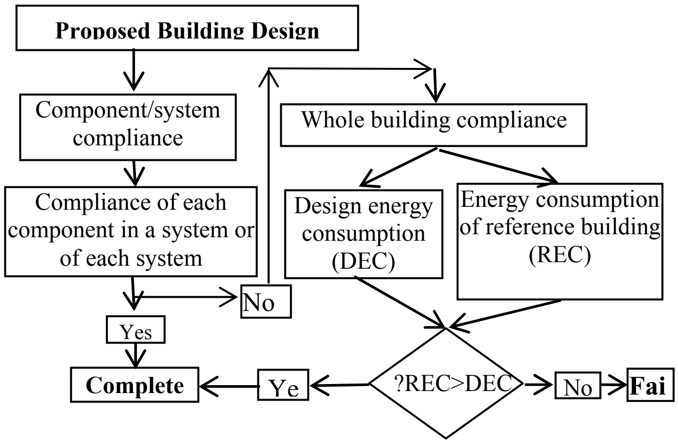


Fig. 2 Illustration of the concept of whole building energy compliance.

In this situation, a "*reference*" or "*generic"* hypothetical building design is set up. This building would have identical dimensions, shape, and functional areas as those of the proposed building design, but the reference building complies with the prescriptive or performance-based requirements. If the annual energy consumption of the proposed building is lower than of the reference building, then this design complies with the requirements under this path. Calculation of annual energy requirement of a building will be based on a method to be described.

4. DEVELOPMENT OF NEW OTTV FORMULATIONS AND THE ENERGY EQUATION

4.1Conceptual and Developmental Background

The existing code uses a single OTTV formulation and same set of parametric data for all buildings for all locations in Thailand.

Concept of New OTTV and Energy Relationship. From the beginning of this code development effort, it was decided that the new OTTV formulation will be developed so that it would be used as a measure of annual average heat gain through building envelope *as sensed by the cooling coil of the* *air-conditioning system* of a building. It is meant to be used in the equation

Annual average cooling coil load (of an air-conditioning system)
= *(OTTV) (wall area) as external factor of load*
+ *lighting, equipment, occupants and ventilation as internal factor of load.*

With such postulate, it can then be used to calculate annual energy use in a given building through the relationship

Annual energy use of a space
= *annual cooling coil load of the space /COP*
+ *annual direct use of energy of lighting and other equipment,*

where COP is the coefficient of performance of the air-conditioning system. The first term in the last equation accounts for air-conditioning energy. .With the OTTV formulation developed this way, the formulation could be used to calculate reference annual energy use of a building design and that of a reference building. In this way the equation can be used in the whole building energy compliance procedure. The OTTV formulation would become an accurate measure of thermal performance of envelope of each category of commercial buildings. The energy equation relates performance of wall, lighting and others to reference annual energy consumption of the whole building.

Consideration of Differences in Regional Climates. The OTTV formulation embodies detailed, hour-by-hour weather data of a location. Once it is developed, it is suitable to the location from which the weather data is taken. At the beginning, it was felt that OTTV formulation could be developed for each building category for each of the four major regions of Thailand. In the compilation of solar radiation data, it was found that the data sets for the year 2000 were most complete for all 4 regions.

During the course of the study it was realized that it would be confusing to adopt different OTTV requirements for each region (For example two buildings in two towns bordoring each other may be subject to different OTTV calculations and different requirements). The weather across Thailand does not differ much in reference to energy consumption of buildings. From simulation, the difference in energy consumption of a building of same design but located in different regions differ marginally (less than 5%). It was decided that a single OTTV formulation for each category of building developed based on Bangkok data (most comprehensive and reliable) would be used. Bangkok weather was also found to cause the highest energy consumption for a given building among the regions.

4.2Parametric Runs in the Development of OTTV Formulations and Energy Equation.

Building energy simulation programs were used to develop the new OTTV formulation and the energy equation. Both the well-known DOE-2 Program (developed and maintained by Laurence-Livermore National Laboratory of the University of California, Berkeley, USA) and a program developed at the Energy Program at the Asian Institute of Technology (EP-AIT Program) were used. The EP-AIT Program uses energy balance principles at all levels and in all equipment operation. It was validated and described in a technical report and published internationally, [10]. A square building comprising 4 identical zones as in Figure 3.1 was used in the parametric runs.

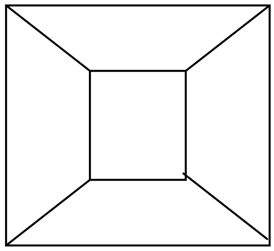


Fig. 3 Building model used in the parametric run.

In each run, the cooling coil load was obtained corresponding to a case. The nominal form of OTTV formulation is

$$OTTV = (1-WWR)(TD_{eq})(U_w) + (WWR)(\Delta T)(U_f) + (WWR)(SHGC)(SC)(ESR),$$

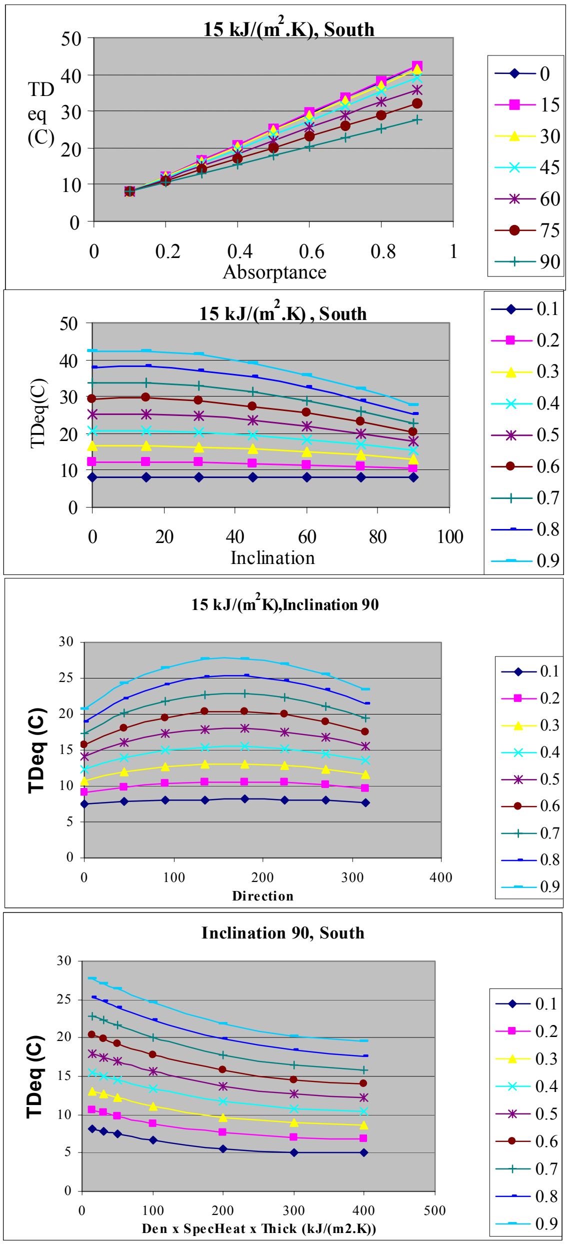
where WWR = window area to overall wall area,
TD_{eg} = equivalent temperature difference of opaque wall,
U_w = thermal conductance of opaque wall,
ΔT = temperature difference for glazed window,
U_f = thermal conductance of glazing,
SHGC = solar heat gain coefficient of glazing,
SC = shading coefficient of shading device, and
ESR = effective solar radiation.

To obtain the value of TD_{eq} in this case, the value of U_w would be varied each time to produce one pair of values of cooling coil load and U_w, while all other parameters are kept constant. A collection of several pairs of such values are then used to regress for the value of TD_{eq}, the equivalent temperature difference. A large number of parametric runs were conducted to obtain complete formulations.

4.3 Results

The following OTTV formulations and energy equation are obtained

OTTV Formulations. The resultant OTTV formulations are expected to be highly accurate since each formulation is specific to one category of building. It is very sensitive to material properties, orientations and inclination angles of wall. It represents heat gain through a wall in an orientation as sensed by the cooling coil and as is transferred to the air-conditioning system. Figure 4 illustrates the variation of TD_{eq} and ESR with respect to its parameters.



a) TD_{eq} variation with surface absorptance, wall inclination, density-specific heat-wall thickness product, and orientation.

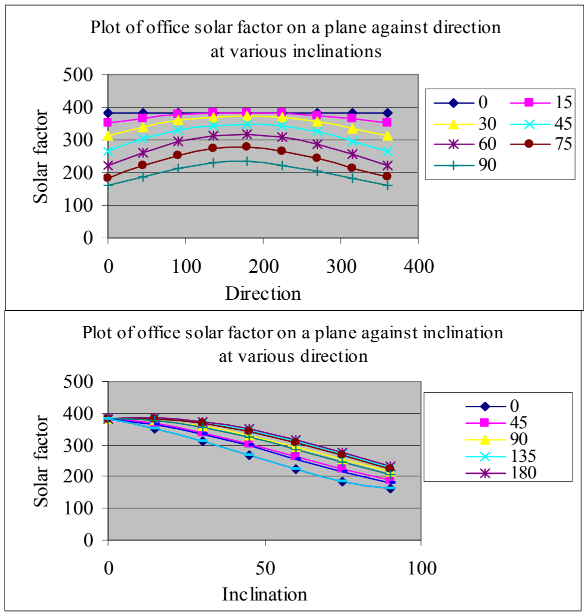


Fig. 4 Variation of TD_{eg} and ESR with respect to their parameters.

The new formulation is highly sensitive to direction, mass and type of buildings. Table 3 illustrates the sensitivity of TD_{eq} with respect to wall mass and type of building.

Table 3 Variation of TD_{eq} with wall mass

	Inclination angle, degree	Direction	Density-specific heat product kJ/(m².K)	Solar Absorptance 0.3	0.5	0.7	0.9
Office	90	South	15	13.0	18.0	22.9	27.8
			30	13.0	18.0	22.9	27.8
			50	12.7	17.5	22.3	27.1
			100	12.2	16.9	21.6	26.3
			200	11.1	15.6	20.1	24.6
			300	9.7	13.7	17.8	21.9
			400	8.9	12.7	16.5	20.3
Dept store	90	South	15	9.8	13.1	16.4	19.7
			30	9.9	13.3	16.6	20.0
			50	10.0	13.4	16.9	20.3
			100	10.1	13.7	17.2	20.8
			200	9.8	13.3	16.9	20.4
			300	9.1	12.5	15.9	19.3
			400	8.5	11.8	15.0	18.3
Hospital	90	South	15	5.6	7.7	9.7	11.8
			30	5.6	7.7	9.8	11.8
			50	5.7	7.7	9.8	11.9
			100	5.7	7.8	9.9	12.0
			200	5.8	8.0	10.1	12.3
			300	5.9	8.1	10.3	12.5
			400	5.9	8.2	10.4	12.6
Hospital	90	South	15	5.6	7.7	9.7	11.8
			30	5.6	7.7	9.8	11.8
			50	5.7	7.7	9.8	11.9
			100	5.7	7.8	9.9	12.0
			200	5.8	0.8	10.1	12.3
			300	5.9	8.1	10.3	12.5
			400	5.9	8.2	10.4	12.6

Decreasing

For an *office building* operating during daytime only, higher wall mass delays or retards transmission of heat to the cooling coil.

For a *department store*, its operating time extends into early part of night so that part of the heat stored during the day is transmitted to the cooling coil when the mass of the wall increases slightly from the minimum. But when the mass of the wall is higher than the critical value, the wall is able to delay transmission of heat to later part of the night so that its effect on the cooling coil becomes smaller.

For a *building used for 24 hours in a day*, the stored heat during the day is transferred to the cooling coil during the night.

The new OTTV formulations are able to capture the heat storage and delay effects as demonstrated by the above results. Other effects such as wall orientations are also captured.

Energy Equation The parametric runs conducted were also regressed to obtain the values of parameters of the energy equation.

Cooling coil load

$= (OTTV)(A_w / A_f) + C_l(LPD) + C_e(EQD) + C_o(OCCU) + C_v(VENT)$.

Table 4 shows values of the parameters obtained. The nominal number of hours of operation of each building category is also given in the table

Table 4 Values of parameters

Building category	C_l	C_e	C_o	C_v	n_h
Office and school Department store	0.84	0.85	0.9	0.9	2340 4380
Hotel and Hospital	1.0	1.0	1.0	1.0	8760

5. ENERGY PERFORMANCE REQUIREMENTS

5.1 Conceptual Framework. The approach taken in this study was first to define a reference condition or system. Alternative and more efficient features were successively considered. The results were then used to convince industry experts to agree to a level of efficiency for each building system. The computer program DOE-2 were used in obtaining time of use (TOU) energy cost.

5.2 Building Envelope System It is observed that static thermal performance of basic opaque components of walls (U-value) are similar. The real difference comes from use of additional layer(s) of insulation. This study then considered brick and cast concrete walls as reference opaque wall in combination with insulation layers.

All single glazing offers similar U-value, coating on glazing affects optical performance. *Double glazing offers lower U-value*, *but real benefit is obtained when one side is coated with low emissivity material* that also possesses spectrally selective property of higher transmittance of visible radiation than transmittance of infrared radiation.

Life cycle costs of combination of reference wall, improved wall and 3 glazing types of *same visible transmittance* were compared when used with each building type. This paper presents results of a reference wall and a wall with insulation used in combination with three glazing types described to help establish performance requirements on walls of the three categories of commercial buildings listed in Table 2.

When the two wall types are used with the three glazing options, the resultant values of OTTV appear in Table 5. In the table, W_1 is the wall of brick with mortar, W_2 is the wall with PE insulation, $F_1$is the tinted float glass, F_2 is the heat reflective glass and F_3 is the double glazing with low-E coating.

Table 5 OTTV of combinations of two wall types and six glazing types at different WWR values

WWR	OTTV (W/m^2)					
	W1&F1	W1&F2	W1&F3	W2&F1	W2&F2	W2&F3
0	46.5	46.5	46.5	8.1	8.1	8.1
0.1	57.7	55.3	50.0	23.2	20.8	15.5
0.2	69.0	64.1	53.6	38.3	33.4	22.9
0.3	80.3	73.0	57.2	53.4	46.1	30.3
0.35	85.9	77.4	58.9	61.0	52.5	34.0
0.4	91.5	81.8	60.7	68.5	58.8	37.7
0.5	102.8	90.7	64.3	83.6	71.5	45.1
0.6	114.1	99.5	67.8	98.7	84.1	52.5
0.7	125.3	108.3	71.4	113.8	96.8	59.9
0.8	136.6	117.2	75.0	128.9	109.5	67.3
0.9	147.9	126.0	78.5	144.0	122.2	74.7
1.0	159.1	134.8	82.1	159.1	134.8	82.1

The combination of Wall 2 and glazing 2 or W_2&F_2 represents the combination with lowest life cycle cost. This is seen from the life cycle costs of different combinations presented in Table 6. If this combination is chosen, the cost of wall for a building will be lowest among the six combinations presented.

Table 6 Life cycle cost of each wall combination

WWR	Life cycle cost (B/m^2/Y)					
	W1&F1	W1&F2	W1&F3	W2&F1	W2&F2	W2&F3
0	210.4	210.4	210.4	197.9	197.9	197.9
0.1	253.8	237.4	259.2	242.6	226.2	248.0
0.2	297.2	264.5	307.9	287.2	254.5	298.0
0.3	340.6	291.5	356.7	331.9	282.8	348.0
0.35	362.3	305.1	381.1	354.2	297.0	373.0
0.4	384.0	318.6	405.5	376.5	311.1	398.0
0.5	427.4	345.6	454.3	421.2	339.4	448.0
0.6	470.8	372.7	503.0	465.8	367.7	498.1
0.7	514.2	399.7	551.8	510.5	396.0	548.1
0.8	557.6	426.8	600.6	555.1	424.3	598.1
0.9	601.0	453.8	649.4	599.8	452.6	648.1
1.0	644.4	480.9	698.2	644.4	480.9	698.2

Based on the values in W_2&F_2 column, for value of WWR at 0.3, the OTTV of this wall is given as 46.1. This value of WWR of 0.3 is the high limit allowable in ASHRAE Standard 90.1. Also, in the existing code, WWR = 0.3 for a reference wall with the same reflective glazing gives a value of OTTV close to 45. To be consistent with the present code, *the requirement for thermal performance of wall in the new code should be set at 50 Wm^{-2}*.

Based on similar considerations, and based on a series of consultations with relevant experts and architects, the energy performance requirements for building envelope of commercial buildings were recommended as in table 7.

Table 7 Recommended minimum allowable energy performance for building envelope

Building type	Requirement
Wall	
Office or school,	O-OTTV < 50 Wm^{-2}
Department store or hypermarket,	S-OTTV< 45 Wm^{-2}
Hotel or hospital	H-OTTV < 30 Wm^{-2}
Roof	
Office and school,	O-RTTV < 15 Wm^{-2}
Department store or hypermarket	S-RTTV < 12 Wm^{-2}
Hotel or hospital	H-RTTV < 10 Wm^{-2}

Table 8 Recommended allowable rated power density for lighting

(1) Category of building	Allowable rated power (W/m^2 of utilized area)
Offices or educational building	14
Department stores, retail stores, shopping centers or hypermarket(2)	18
Hotels, hospitals/Convalescent homes	12

5.3 Lighting System

In this case a building model was created for each type of building under consideration. Typical functional areas were identified for each building type. The level of illuminance or light flux per area was chosen in accordance with typical, full illuminance, design for each functional area. Different luminaires each with a different combination of lamp, ballast, and fixture were then considered to be used to serve each functional area. The lumen method for uniform lighting was then used to find the area of coverage of each set of luminaire and the lighting power density corresponding to such set. When the cost of each set of luminaire is known, the cost of luminaire per unit floor area of each functional area were calculated. With this method, the power density per unit area and the equipment cost per unit area could be calculated. Simulation program DOE-2 was then be used to calculate the annual electricity cost from using such set of luminaire in the given functional area.

Figure 5 illustrates life cycle costs of different luminaire options for office building model.

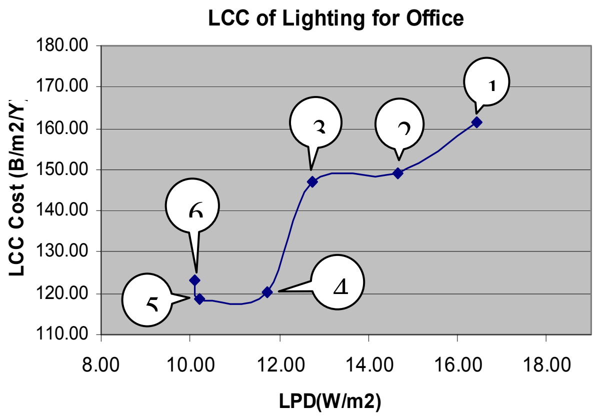


Fig. 5 Life cycle costs of different luminaire options.

Similar method is used for other types of buildings. Consultation with experts in a series of meetings resulted in the following recommendations for minimum performance requirements on lighting system.

5.4 Air-conditioning System

The same concept was applied to air-conditioning system. For a large air-conditioning system, the main equipment that consumes 65% of power are the chillers. Given an air-conditioning system, the choice of chillers can affect system performance, while other parts contribute less to the overall performance.

Requirements on Chillers The following graphs in Figure 6 compare results of life cycle costs from use of different chillers of different efficiency (or COPs) for a hypermarket building. The cost of each chiller at each given rated performance is obtained from the vendor of a well-known manufacturer of air-conditioning systems and components.

The Department for Development of Alternative Energy and Energy Efficiency in the Ministry of Energy has programs for promotion of efficient chillers.

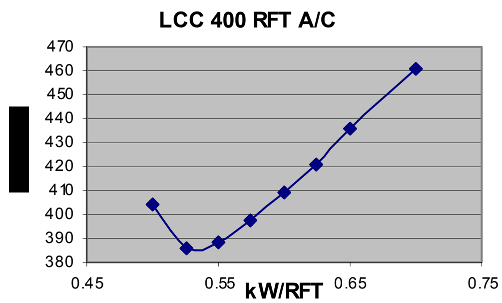


Fig. 6 Life cycle cost curve for the air-conditioning system of a hypermarket building corresponding to different COPs of chillers used.

The recommended value for coefficient of performance for large chillers had been 0.63. After consultation with Air-conditioning professionals the values in Table 9 were recommended.

Table 9 Recommended performance requirements for chillers.

Category and size	Minimum performance, COP (kW/TR)
Air-cooled water chiller	
Up to351.7 kW_{th} (100 TR)	(1.30) 2.70
Over 351.7 kW_{th} (100 TR)	(1.20) 2.93
Water-cooled water chiller	
Less than 527.5 kW_{th} (200 TR)	(0.90) 3.91
From 527.5 kW_{th} and less than 703.3 kW_{th} (250 TR)	(0.75) 4.69
From 703.3 kW_{th} and less than 879.2 kW_{th} (300 TR)	(0.67) 5.25
From 879.2 kW_{th} and less than 1,758.3 kW_{th} (500 TR)	(0.65) 5.40
Over 1,758.3 kW_{th}	(62.0) 5.67

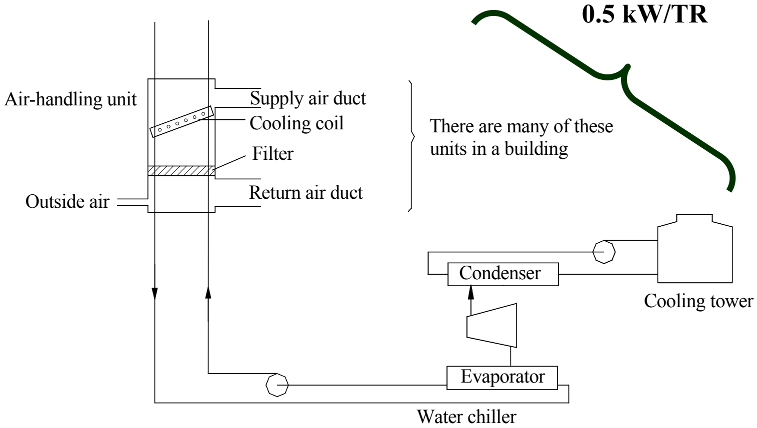


Fig. 7 Requirements on other part of the air-conditioning system.

Other Parts of an Air-conditioning System. The air-handling system, condenser water cooling system, and chilled water transport system taken together had been recommended a rated minimum coefficient of performance of 7.03 (0.5 kW/TR). Figure 7 illustrates the requirements.

For unitary air-conditioners, the levels recommended were identical to those at Label 4 of the prevailing energy labeling scheme.

6. ENERGY COMPLIANCE OF SYSTEMS AND OF THE WHOLE BUILDING

If one or more of the three systems of a proposed building design cannot comply with the corresponding system performance requirements, then the developer can submit the proposed building design to be assessed under the whole building energy compliance procedure.

Rated Energy Requirement of a Proposed Building Design. The rated energy requirement of the proposed building design is calculated from the following relationship

$$E_{pa} = \sum_{\substack{i=1\\i\neq j}}^{n}\left[\frac{A_{wi}\left(OTTV_i\right)}{COP_i}+\frac{A_{ri}\left(RTTV_i\right)}{COP_i} + A_i\left\{\frac{C_l\left(LCD_i\right)+C_e\left(EQD_i\right)+130C_o\left(OCCU_i\right)+24C_v\left(VENT_i\right)}{COP_i}\right\}\right]n_h + \sum_{i=1}^{n}A_i\left(LCD_i+EQD_i\right)n_h$$

The first summation in the expression above accounts for rated air-conditioning energy for a year, and the second summation accounts for the energy consumed directly by lighting and other equipment. The summation includes all air-conditioned zones and unconditioned spaces, and accounts for the corresponding area of each space. No air-conditioning energy is contributed from unconditioned spaces. The values of coefficients of thermal power contribution to the load of the air-conditioning systems by lighting, equipment, occupants and ventilation: C_l, C_e, C_o, and C_v are given in Table 4. The rated energy requirements of a building accounts for energy use during the nominal operating hour, n_h, of the given building category only. The number of operating hours of each building category is also given in Table 4.

Rated Energy Requirement of the Reference Building. A reference building model of the same shape, same floor area, same envelope area and same orientation is set up when the whole building energy compliance option is required. The model possesses air-conditioned zones and unconditioned spaces identical to those of the proposed building design. Each zone and each space comprises equipment power density (EQD), density of occupancy (OCCU), and ventilation rate (VENT) identical to those in the zones and spaces of the proposed building design.

However, the OTTVs of the walls and RTTVs of the roofs in all facades of the reference building comply with required values of OTTV and required values of RTTV of building of that category. Lighting power density in each zone and space takes on a common value LPD_c that complies with the relevant minimum performance requirements of the relevant category of building. The coefficient of performance of each air-conditioning system serving a space *i*, COP_{ci}, complies with the required standard performance of the given type and size as described in Section 5.2. The rated energy requirement of the reference building model is to be calculated from

$$E_{pc} = \sum_{\substack{i=1\\i\neq j}}^{n}\left[\frac{A_{wi}(OTTV_c)}{COP_{ci}}+\frac{A_{ri}(RTTV_c)}{COP_{ci}} + A_i\left\{\frac{C_l(LPD_c)+C_e(EQD_i)+130C_o(OCCU_i)+24C_v(VENT_i)}{COP_{ci}}\right\}\right]n_h + \sum_{i=1}^{n}A_i(LPD_c+EQD_i)n_h$$

The proposed building design is considered to comply under whole building energy requirement when E_{pa} is less than E_{pc}.

7. CONCLUSION

The new building energy code as described improves over the existing code. It continues to use system performance requirements on the three major systems of a building. Moreover, the system requirements for air-conditioning system are now complete. With the use of the energy equation, the contribution of energy consumption from each system, at the efficiency level corresponding to the rated performance of each system, to the total energy consumption of the whole building has become explicit and clear. This would enable consultants and building proprietors to assess benefits and costs of alternative component and system options more precisely. To some extent, this would help alleviate some of the existing problems in the building energy service industry, [8]. Furthermore, the influences of building shape mass, wall color, and wall orientation on energy performance of wall and on the whole building are now clearly related. The whole building energy compliance option introduces a new degree of flexibility aimed at allowing more freedom in designing a building while allowing trading off system requirements that are hoped to lead to more optimized design that can achieve higher efficiency. The development of the new code takes into account new technologies used in new equipment. The new code is also updated in terms of new technologies.

A new ministerial regulation or revision of existing ministerial regulation for mandatory application of the new code must be drafted and implemented. The draft would also address other deficiencies identified earlier, [11]. In order to facilitate application of the code, a software (computer program) should be developed. Training of building professionals on the new code must be conducted so the new code could be implemented with full cooperation from building professionals. It is intended that building professionals who design buildings and systems will be trained, qualified and registered. The new code should help address and overcome some short comings in the existing code and its implementation.

REFERENCES

[1] Energy and Industry Department, *Energy Indicators of Developing Member Countries.* Asian Development Bank, Manila, July 1992.
[2] Economic and Development Resource Center, 2001*, Key Indicators 2001: Growth and Change in Asia and the Pacific*, Asian Development Bank, Oxford University Press.
[3] Energy Information Administration, *Annual Energy Review 1984, DOE/EIA-0384184).* Energy Information Administration, US Department of Energy, Washington DC, April 1985.
[4] Peter Rumsay and Ted Flanigan, *Compendium: Asian Energy Efficiency Success Stories*, International Institute for Energy Conservation, GEEI Publications, Washington DC, USA, 1995.
[5] Surapong Chirarattananon, Pattana Rakwamsuk, and Jinda Kaewkiew, A proposed building performance standard for Thailand: an introduction and a preliminary assessment, *Proceeding of the ASHRAE Far East Conference on air-conditioning in humid climate*, Kuala Lumpur, November 1989.
[6] ASHRAE Standards 90A, 90b, and 90C*, Energy Conservation in New Building Design*, ASHRAE, Atlanta, G.A., 1980.
[7] Deborah Lynn Bleviss and Vanessa Lide (editors), *Report of a Conference on Energy Efficiency Strategies for Thailand*: *Building Sector Session,* Surapong Jiraratananon and Patana Rakwamsuk, The Potential for Energy Efficiency in Thailand's Building Sector, March 1988, Pattaya, Thailand, International Institute for Energy Conservation, Unversity Press of America. Inc., 1989.
[8] Surapong Chirarattananon and Juntakan Taweekun, A Technical Review of Energy Conservation Programs for Commercial and Government Buildings in Thailand, *Energy Conversion and Management*, 2003, **44**, 742-762.
[9] ASHRAE Standards 90.1-1999*, Energy Efficient Design of New Buildings Except Low-Rise Buildings*, ASHRAE, Atlanta, G.A., 1999.
[10] Surapong Chirarattananon and Juntakan Taveekun, An OTTV-based Energy Estimation Model for Commercial Buildings in Thailand, *Energy and Buildings Journal*, **36**, 680-689, 2004.
[11] Energy Research Institute, Chulalongkorn University, A Report on the Study to Revise Royal Decree Ministerial Regulations and Ministerial Announcement of the Energy Conservation Promotion Act, submitted to Department of Energy Development and Promotion, 2001.