BUILDING ENERGY CONSERVATION FOR SUSTAINABILITY

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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 that the code would be implemented on a mandatory basis on new buildings by setting 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. 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. For residential houses, voluntary energy rating should be used. The objective is to create an awareness of building designs that would enhance thermal comfort, visual comfort, and other desirable qualities while minimizing the use of air-conditioning. Higher scores should be accorded to criteria of comfort and achievement of comfort through means requiring low level of energy. Innovation, functionality and aesthetics are criteria that are accorded the rest of the scores, while and compliance with applicable building laws are mandatory but should not be accorded any score. These programs would lead Thailand towards the path of sustainability for future generation.
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 members of the authors of this paper in 1987 using a code 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 stipulated in a set of Ministerial Regulations, or By-laws of the ECP Act, its content being based on the 1987 code and on a study commissioned by the National Energy Administration, the original fore bearer of the Department for Alternative Energy Development and Energy Efficiency, in 1991. 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.

For existing buildings, compulsory energy and environmental labeling has been used successfully in USA and Europe. It is thought that labeling scheme for existing commercial buildings in Thailand could be developed based partially on the criteria developed in the new code.

Attempts to promote energy efficient *new houses* have been undertaken by the Department for Development of Alternative Energy and Energy Efficiency (DEDE) and Energy Policy and Planning Office (EPPO). However, in almost all programs implemented so far, air-conditioning is either explicitly or implicitly used to achieve thermal comfort. One demonstration program on energy efficient houses even feature fully air-conditioned houses where every space in the houses under demonstration is air-conditioned.

In energy labeling, a reputable institution is responsible for evaluating buildings or houses using criteria and procedures developed and accepted for labeling. A non-profit or governmental organization would introduce the labels. The public would be assured that certain label possesses certain efficiency level. Quantifiable criteria need to be developed and adopted for such labeling program for buildings and houses.

This paper outlines some of the concepts and strategies to form the criteria mentioned. It also presents some technical backgrounds the authors have used to contribute to the development of the criteria.

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.

2.1 Components 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. The existing 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 FOR COMMERCIAL BUILDINGS

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.

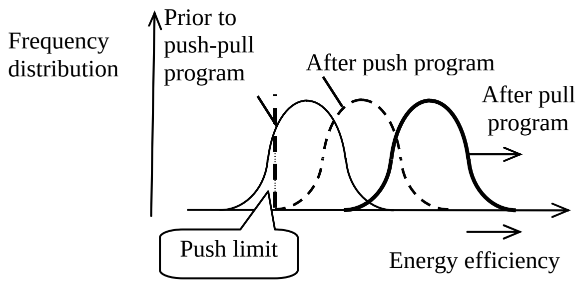


Figure 1 Movement of distribution of energy efficiency from push and pull programs.

The mandatory requirements for energy efficiency of buildings will eliminate buildings whose energy performance cannot meet the requirements. But it is necessary to be cautious 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.

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.

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

Coefficient of performance of the air-conditioning system is thus adopted.

Whole Building Energy Performance Compliance. This is used in ASHRAE Standard 90.1-1999 for Energy Efficient Design of New Buildings, [9]. Figure 2 illustrates the concept.

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.

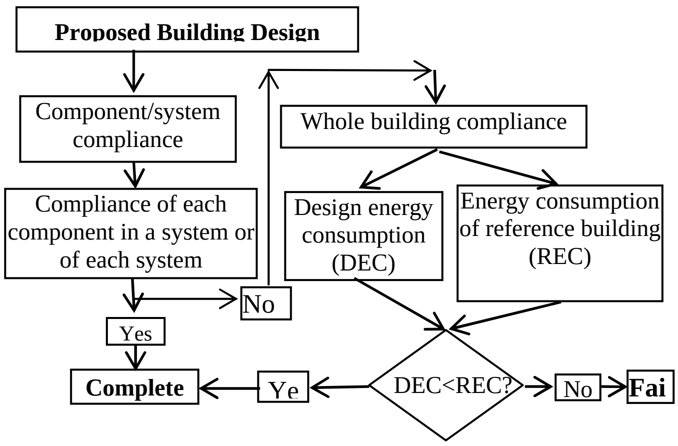


Figure 2. Illustration of the concept of whole building energy compliance.

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

4.1 **Conceptual 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.

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

Computer codes for building energy simulation 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. In each run, the cooling coil load was obtained corresponding to a case. The nominal form of OTTV formulation is

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

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.

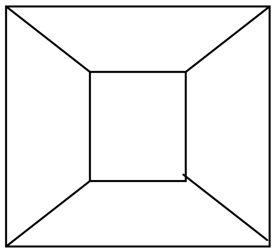


Figure 3 Building model used in the parametric run.

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} with respect to four parameters. and Figure 5 illustrates variations of ESR with directions and inclination angles

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.

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.

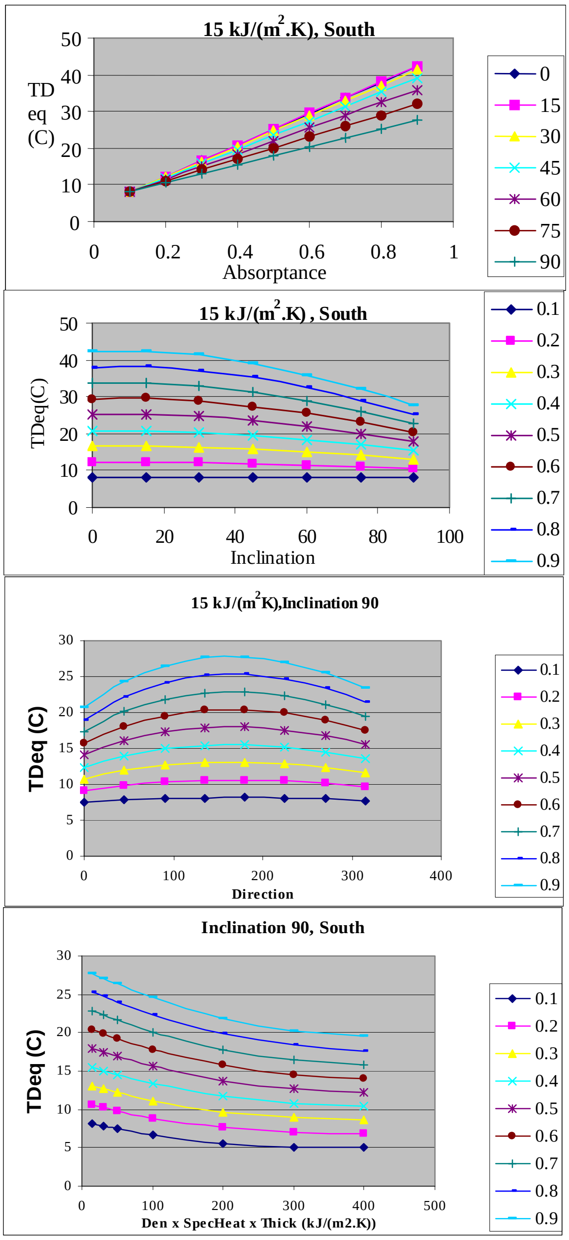


Figure 4 Variation of TD_{eg} with respect to absorptance,wall inclination, density-specific heat-wall thickness product, and orientation.

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

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

Energy use over a period

= Cooling coil load/COP + direct energy

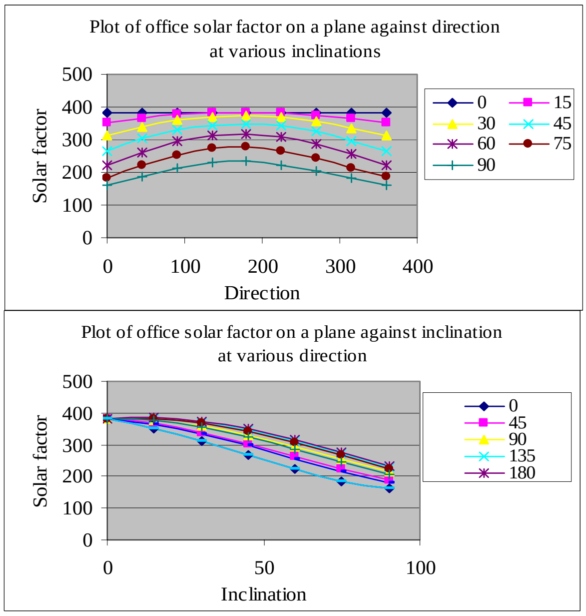


Figure 5 Effective solar radiation, variation with respect to orientation and plane inclination angle.

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	Decreasing
			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	7.19	
			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	
Hotel &Hospita	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	0.12	
			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	

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	0.84	0.85	0.9	0.9	2340
Department store					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.

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 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

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 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

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}

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. of luminaire in the given functional area.

Figure 6 illustrates life cycle costs of different luminaire options for office building model.

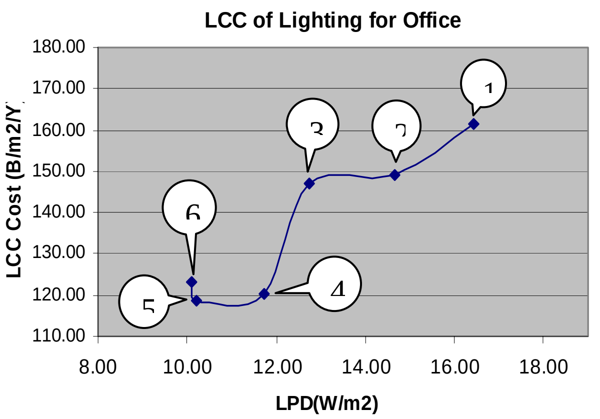


Figure 6. Life cycle costs of different luminaire options.

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

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.

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

5.4 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 7 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.

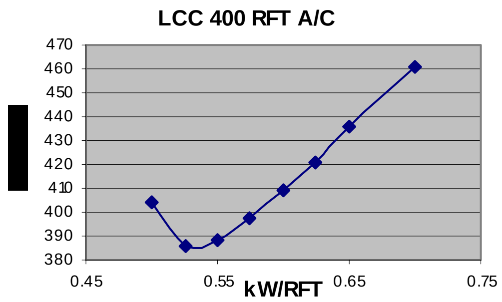


Figure 7. Life cycle cost curve for the air-conditioning system of a hypermarket building corresponding to different COPs of chillers used.

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.

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

Table 9. Recommended performance requirements for chillers.

Category and size	Minimum performance, COP (kW/TR)
Air-cooled water chiller	
oUp t351.7 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}	(0.62) 5.67

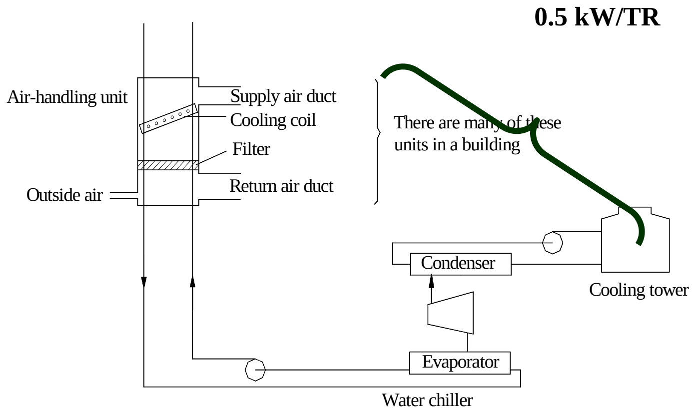


Figure 8. Requirements on other part of the air-conditioning system.

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.

The first summation in the expression 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.

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

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 uniformly 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 lighting power density 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 5.4. The rated energy requirement of the reference building model is to be calculated from the following formulation

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

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

7. CONCEPTUAL FRAMEWORK FOR RESIDENTIAL BUILDINGS

The objective of energy conservation program for residential houses is to promote development of quality, low-energy houses through a scheme of rating house designs. The rating scheme should be applicable both to designs of houses not yet constructed and existing houses. The method of rating should comprise quantifiable criteria. Such program should also be consistent with the general concept and practice of labeling program. The DSMO would conduct promotion campaign to create awareness and understanding of the quality low-energy house label. Here, a whole new set of criteria of quality low-energy houses must be developed in the Thai context. It must account for the weather of Thailand and Thai preferences for housing.

7.1 Concept of Rating Criteria.

When a question was posted on a web board on what desirable qualities a person would seek in buying a house, two general categories of the responses were received.

The first category is related directly to the house itself, and those that can be achieved by design or choice of construction. Among these are thermal comfort, affordability, functionality, aesthetics, accommodation of threes near or in the house to give a sense of being close to nature, and energy conservation. The energy issue usually included in criterion of affordable operating cost and usually is ranked in the middle in terms of priority. Some responses concern safety such as requirements on use of automatic earth leakage breaker, electrical grounding, and that location of electrical outlets should be inaccessible to small children. Some responses fall in the issue of security such as the desirability of brick walls to deter breaking in by burglars.

The second category of responses concerns location, surrounding and social setting. These include being close to mass transit system, the house being in secure area but not too close to noisy main roads, and being among amicable sociable neighbors. This second category of issues cannot be addressed by our program.

We group the desirable criteria under the first category into five main criteria and each allocated a score as shown in Table 10. In the first two criteria, procedures are to be developed to give objective scores. In the third and fourth criteria, subjective scores are inevitable, but experts of diverse backgrounds are expected to be employed to give scores.

Table 10 Main criteria for quality low-energy houses.

Item	Score	Description
Energy	30	Electricity used for comfort and lighting.
Comfort	30	Thermal, visual, acoustical, etc.
Innovation	25	Design that enhances energy efficiency and comfort
Aesthetics	15	This includes functionality
Safety	P/F	A design must be safe (either pass or fail) before it will be rated.

Health, electrical safety, security and similar issues are to be made as explicit requirements. These include the use of electrical grounding and earth leakage breaker, siting electrical outlets out of reach of children and use of safe construction materials.

Similar responses to similar questions have been obtained in Japan, [12] and South Africa, [13]. Home rating schemes have been developed and used in Australia, [14], USA, [15], and Canada, [16]. The European Union has also developed a common approach on energy conservation for buildings that include houses, [17]

7.2 Strategy for Rating Program.

Two general categories of issues of strategy for the rating scheme to succeed can be identified. One is related to size and cost of houses to be included in this scheme. The other issue is technical in nature.

Strategic Issues on Size, Cost, Type and Location From the onset, it was clear those could well afford to own villas would object to restriction on their manner of use of electricity while less well to do people could not afford air-conditioning. For the program to succeed, the program should target first at *medium size houses* for *small families* located in suburban area. Since one of the aim is to reduce the use of air-conditioning, the location should not be subject to heat island effect of big city. Table 11 illustrates the types, sizes and costs of houses chosen as targets.

Table 11 Types, sizes and costs of target houses.

Type	Size (m^2) of useable area	Occupancy (No. of person)	Construction Cost (MB)
Detached houses			
D1. Single storeyed	140	4	2.1
D2. Two storeyed	140	4	2.1
D3. Two storeyed	250	6	3.8
Townhouses			
T. Two storeyed	120	4	1.8

Strategy on Measure of Energy Use and Comfort. In hot and humid climate, air-conditioning is the simple means used to achieve thermal comfort. In order to avoid or to reduce air-conditioning, it is important to understand the condition of thermal comfort, factors that affect thermal comfort and the climate environment of Thailand. Also, there are diverse use of electricity in a household. We are mainly concerned with the use of electricity to achieve comfort. Only the use of electricity to achieve thermal and visual comfort should be encompassed in the energy conservation criterion. Use of electricity for ironing, for cloth washing for entertainment, etc., are too diverse. These uses are unrelated to the design of a house and other programs are available that target energy efficiencies of these uses.

In order to account for use of electricity it is necessary first to set reference times and spaces of occupancy. For a middle-class family, both husband and wife work and children would attend school. The house would not be occupied during daytime on weekdays. During holidays, the common area that the family is expected to occupy during daytime is the living room, where electricity may be used to run air-conditioner to achieve thermal comfort. Electric lighting may be used in all rooms for any time of a day except night time. It is necessary to set reference spaces and time of occupancy of spaces that electricity used to achieve comfort will be accounted. Table 12 lists the reference spaces and occupancy.

Table 12 Reference occupancy, activities, and spaces for accounting of electricity use for comfort and lighting.

Space	Occupancy	Activity	Use of electricity
Primary			
Living room	Weekdays: 250 days 18.00-21.00 Holidays: 115 days 06.00-21.00	Seated	Comfort and lighting
Bed rooms	Everyday: 365 days 21.00-06.00	Reclining	Comfort
Secondary			
Kitchen			Lighting
Storage	Same as living room.		Lighting
Bath rooms			Lighting
Etc.			

8. COMFORT AND CLIMATE

If air-conditioning is used, it can be assumed that thermal comfort can be achieved at all time in the tropical climate of Thailand. To avoid or to reduce air-conditioning, it is necessary to examine the concept of thermal comfort and the climate environment in detail.

8.1 Thermal Comfort

Four physical variables are identified to influence thermal comfort: air temperature, relative humidity, mean radiant temperature of surrounding, and velocity of wind surrounding a person. Two personal variables are also relevant: metabolic rate related to the level of vigor of a person and his level of clothing. All these six variables interplays in influencing comfort sensation and can be used to trade off one against another.

Extensive studies on thermal comfort in air-conditioned environment have been documented. Professional society such as the American Society for Heating Refrigerating and Air-conditioning Engineers (ASHRAE) documents studies by well-known researchers such as Fanger, Gagge, etc., and summarizes mathematical relationships relating the six variables to predicted mean vote (PMV) and predicted percents of person dissatisfied (PPD) for a given thermal environment, [18]. Similar results appear in documents of International Institute, [19]. Table 13 gives values of optimum operative temperatures for two conditions. The operative temperatures is the temperature of a situation when air temperature equals mean radiant temperature that gives the same thermal sensation as the condition with given air temperature and given mean radiant temperature.

Table 13 Optimum temperatures for two conditions in accordance to criteria of ASHRAE.

Condition				Optimum operative temperature, (°C)
Clothing	Activity	Wind speed	Relative humidity	
Standard office				
Long sleeve shirt, trousers, shoes with socks	Sedentary Met 1.2	<0.15 m/s	50%	25
Home				
Short sleeve shirt, shorts, no shoes	Reclining Met 0.8	0.8 m/s	60%	30.5

Even for a person accustomed to air-conditioning, the above results suggest that comfortable temperature in a home condition can be much higher than normally perceived and that air movement can be used to an advantage. Aulicium, [20], and Humphreys,[21], suggest that for a person in natural surrounding, his sensation of thermal comfort would be strongly influenced by the prevailing temperature. They concluded that the neutral temperature, when a person neither felt cool nor warm should be related to the prevailing outdoor air temperature of the given month in the given location as

$$T_n \quad = \quad 17.6 + 0.31\,T_o$$

where T_n is the neutral temperature and T_o is the prevailing outdoor temperature. Based on this relationship, the neutral temperature for a prevailing outdoor temperature of 33 C is

$$T_n \quad = \quad 27.8\,C\left(T_o = 33\,C\right).$$

Szokolay, [22], suggests that air movement around the body of a person can cause a sensation of temperature reduction. He developed a relationship of the form.

$$DT = \quad 6v - v^2$$

where DT is the drop in temperature as sensed by a person when the wind of speed v flow past his body. *With a wind speed of 1 m/s, the drop in temperature is* $DT = \quad 5 \quad C$

This result implies that, even when the air temperature is 33 C, a person using a fan to drive wind past his body at a speed of 1 m/s will have an equivalent sensation of air temperature of 28 C. This is the neutral temperature arrived at from the relationship suggested by Auliciums.

Table 14 Equivalent temperature sensed by a person when wind speed is 1 m/s

Prevailing outdoor temperature, T_0, C	Neutral temperature, T_n, C	Equivalent temperature, C
28	26.3	23
29	26.6	24
30	26.9	25
31	27.2	26
32	27.5	27
33	27.8	28
34	28.1	29

Table 14 shows the resultant temperature sensed by a person under a prevailing temperature and a given wind speed. It is seen from these examples that for a house in suburban area when natural air flow is assisted by electric fan to increase the speed of flow at acceptable level, adaptive thermal comfort or natural comfort could be achieved for prevailing temperature of up to 33 C. Studies undertaken in Bangkok for subjects working in unconditioned spaces also obtained 28.5 C as the neutral temperature, [123] and [24].

8.2 Climate

The climate of Thailand comprises four patterns, each prevailing in four different periods of the year. Table 15 gives a summary of temperatures taken from a weather record for the year 2000.

Table 15 Temperatures and climate periods.

Period	Description	Dry-bulb temperature, C		
		Mean daily minimum	Mean daily average	Mean daily maximum
1Nov-15Feb	Cool dry	22.17	27.54	34.44
16Feb-31May	Hot dry	24.78	29.36	36.08
1Jun-15Aug	Early rainy	25.24	29.11	35.07
16Aug-31Oct	Late rainy	24.86	28.64	34.97

Four reference days are identified each with its maximum, average, and minimum temperatures matching the mean daily maximum, average, and mean daily minimum temperatures of the period. Table 16 and Table 17 shows values of temperature, solar radiation, daylight illuminance and wind speed for the reference day of the hot and dry period. Table 18 shows the corresponding values for the reference day of the late rainy period. These two days represent the means of the high extremes of the year.

Natural Comfort at Night. From night till morning (21.00-06.00), the maximum air temperatures of both days never exceed 28 °C. This is true also for all days in a year. This implies that with introduction of sufficient exterior air for circulation in a bedroom, and if there is an absence of heat storage by the masses of walls in the room, condition of natural or adaptive comfort should be attainable. If the air circulation is sufficiently strong so as to force air movement of sufficient speed, or if an electric fan is used to force air movement, natural comfort should be achievable even if there is some thermal stress such as when mean radiant temperature in the room exceeds air temperature. If a close examination is made, the air temperature in the period before midnight can be observed to be higher than that for the period after midnight. In case abnormal condition exists that necessitates use of cooling, it is likely that the need will be more pronounced for the period before midnight.

Natural Comfort During Morning. Air temperatures of both days during morning period do not exceed 34 °C. During night time, heat stored in the wall of the living room should be released naturally to the cool night air. With careful design, the temperature of the interior surfaces should have still maintained a temperature lower than the air temperature. Under this condition, natural comfort should be attainable with assistance of an electric fan to force air movement.

Higher Temperature in the Afternoon. In the afternoon, air temperature reaches over 38 °C for the reference day of the hot and dry period and reaches over 36 °C for the other day. To achieve thermal comfort, some forms of cooling will be required. The maximum duration for cooling may be up to the whole of the afternoon, till 19.00.

Solar Radiation and Daylight. Table 17 exhibits values of global, diffuse horizontal and beam normal illuminance of daylight. The table also contains the corresponding values for solar radiation for 12 March 2000, the reference day of the hot and dry period. It is clear that between 7.00 to 17.00 global illuminance values remain above 5 klux and solar radiation also remains above 50 Wm^{-2}. These are true for all days in a year.

Passive Cooling. When the wet-bulb temperature of air T_w in Table 16 and Table 17 is examined, it is seen that during night time it falls below 24 °C.

Table 16 Weather of 12 March 2000 in the hot and dry period.

Hour	T_{amb} (C)	RH_{amb} (%)	T_w (C)	T_{sky} (C)	*Wind* (m/s)
0	26.89	84.08	24.74	19.16	1.52
1	26.66	85.56	24.72	19.01	1.7
2	26.32	87.23	24.63	17.98	1.41
3	25.94	88.94	24.49	17.59	1.14
4	25.39	91.57	24.31	15.68	1.12
5	24.83	92.9	23.93	14.52	0.97
6	23.58	94	22.84	15.75	0
7	23.7	94.81	23.06	20.39	0.36
8	26.33	73.55	22.69	15.74	0.75
9	29.57	45.16	20.73	15.5	1.71
10	32.06	33.95	20.34	18.04	2.08
11	33.54	27.61	19.94	19.79	2.75
12	34.45	26.47	20.29	20.95	2.66
13	35.83	24.01	20.60	21.77	2.22
14	37.29	23.56	21.47	22.57	1.82
15	38.33	20.4	21.26	22.29	2.06
16	38.04	20.42	21.07	21.08	1.86
17	36.95	20.33	20.33	19.5	1.32
18	33.69	28.55	20.27	17.4	0.52
19	29	40.68	19.42	15.44	0.46
20	28.44	45.34	19.86	15.24	1.56
21	28.23	52.62	21.00	17.4	1.6
22	27.53	56.94	21.15	17.8	1.17
23	26.78	61.26	21.21	17.28	0.95

Note: T_{amb} = ambient air temperature, C,
RH_{amb}= relative humaidity of ambient air, %,
T_w = wet=bulb temperature of ambient air, C,
T_{sky} = equivalent temperature of the sky, C, and
Wind = wind speed, m/s.

This suggests that some form of passive cooling would be applicable. Figure 9 exhibits the diagram of a cooling tower, a water storage tank and a radiant cooling panel in a room.

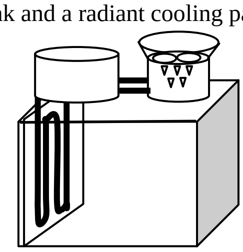


Figure 9 A passive cooling system.

The system in Figure 3 exhibits one application of passive cooling where cooling tower is employed to evaporatively cool the water in an insulated storage tank during night time. The cooled water is then used in cooling panels in the living room during the hot period to reduce mean radiant temperature and partly to cool the air in the room. This system could be employed to provide low-energy passive cooling.

Sky Temperature Because of the presence of clouds in the sky during raining season, the equivalent temperature of the sky (that is derived from measured thermal radiation from sky) remains high all day. Night sky cooling is not practical. Only in dryer periods that sky temperature falls below air temperature.

Wind Speed. In most locations in Thailand, wind speed is low. This suggests that the volume of natural flow of wind through openings into a house would be small and inadequate for removal of heat. Mechanical or other means may be required to force sufficient rate of flow. Sufficient size of window area and number of windows on walls in different direction for a room are needed to allow adequate flow of natural ventilation air.

Table 17 Weather of 23 September 2000 in the late rainy period.

Hour	T_{amb} (C)	RH_{amb} (%)	T_w (C)	T_{sky} (C)	Wind (m/s)
0	24.29	93.94	23.53	27.13	0.01
1	24.29	93.63	23.49	27.35	0.48
2	24.41	93.26	23.57	27.45	0.47
3	24.55	93.1	23.68	27.55	0
4	24.65	93.05	23.77	27.68	0
5	24.61	93.18	23.75	27.69	0.09
6	24.64	93.62	23.84	27.65	0
7	25.56	90.34	24.31	28.54	0.42
8	27.13	80.74	24.49	29.83	1.2
9	29.46	70.81	25.14	29.4	0.96
10	31.82	61.27	25.62	28.45	1.29
11	31.4	61.12	25.23	30.73	1.68
12	31.98	59.16	25.38	31.12	1.83
13	33.57	49.74	24.90	30.44	2.19
14	35.43	43.74	25.13	31.47	1.49
15	36.71	39.82	25.24	30.62	1.82
16	34.07	51.27	25.63	29.18	1.93
17	29.32	70.59	24.97	26.43	2.23
18	26.04	86.07	24.20	28.18	2.17
19	24.36	94.24	23.64	26.59	1.11
20	24.43	93.58	23.63	26.05	0.84
21	24.61	92.5	23.66	25.99	0.13
22	24.63	93.06	23.76	25.35	0.47
23	24.74	93.1	23.87	25.22	0.49

Beam component of solar radiation reaches over 900 Wm^{-2} and its global component reaches over 1,000 Wm^{-2} at noon. These are the intensities that the designer of a house must contend with. Proper and adequate shading must be provided. However, daylight illuminance from diffuse skylight could be introduced through window to provide adequate vertical illuminance. In residential houses, sufficient vertical illuminance is pleasant and gives a sense of well-being.

Ground Temperature Temperatures below ground level for most locations in Thailand are close to the average air temperature of the given location. Houses constructed partially below ground level will not benefit from lower ambient air temperature at night. Table 19 exhibits sample temperatures for up to 1 m of depth for Pathum Thani, near Bangkok.

Table 18 Daylight illuminance and solar radiation on 12 March 2000.

Hour	E_{vkh} (klux)	E_{vb} (klux)	E_{vg} (klux)	E_{ekh} (W/m^2)	E_{eb} (W/m^2)	E_{eg} (W/m^2)
6	0.04	0	0.04	0.15	0	0.15
7	4.76	9.78	5.92	41.62	133.14	89.95
8	12.64	44.42	28.77	96.46	592.46	440.83
9	17.16	69.41	57.50	130.31	803.39	739.96
10	20.35	76.85	78.67	161.59	888.79	947.02
11	23.21	78.05	92.18	192.18	906.82	1051.23
12	26.1	76.02	98.12	213.28	908.63	1072.26
13	26.46	75.01	97.37	211.3	905.99	1006.72
14	26.19	70.32	87.93	201.9	859.83	846.52
15	23.6	66.8	73.68	178.11	818.7	644.23
16	20.22	54.48	51.24	148.3	696.91	391.63
17	14.18	34.27	26.15	101.11	489.93	152.14
18	4.46	8.04	5.30	28.18	144.91	28.18
19	0.02	0	0.02	0	0	0

Note: E_{vkh} = diffuse horizontal sky illuminance,
E_{vb} = beam normal illuminance,
E_{vg} = global illuminance,
E_{ekh} = diffuse horizontal irradiance,
E_{eb} = beam irradiance, and
E_{eg} = global irradiance.

Table 19 Soil temeperature (C), Pathum Thani.

Depth (m)	Jan	April	July	Oct	Average
0	29.2	31.1	30.5	30.2	29.8
0.05	30.1	32.0	30.4	30.5	30.4
0.1	29.7	31.7	30.4	30.6	30.3
0.2	29.3	31.8	30.6	30.8	30.5
0.5	30.4	33.5	33.4	33.6	33.1
1.0	27.4	29.2	29.0	29.3	28.9

9. DEVELOPMENT OF REFERENCE CALCULATION PROCEDURE

With reference occupancy, activities, and spaces defined as in Table 12, the main task in the development of the home rating scheme is the development of an objective scoring method for comfort and an objective scoring method for energy conservation.

A household appliance is used mainly to perform one function, physical measurement method to obtain value of energy efficiency of the appliance used to perform its function is simple to develop. Standard testing procedures and testing apparatuses are already developed and defined by international organizations.

Unlike household appliances, a house is used to serve many functions. The conditions under which the functions are performed can be defined as in Table 3. The tool that can be used to produce outputs for scoring in the rating scheme is an adopted building energy simulation program.

For scoring on thermal comfort, the condition of the environment of the spaces specified in Table 3 must be calculated using standard climate condition. Such climate condition is exemplified by the weather condition in Table 7 and Table 8. The required environmental parameters that are expected to be obtained from a given simulation program are temperature of air in the given space, relative humidity, mean radiant temperature and wind speed. These are the physical variables used to determine thermal comfort. The personal variables are defined as in Table 11.

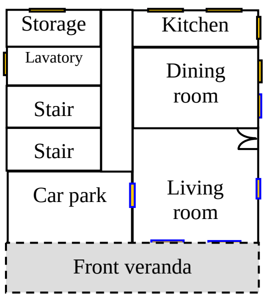
Visual comfort. If daylighting is employed, as this should be promoted by such a rating scheme, daylight illuminance on vertical and horizontal surfaces should be calculated by the simulation program or by other means. Glare condition also be identified and evaluated. A robust simulation program should be able to produce output on light quantities and some light qualities from daylight entry as well as accounting for the radiation heat gain that accompanies daylight.

Energy Efficiency Output on consumption of energy or electricity is usually expected to be obtained from an energy simulation program. But in the case here where avoidance of use of air-conditioning and alternative means of achieving comfort are encouraged, the scheme and schedule of use of various means to achieve comfort must be described as a part of the design of a house. If a design uses new and innovative technology, a specific module of program may need to be developed to stimulate its operation. However, for such specific case, the building designer may also be required to produce his calculation of the energy consumption and demonstrates his procedure to the satisfaction of an expert group.

Reference House and Reference Outputs. In most rating schemes, a reference house design is adopted. The values of environmental parameter output and energy output calculated from the adopted simulation are then used to form reference score on energy consumption. For our case, reference scores on thermal comfort and visual comfort must also be developed.

10. REFERENCE HOUSE AND SAMPLE OUTPUTS

As a part of the present project a sample reference house is adopted. The plan of the ground floor is shown in Figure 10.



Ground floor

Figure 10 The plan of the ground floor of the reference house.

Volume of Circulation of Air Due to Wind The wind pressure on the windows of the living room can be calculated when wind speed and direction is given such as those in Table 7. Based on the principle of balance of air flow, the volumetric flow of air through each window can be calculated. The volume of air flow into the living room for 12 March is shown in Figure 12.

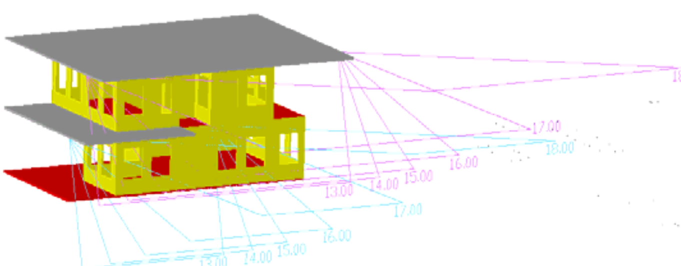


Figure 11 Shades on the south façade on the afternoon of 12 March.

Figure 11 exhibits the pattern of the shades casted by the roof of the house on the southern façade during the afternoon of 12 March.

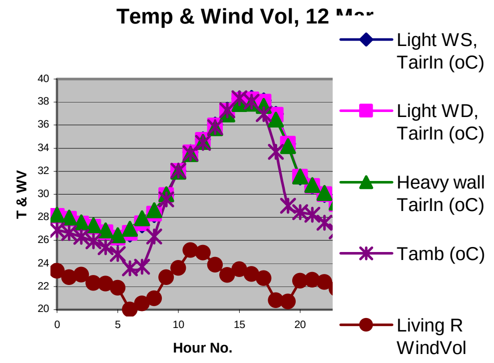


Figure 12 Air temperatures in living room for 12 March.

Air temperature and Mean Radiant Temperature The building energy simulation program developed at AIT that has been used in the development of the new Building Energy Code for Thailand [14], was used to calculate the environmental condition in the living room. Figure 6 exhibits the results of air temperatures in the living room when different wall compositions are used. The program is able to produce wall temperatures that can be used to compute mean radiant temperature. With these outputs the condition in the room can be assessed for comfort. Energy consumption computation is generally straighter forward.

11. CONCLUSION

In order to achieve real energy savings for buildings, both mandatory and voluntary types of program must be implemented simultaneously. Appropriate quantitative criteria must be developed and used with all programs.

For commercial buildings, air-conditioning has now reached saturation. Even though it is desirable to reduce the use of air-conditioning, it may not be realistic at present. The use OTTV as measure of performance of building envelope for air-conditioned building is appropriate for Thailand where the climate is hot and humid. Mandatory requirements on minimum performance building envelope system, electric lighting system, and air-conditioning system as in the existing Ministerial regulations are appropriate for new buildings, not yet constructed. But labeling program should be developed for application to existing buildings.

For residential buildings, quantitative criteria should be developed for rating and labeling of house designs. In this case, it is believed that it should be implemented on a voluntary basis.

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