

# DEVELOPMENT OF COOLING LOAD TEMPERATURE DIFFERENTIAL VALUES FOR BUILDING ENVELOPES IN THAILAND

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## ABSTRACT

This article describes the development of cooling load temperature differential (CLTD) values for building envelopes made of materials commonly used in Thailand and using Bangkok weather data. The Bangkok design weather data are selected from 12 years of data collected by the meteorological department. Two sets of weather data for Bangkok are chosen. The first weather data set was selected based on dry bulb temperature of 0.4% annual cumulative frequency of occurrence. The second weather data set was selected based on dry bulb temperature of 0.4% hourly cumulative frequency of occurrence and solar radiation obtained from the ASHRAE mathematical model. The room parameters which have effects on thermal response, such as building envelope material, room decoration, and room conditions are investigated. 288 different room types for each exterior wall type and each roof type were checked. The values of amplitude and delay based on conduction weighting factors for a sinusoidal heat gain are analyzed. The distribution of the amplitude and delay of similar thermal response are grouped together and represented by a single point in the group. For each set of design weather data, 7 CLTD tables for exterior walls and 6 CLTD tables for roofs are developed.

**Key Words:** cooling load, building, envelope, Thailand.

## I. INTRODUCTION

Thailand is a country located in a tropical zone near the equator. The weather is rather hot and humid most of the year. Air conditioning systems in commercial and residential buildings have become an essential part of every day life for most people in Thailand. To be able to predict a rather accurate cooling load for a building for sizing cooling equipment would help designers to achieve more efficient air conditioning systems in terms of energy usage and thermal comfort. The building cooling load is dependent on local weather, thermal characteristics of material used for building envelope, and building usage. In order to accurately calculate the building

cooling load, it usually requires a large and complex energy simulation computer program such as DOE 2.1E or BLAST which use the transfer function method and heat balance method to calculate the cooling load, respectively. This kind of computer program, usually requires local annual weather data (8760 hours) and requires a complex and lengthy data input (Chaiyapinunt *et al.*, 1999). Therefore, this type of simulation program is not very popular for most designers, who prefer a more compact and easy to use method for calculating the building cooling load.

A more simplified version for calculating a cooling load using the transfer function method is to use the one step procedure first presented in the 1977 ASHRAE Handbook of Fundamentals. The method is now called the cooling load temperature differences (CLTD), solar cooling load factors (SCL), and internal cooling load factors (CLF) method. This method makes hand calculation of cooling load possible. ASHRAE (1997) has developed the CLTD values for exterior walls and roofs based on solar radiation

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variation typical of 40°N latitude on July 21 with certain outside and inside air temperature conditions and based on building materials commonly used in North America. The accuracy of the CLTD values could be in question when the location of the building is not at 40°N (especially below 24°N). Building material which does not match the ones used to generate the CLTD values by ASHRAE would also affect the accuracy of the cooling load calculated.

The purpose of this article is to describe the development of cooling load temperature differential (CLTD) values for building envelopes made of materials commonly used in Thailand and using Bangkok (latitude 13.7°N) weather data. With these values, the cooling load calculation of buildings in Thailand can be easily manually performed with more accuracy.

## II. COOLING LOAD CALCULATION

The cooling load for a building results from four sources: conductive heat gain through surfaces such as windows, walls, and roofs; solar heat gain through fenestration; internal heat gain from lights, people, and equipment; and heat gain from infiltration. The transfer function method (TFM) (Mitalas, 1972) used for calculating the cooling load uses a two step procedure. First establishing the heat gain from all sources by applying a series of weighting factors to calculate the heat gain and then converting such heat gain to cooling load by a second series of weighting factors or so called coefficients of room transfer function. The cooling load temperature difference method is a simplified method of TFM for direct one step calculation of cooling load. The cooling load temperature difference (CLTD) is used to determine the cooling load for surfaces as follows

$$Q=UA \text{ (CLTD)} \quad (1)$$

where  $U$ = overall heat transfer coefficient for surface, W/m<sup>2</sup>-°C

$A$ = area of surface, m<sup>2</sup>.

## III. WEATHER DATA

### 1. Weather Data Based on 0.4% Annual Cumulative Frequency of Occurrence

The weather data for a day used for calculating CLTD values are selected from 12 years (1988-1999) of Bangkok weather data collected by the meteorological department. The selection is done based on considering the most influential parameters on the cooling load which are solar radiation and dry bulb temperature. The selected 0.4% cumulative annual frequency of occurrence for dry bulb temperature and

global radiation as suggested by ASHRAE (1997) are chosen. The values of ambient dry bulb temperature and solar global radiation corresponding to 0.4 annual percentiles represent the value that is exceeded on average by 0.4% of the total number of hours in a year (8760). The 0.4% value of dry bulb temperature is the value at the 35th hour ((0.4/100)×8760) of the annual data. The average value of dry bulb temperature at 0.4% annual cumulative frequency of occurrence of 12 years data is 36°C with the average mean daily range of 7.72°C. Then the design daily dry bulb temperature is obtained by the following relationship as

$$T_o=T_d-DrX \quad (2)$$

where  $T_o$  =hourly dry bulb temperature, °C

$T_d$  =maximum dry bulb temperature, °C

$Dr$  =mean daily range (7.72°C)

$X$  =percentile of daily variation of dry bulb temperature

Then the mean coincident of solar radiation and related weather data are obtained. The 24 hour dry bulb temperature with its coincident weather data are arranged as weather data for a design day.

The second set of weather data shall be selected based on solar global radiation. The solar global radiation data are only collected in day time, with 15 hours period in a day (5475 hours in a year). The 0.4% annual cumulative frequency of occurrence for global radiation shall be the values at the 22nd hour ((0.4/100)×5475). The average values of 0.4% annual cumulative frequency of occurrence for global radiation of 12 years data is 1021 watt per square meter. Then the average values of the global radiation and its coincident dry bulb temperature and other related weather data in the rest of the day are obtained from the data on the selected day. In order to use DOE 2.1E to accurately calculate building cooling load, the weather data input have to be in the Typical Meteorological Year (TMY) format. This format requires the solar radiation data input in 3 components: global, direct normal, and diffuse radiation. The diffuse and direct normal radiation components can be obtained by using the mathematical model suggested by Chaiyapinunt and Mangkornsaksit (2000) applied to the measured global radiation.

The cooling load of the selected building calculated by DOE 2.1E using two weather data sets are compared. The one which gives a greater value of cooling load will be chosen. Therefore, the weather data selected based on dry bulb temperature of 0.4% hourly annual cumulative frequency of occurrence and its coincident weather data is chosen to be the relevant weather data. The dry bulb temperature,

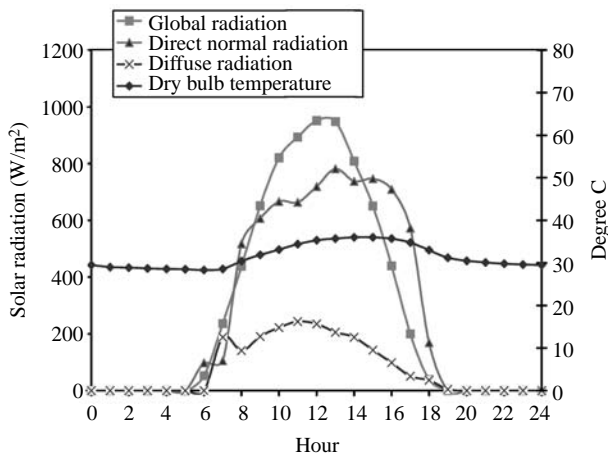


Fig. 1 Weather data based on dry bulb temperature of 0.4% annual cumulative frequency of occurrence and its coincident solar radiation data

global, direct normal, and diffuse radiation of the design weather data are shown in Fig. 1.

## 2. Weather Data Based on 0.4% Hourly Cumulative Frequency of Occurrence

There is another method to find weather data used for calculating cooling load to ensure predicting a maximum building cooling load in a year. The method is adopted from the so called TAC method (Technical Advisory Committee of ASHVE, a former organization of ASHRAE) (Takeda, 1990/91) by using cumulative frequency of hourly data over several years. In this study, the method is modified by selecting the data based on 0.4% hourly cumulative frequency of occurrence for the whole 12 years data. The selection is done by rearranging the chosen measured data (dry bulb temperature and global radiation) at each hour in a day (i.e. say at 11 o'clock) for the whole 12 years from maximum value to minimum value and choosing value at 0.4% from the maximum value. One will get a set of 24 hours dry bulb temperatures and a set of 24 hours global radiation readings. Then, the coincident weather data for each set of chosen data are selected. It turned out that with this kind of selecting method the distribution of coincident weather data with chosen data has an irregular pattern, especially the dry bulb temperature values, which are coincident with the selected global radiation values. Therefore, in this study, the 24 hours selected dry bulb temperatures based on 0.4% hourly cumulative frequency of occurrence are chosen as relevant weather data. To eliminate the problem of poor coincident weather data, the coincident solar data are obtained from the ASHRAE mathematical model of a clear day condition based on April 21. The maximum dry bulb

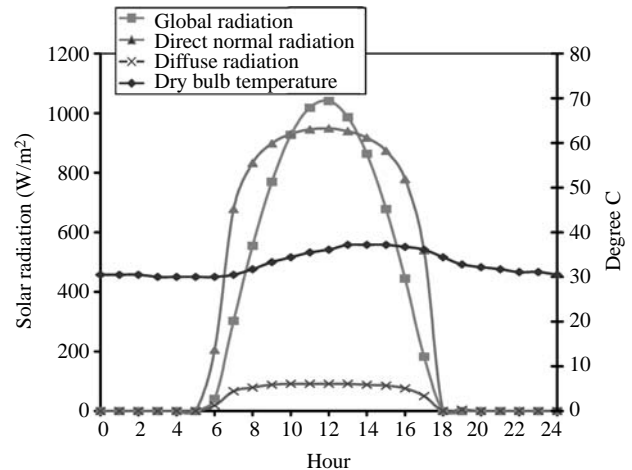


Fig. 2 Weather data based on dry bulb temperature of 0.4% hourly cumulative frequency of occurrence and solar radiation from ASHRAE mathematical model

temperature in the considered weather data is found to be 37.2°C. The dry bulb temperature, global, direct normal, and diffuse radiation of the selected design weather data are shown in Fig. 2.

## IV. BUILDING ENVELOPES AND PARAMETRIC STUDY

Building envelopes which are made of material commonly used in Thailand are chosen as 7 types of exterior wall, 6 types of roof with their properties taken from the Building manual (1998), OTTVEE (1999), and FTI/DOE material library (1993). The details of chosen building envelopes and partitions are shown in Tables 1, 2 and 3. The concept of calculating cooling load by the CLTD method is to simplify the TFM method into a product of CLTD values and a product of  $U$  and  $A$  as shown in Eq. (1). The cooling load calculated by using the TFM method is based on its weighting factors to convert building heat gain into building cooling load for each type of room construction, geometry, and decoration. Therefore, the study of the cooling load for different room construction, geometry, and decoration can be also done by studying the variation of its weighting factors. 13 parameters describing room construction, geometry, and decoration are analyzed in order to assess their effect on room thermal response when compared to other parameters as suggested by Sowell (1985b). They are room geometry, room height, room location, number of exterior walls, exterior wall construction, percentage of glass on the exterior wall, partition type, degree of interior shading, mid-floor type, floor covering, roof type, ceiling type, and furniture. These parameters and variations in each one are shown in Table 4. These parameters are varied systematically

**Table 1 Wall types and overall heat transfer coefficient for walls**

Wall No.	Structure	Mass per unit wall area (kg/m <sup>2</sup> )	U (Watt/m <sup>2</sup> -°C)
1	Wall of brick with cement finishing - 10 mm. cement plaster+150 mm.brick+10 mm. cement plaster	246.0	1.222
2	Wall with insulation in the middle - 5 mm. sandstone+160 mm. polyurethane foam +75 mm. glass fiber+20 mm. air gap+12 mm. asbestos cement board	46.5	0.111
3	Wall with concrete block - 5 mm aggregate cement+10 mm gypsum board + 5 mm air gap+75 mm concrete block+25 mm marble	156.6	1.703
4	Concrete wall with cement finishing - 50 mm. light weight high density concrete	64	3.527
5	Wall of brick with cement plaster - brick with cement plaster on both sides with total thickness of 80 mm	136.0	3.950
6	Prefabricated wall - 5 mm. cement plaster+75 mm. superbloc + 5 mm cement plaster	57.0	2.936
7	Wall of concrete block brick with cement finishing - 15 mm. cement plaster+75 mm. concrete block brick+15 mm. cement plaster	82.3	1.333

Note: the contents in the structure column in the table: first line shows the description of each wall type and the next line shows its components starting from the outside layer toward the inside layer of the wall

**Table 2 Roof types and overall heat transfer coefficient for roofs**

Roof No.	Structure	Mass per roof area (kg/m <sup>2</sup> )	U (Watt/m <sup>2</sup> -°C)
1 (ceiling)	100 mm concrete slab with insulation - 100 mm concrete+100 mm air gap+75 mm glass fiber+10 mm gypsum board	252.5	0.391
1 (no ceiling)	Concrete slab - 100 mm concrete slab	240	3.448
2 (ceiling)	200 mm concrete slab with insulation - 200 mm concrete+100 mm air gap+75 mm glass fiber+10 mm gypsum board	492.5	0.380
2 (no ceiling)	Concrete slab -200 mm concrete slab	480	2.783
3 (ceiling)	Concrete roof tile with insulation - 12 mm concrete roof tile+100 mm air gap +50 mm glass fiber+10 mm gypsum board	39.8	0.536
3 (no ceiling)	Concrete roof tile -12 mm concrete roof tile	28.8	4.292

Note: the contents in the structure column in the table: first line shows the description of each roof type and the next line shows its components starting from the outside layer toward the inside layer of the roof

**Table 3 Partition types and overall heat transfer coefficient for partition**

Partition No.	Structure	Mass per area (kg/m <sup>2</sup> )	U (Watt/m <sup>2</sup> -°C)
1	Concrete block with cement plaster finishing - 12.5 mm cement plaster+75 mm concrete block+12.5 mm cement plaster	82.3	1.333
2	Gypsum board with air gap - 10 mm gypsum board+100 mm air gap + 10 mm gypsum board	16.0	1.091

Note: the contents in the structure column in the table: first line shows the description of each partition type and the next line shows its components starting from the inside layer to the outside layer of the partition

**Table 4 Room parametric level definitions**

No.	Parameters	Levels	Description
1	Room geometry	1	4.57 × 4.57 m
2	Room height	1	3 m
3	Room location	2	mid floor, top floor
4	Number of exterior walls	1	1 exterior wall
5	Exterior wall construction	7	7 exterior wall types
6	Percentage of glass on the exterior wall	2	50%, 90%
7	Partition type	2	concrete block with cement plaster, gypsum board with 100 mm air gap
8	Interior shade compared to glass area	3	0% 50% 100%
9	Floor type	3	75 mm, 125 mm, 200 mm concrete
10	Floor covering	2	carpet with rubber pad, vinyl tile
11	Roof type	3	3 roof types
12	Ceiling type	2	10 mm gypsum board, w/o ceiling
13	Furniture	2	with, without

so that all possible combinations of these parameters are studied. From Sowell (1984) under ASHRAE project 359-RP and Sowell (1988a) it was found that the exterior wall construction, percentage of glass on the exterior wall, and roof type have small effect on room thermal response when compared to other parameters. These parameters are dropped out from the parametric study. The combination of the rest of the parameters and their variation give a total 288 different room conditions. The next thing is to minimize the number of room conditions by grouping the room conditions which have similar thermal responses together. The room thermal response can be studied by using the pair of numbers that represent amplitude and time delay of the cooling load for a sinusoidal heat gain of 1 unit amplitude in a 24 hour period. (as suggested by Sowell (1985a, 1988b) and Kerrisk (1981)). The related equations are as follows

$$Q_t = v_o q_t + v_1 q_{t-1} + v_2 q_{t-2} - w_1 Q_{t-1} - w_2 Q_{t-2} \quad (3)$$

where  $Q_t$  = cooling load at time  $t$ , W

$v_i, w_i$  = coefficient of room transfer function or weighting factors

$i$  = index

$q_t$  = hourly heat gain at time  $t$

and

$$q = q_{\max} \sin(\pi t / 12) \quad (4)$$

$$Q / q_{\max} = r = a \sin(\pi t / 12 - \phi) \quad (5)$$

where  $Q$  = cooling load

$q$  = hourly heat gain

$q_{\max}$  = maximum heat gain of magnitude 1 Watt

$a$  = amplitude

$\phi$  = phase lag (radians)

$r$  = dimensionless cooling load

and now consider at  $t=0$  and  $t=6$  hours

$$r_o = -a \sin \phi \quad (6)$$

**Table 5 Conduction weighting factors of the representative point in each wall type**

Wall No.	Amplitude	Delay	$v_0$	$v_1$	$v_2$	$w_1$	$w_2$
1	0.778	0.538	0.68508	-0.67568	0.11202	-1.07039	0.20466
2	0.794	0.556	0.68795	-0.68514	0.12119	-1.09104	0.22613
3	0.762	0.600	0.66393	-0.64413	0.10525	-1.05780	0.19705
4	0.762	0.507	0.67160	-0.65692	0.10858	-1.06189	0.20329
5	0.757	0.508	0.66640	-0.65851	0.11327	-1.07145	0.21155
6	0.769	0.515	0.67535	-0.66311	0.11118	-1.06787	0.20799
7	0.783	0.534	0.68799	-0.66330	0.10525	-1.04849	0.19241

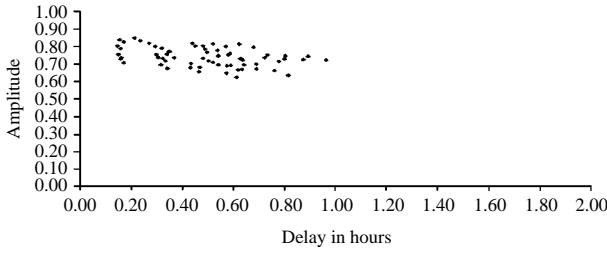


Fig. 3 Amplitude and delay obtained from conduction weighting factors for 288 room conditions

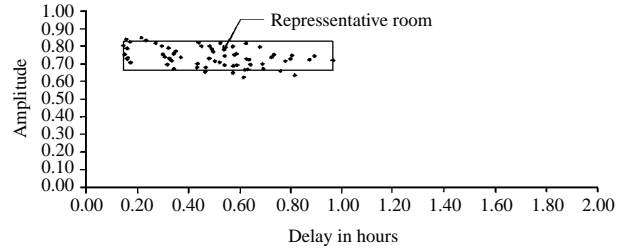


Fig. 4 Amplitude and delay obtained from conduction weighting factors for 288 room conditions and its rectangle with representative room

$$r_6 = a \cos \phi \quad (7)$$

$$a = (r_0^2 + r_6^2)^{1/2} \quad (8)$$

$$\phi = \arctan(-r_0/r_6) \quad (9)$$

$$d = 12\phi/\pi \quad (10)$$

where  $d$ =time delay

The room weighting factors in the conduction part of the envelopes (conduction weighting factor) for 288 room conditions are calculated by using DOE 2.1E. Then, the amplitude and delay (Eqs. 8 and 10) for each room are calculated for all 288 rooms. The magnitude of the amplitude and delay of 288 rooms are plotted in Fig. 3. Some points shown in the figure contain 3 or more closest values at each point. Each room defined by a particular combination of parameters shown in Table 4 has a thermal response that may be different from others. However, in order to avoid having to calculate CLTD values for each room ( $288 \times 7 \times 6 \times 2 = 24192$  rooms), it is desirable to somehow identify rooms that have similar responses and group them together into a small number of room types. Rooms that have values of amplitude and delay shown close together in Fig. 3 mean that those rooms have similar thermal response and can be grouped and represented by a single point in the group. A room in a particular group will have error associated with it proportional to its distance from its representative point in the amplitude and delay plot. With the normal engineering accuracy goal of

$\pm 10\%$  of actual value and based on hourly calculation, Sowell (1985a, 1988c) suggested that the criteria for accepted error shall be 0-20% for amplitude and  $\pm 1/2$  hour for delay. This suggests a rectangle with a lower bound no less than 80% of the upper bound and the horizontal dimension of the rectangle shall be 1 hour ( $\pm 1/2$  hour). Fig. 4 shows the rectangle on an amplitude and delay plot and the representative point. Since, for the amplitude and delay values of conduction weighting factors for one type of exterior wall, roof, and percentage of glass, almost every point falls in one rectangle. Only very few points are out of this rectangle and they are very close to the rectangle. Therefore, one room type can be adopted to represent all 288 room conditions. For 7 exterior wall types and 6 roof types the representative amplitude and delay values and their conduction weighting factors are shown in Tables 5 and 6.

## V. COOLING LOAD TEMPERATURE DIFFERENTIAL VALUES AND THEIR ACCURACY

After specifying the represented weighting factors for each type of exterior wall and roof, the room cooling load for each set of weather data can be calculated by using DOE 2.1E. Then the CLTD values for each hour at a certain orientation can be obtained by dividing the calculated cooling load by the product of overall heat transfer coefficient for surface and area of surface. The CLTD values based on first set of weather data are shown in Tables 7 and 8 and CLTD

**Table 6 Conduction weighting factors of the representative point in each roof type**

Roof No.	Amplitude	Delay	$\nu_0$	$\nu_1$	$\nu_2$	$w_1$	$w_2$
1(ceiling)	0.778	0.538	0.68508	-0.67568	0.11202	-1.07039	0.20466
1(no ceiling)	0.702	0.435	0.62567	-0.63800	0.13349	-1.08726	0.24391
2(ceiling)	0.778	0.539	0.68508	-0.67628	0.11224	-1.07126	0.20504
2(no ceiling)	0.702	0.508	0.62572	-0.63572	0.12408	-1.08485	0.22716
3(ceiling)	0.778	0.541	0.68443	-0.66733	0.10560	-1.05692	0.19355
3(no ceiling)	0.753	0.440	0.61640	-0.60158	0.10977	-1.03194	0.20080

**Table 7 CLTD table for wall (°C) based on first set of weather data**

Wall face	(Wall number 1)												Hour											
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N	11	10	9	9	8	8	7	7	7	8	8	9	10	11	12	12	13	14	14	14	14	13	12	12
NE	11	11	10	9	9	8	7	8	8	10	12	13	15	16	16	17	17	17	16	16	15	14	13	12
E	12	11	10	10	9	8	8	8	9	10	13	15	16	17	18	18	18	18	17	17	16	15	14	13
SE	11	10	9	9	8	8	7	7	8	9	10	12	13	14	15	15	15	15	15	15	14	13	12	12
S	9	8	8	7	7	6	6	6	6	6	7	7	8	9	10	11	11	12	12	11	11	11	10	10
SW	14	13	12	11	10	10	9	8	8	8	9	9	10	10	11	13	14	16	17	18	17	17	16	15
W	17	16	15	14	13	12	11	10	10	10	10	10	11	11	13	14	16	19	21	21	21	21	19	18
NW	16	15	13	12	12	11	10	9	9	9	9	10	10	11	12	14	15	17	19	20	20	19	18	17
Wall face	(Wall number 2)												Hour											
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N	12	11	9	9	8	7	6	6	5	6	6	8	9	10	11	13	14	14	15	16	15	15	14	13
NE	11	10	9	8	7	7	6	6	6	7	9	12	14	16	18	18	19	19	18	18	17	15	14	13
E	12	11	10	9	8	7	6	6	6	7	10	13	16	18	19	20	20	20	19	19	17	16	15	13
SE	11	10	9	8	7	7	6	5	5	6	8	10	12	14	16	16	17	17	17	16	16	15	13	12
S	9	9	8	7	6	6	5	5	5	5	5	6	7	8	10	11	12	12	13	13	13	12	11	10
SW	15	14	12	11	10	9	8	7	6	6	6	7	8	9	10	12	13	16	18	19	20	19	18	17
W	19	17	15	13	12	10	9	8	7	7	7	8	8	9	11	12	15	18	21	23	24	24	23	21
NW	18	16	14	12	11	10	9	8	7	7	7	7	8	9	10	12	14	17	19	21	22	22	21	19
Wall face	(Wall number 3)												Hour											
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N	8	7	6	6	5	4	4	5	6	8	9	11	12	14	15	16	16	17	16	15	14	12	11	9
NE	8	7	6	5	5	4	4	6	9	13	16	19	20	20	20	19	19	18	16	14	13	11	10	9
E	8	7	6	5	5	4	5	6	10	14	18	21	22	22	22	21	20	18	17	15	13	12	10	9
SE	7	7	6	5	5	4	4	5	8	11	14	16	18	18	18	18	17	17	15	14	12	11	10	8
S	7	6	5	5	4	4	4	4	5	6	7	9	10	12	13	14	14	14	13	12	11	10	9	8
SW	11	9	8	7	6	5	5	5	5	6	8	9	11	13	15	18	20	22	22	21	19	17	14	13
W	13	11	10	8	7	6	6	5	6	7	8	9	11	13	17	20	24	27	28	27	24	21	18	16
NW	12	11	9	8	7	6	5	5	6	7	8	9	11	13	16	19	22	25	25	24	22	19	17	14
Wall face	(Wall number 4)												Hour											
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N	3	3	3	2	2	3	6	10	13	15	16	17	17	18	18	18	17	14	10	7	6	5	4	4
NE	3	3	2	2	2	5	11	20	27	28	26	22	19	18	17	15	13	10	8	6	5	5	4	4
E	3	3	3	2	2	5	12	22	30	32	29	24	20	18	17	16	13	11	8	6	5	5	4	4
SE	3	3	3	2	2	4	8	16	22	25	24	21	18	17	16	15	13	10	8	6	5	5	4	4
S	3	3	2	2	2	2	5	7	10	12	14	15	16	16	16	14	12	10	7	6	5	4	4	4
SW	4	3	3	3	2	3	5	7	10	12	14	15	18	23	26	28	28	22	15	10	7	6	5	4
W	4	4	3	3	2	3	5	7	10	12	14	15	20	27	33	37	38	31	20	13	9	7	6	5
NW	4	4	3	3	2	3	5	7	10	12	14	15	19	25	29	33	34	28	18	12	8	7	6	5

**Table 7 CLTD table for wall (°C) based on first set of design data (continue)**

Wall face	(Wall number 5)										Hour													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N	4	3	3	3	2	3	4	7	10	13	14	15	16	17	17	18	17	16	13	10	8	6	5	5
NE	4	3	3	3	2	3	7	13	20	24	25	23	21	19	18	16	15	12	10	8	7	6	5	4
E	4	3	3	3	2	3	8	15	23	27	28	25	22	20	18	17	15	13	10	8	7	6	5	4
SE	4	3	3	3	2	3	6	11	17	20	22	21	19	18	17	16	14	12	10	8	7	6	5	4
S	4	3	3	2	2	2	3	5	8	10	12	13	14	15	15	15	13	11	9	7	6	5	5	4
SW	5	4	4	3	3	3	4	5	7	10	12	13	16	19	23	26	27	24	19	14	11	8	7	6
W	6	5	4	3	3	3	4	6	8	10	12	13	17	22	28	33	35	33	26	19	14	10	8	7
NW	5	4	4	3	3	3	4	5	7	10	12	13	16	21	25	29	31	30	23	17	13	10	8	6

Wall face	(Wall number 6)										Hour													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N	3	3	3	2	2	3	6	10	14	16	17	17	17	18	18	18	18	15	11	8	6	5	5	4
NE	3	3	3	2	2	4	11	20	27	29	27	23	20	18	17	16	13	11	8	6	5	5	4	4
E	3	3	3	2	2	5	12	22	31	33	30	25	20	19	17	16	14	11	8	6	5	5	4	4
SE	3	3	3	2	2	4	8	16	23	25	24	21	19	18	17	15	13	11	8	6	5	5	4	4
S	3	3	3	2	2	2	4	8	10	13	14	15	16	16	16	15	13	10	8	6	5	4	4	4
SW	4	3	3	3	2	3	5	7	10	12	14	15	18	23	26	28	28	23	15	10	7	6	5	5
W	4	4	3	3	2	3	5	8	10	12	14	16	20	27	33	37	38	32	21	13	9	7	6	5
NW	4	4	3	3	2	3	5	7	10	12	14	16	19	25	29	33	34	29	19	12	8	7	6	5

Wall face	(Wall number 7)										Hour													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N	6	5	5	4	4	3	4	6	9	11	13	14	15	16	17	18	18	17	15	13	11	9	8	7
NE	6	5	4	4	3	4	6	10	16	20	23	23	22	21	20	19	17	16	13	11	10	8	7	6
E	6	5	4	4	3	4	6	11	18	23	25	25	24	22	21	20	18	16	14	12	10	9	8	7
SE	6	5	4	4	3	3	5	9	13	17	20	20	20	19	19	18	17	15	13	11	10	8	7	6
S	5	5	4	4	3	3	3	5	7	9	11	12	13	14	15	15	15	13	12	10	9	8	7	6
SW	8	7	6	5	4	4	4	5	7	9	11	12	14	17	20	22	25	25	22	18	15	13	11	9
W	9	8	7	6	5	4	4	6	7	9	11	12	14	18	23	27	31	32	28	23	19	16	13	11
NW	9	7	6	5	5	4	4	6	7	9	11	12	14	17	21	25	28	29	26	21	18	15	12	10

**Table 8 CLTD table for roof (°C) based on first set of weather data**

Roof No.	Hour																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1(CL)	14	12	11	9	8	7	7	7	9	12	17	22	27	31	34	36	36	34	31	28	24	21	19	16
1(NC)	6	5	4	3	3	2	3	5	10	16	22	27	31	35	36	35	32	28	23	19	15	12	10	8
2(CL)	21	20	19	18	17	16	15	14	14	14	15	16	18	20	22	24	26	27	27	27	26	25	24	23
2(NC)	16	14	13	12	10	9	8	8	8	10	12	15	18	21	24	26	28	28	27	25	23	21	19	18
3(CL)	12	11	10	8	7	7	7	8	11	16	21	26	31	34	36	36	35	32	28	25	22	19	16	14
3(NC)	6	5	4	3	3	2	4	7	11	17	23	27	31	33	33	32	28	24	20	16	13	11	9	7

Note: CL=ceiling , NC=no ceiling, inside air temperature 25°C

values based on second set of weather data are shown in Tables 9 and 10. The CLTD values shown are based on inside air temperature of 25°C, outside surface film resistance of 0.058 m<sup>2</sup>°C/W, inside surface resistance of 0.121 m<sup>2</sup>°C/W and dark surface.

The results of cooling load due to heat gain

through opaque envelopes using CLTD values developed from the first set of weather data and the second set of weather data for selected walls and roofs are compared. The selected envelopes are exterior wall number 5 oriented East-West and roof number 1 having areas of 12 and 16 square meters, respectively.

**Table 9 CLTD table for wall (°C) based on second set of weather data**

Wall face	(Wall number 1)												Hour											
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N	11	10	10	9	9	8	8	8	8	8	9	9	10	11	11	12	13	13	13	13	13	13	12	11
NE	13	13	12	11	10	10	9	9	11	13	15	17	18	19	19	19	19	19	19	18	17	16	15	14
E	15	14	13	12	11	10	10	10	12	15	17	20	21	22	22	22	21	21	20	19	18	17	16	16
SE	13	12	12	11	10	9	9	9	10	12	14	16	17	18	19	19	19	18	18	17	17	16	15	14
S	10	10	9	9	8	8	7	7	7	7	8	8	9	10	11	11	12	12	13	12	12	12	11	11
SW	15	14	14	13	12	11	10	10	9	9	10	10	11	11	12	14	16	18	19	19	19	18	17	16
W	18	17	16	15	14	13	12	11	11	11	11	11	12	13	15	18	20	22	23	23	22	20	19	19
NW	16	15	14	13	12	11	11	10	10	10	10	11	11	12	14	16	18	20	20	20	19	18	17	17
Wall face	(Wall number 2)												Hour											
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N	11	11	10	9	8	7	7	6	6	7	7	8	9	10	11	12	13	14	14	15	15	14	13	12
NE	13	12	11	10	9	8	7	7	8	9	12	16	18	21	22	22	22	21	21	20	19	17	16	15
E	14	13	12	10	9	9	8	7	8	10	14	18	21	24	25	25	25	24	23	22	20	19	17	16
SE	13	12	11	10	9	8	7	7	7	9	11	14	17	19	20	21	21	21	20	19	18	17	16	14
S	11	10	9	8	8	7	7	6	6	6	6	7	8	9	11	12	13	13	14	14	14	13	12	11
SW	17	15	14	13	11	10	9	8	8	7	8	8	9	10	11	13	15	17	20	21	22	22	20	19
W	20	18	16	15	13	12	10	9	9	8	8	9	9	10	11	13	16	19	22	25	26	26	24	22
NW	18	16	15	13	12	11	9	9	8	8	8	8	9	10	11	12	14	17	20	22	23	23	21	20
Wall face	(Wall number 3)												Hour											
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N	8	8	7	6	6	5	5	6	7	8	10	11	12	13	14	15	15	16	15	14	13	12	11	9
NE	9	8	7	7	6	6	6	9	13	18	21	23	24	24	23	22	21	20	18	16	14	13	11	10
E	9	8	8	7	6	6	7	10	15	21	25	28	28	27	26	25	23	21	19	17	15	14	12	11
SE	9	8	7	7	6	6	6	8	12	16	20	22	23	23	22	21	20	19	18	16	14	13	11	10
S	8	7	7	6	5	5	5	5	6	7	8	10	11	13	14	14	15	15	14	13	12	11	10	9
SW	12	11	9	8	7	7	6	6	7	8	9	10	11	13	16	19	22	25	25	23	21	18	16	14
W	14	13	11	10	8	7	7	7	7	8	9	10	12	14	17	21	26	29	30	28	25	22	19	17
NW	13	11	10	9	8	7	6	6	7	8	9	10	11	13	16	19	23	26	26	24	22	19	17	15
Wall face	(Wall number 4)												Hour											
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N	4	4	3	3	3	4	8	11	13	14	15	15	16	16	16	17	16	13	10	8	6	6	5	5
NE	4	4	4	3	3	7	18	30	34	33	29	24	20	18	17	16	14	11	9	7	7	6	5	5
E	4	4	4	3	3	8	21	35	41	40	35	28	22	20	18	17	15	12	9	8	7	6	5	5
SE	4	4	4	3	3	6	15	25	31	32	29	24	20	18	17	16	14	11	9	7	6	6	5	5
S	4	4	4	3	3	4	5	8	10	13	15	16	17	16	16	15	13	11	8	7	6	5	5	4
SW	5	4	4	4	4	4	5	8	10	12	14	16	19	24	30	33	32	23	15	11	8	7	6	5
W	5	5	4	4	4	4	6	8	10	12	14	16	20	27	36	42	42	30	18	12	10	8	7	6
NW	5	4	4	4	4	4	5	8	10	12	14	15	18	23	30	36	36	26	16	11	9	7	6	5
Wall face	(Wall number 5)												Hour											
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N	5	4	4	4	3	4	6	9	11	12	13	14	15	15	16	16	16	15	12	10	8	7	6	5
NE	5	4	4	4	3	5	12	21	27	30	29	26	22	20	19	17	16	13	11	9	8	7	6	5
E	5	4	4	4	4	5	13	25	33	36	35	31	26	22	20	18	16	14	11	10	8	7	6	5
SE	5	4	4	4	4	5	10	18	24	28	28	26	22	20	19	17	16	13	11	9	8	7	6	5
S	5	4	4	4	3	3	4	6	8	10	12	14	15	16	16	15	14	12	10	8	7	6	6	5
SW	6	5	5	4	4	4	5	6	8	10	12	14	17	21	25	29	31	27	20	15	12	10	8	7
W	6	6	5	4	4	4	5	6	8	10	12	14	17	22	29	36	39	34	25	19	14	11	9	8
NW	6	5	5	4	4	4	5	6	8	10	12	13	16	20	25	31	33	29	22	16	13	10	8	7

**Table 9 CLTD table for wall (°C) based on second set of weather data (continue)**

Wall face	(Wall number 6)											Hour												
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N	4	4	4	3	3	4	8	11	13	14	15	16	16	16	17	17	17	14	10	8	7	6	5	5
NE	4	4	4	3	3	7	18	30	35	34	30	24	20	19	18	17	15	12	9	8	7	6	5	5
E	4	4	4	4	4	7	21	36	41	41	36	28	22	20	18	17	15	12	9	8	7	6	6	5
SE	4	4	4	4	3	6	15	26	31	32	30	25	21	19	18	17	15	12	9	8	7	6	5	5
S	4	4	4	3	3	4	5	8	11	13	15	16	17	17	16	15	14	11	9	7	6	6	5	5
SW	5	5	4	4	4	4	5	8	11	13	14	16	19	24	30	34	33	24	15	11	8	7	6	6
W	5	5	4	4	4	4	6	8	11	13	14	16	20	27	36	43	43	32	19	13	10	8	7	6
NW	5	4	4	4	4	4	5	8	11	13	14	15	18	23	30	36	36	27	17	11	9	7	6	6

Wall face	(Wall number 7)											Hour												
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N	7	6	5	5	5	5	6	8	10	11	13	14	14	15	16	16	17	16	14	12	11	9	8	7
NE	7	6	6	5	5	5	9	16	22	26	27	27	25	23	22	21	19	17	15	13	11	10	9	8
E	7	6	6	5	5	5	10	19	26	31	32	31	29	26	24	22	21	18	16	14	12	10	9	8
SE	7	6	6	5	5	5	8	14	20	24	26	26	24	23	21	20	19	17	15	13	11	10	9	8
S	6	6	5	5	5	4	5	6	8	9	11	13	14	15	16	16	15	14	13	11	10	9	8	7
W	9	8	7	6	6	5	5	6	8	10	11	13	15	18	21	25	28	27	23	20	16	14	12	10
W	10	9	8	7	6	6	6	7	8	10	11	13	15	19	24	30	34	34	29	24	20	17	14	12
NW	9	8	7	6	6	5	5	6	8	10	11	13	14	17	21	26	30	29	25	21	18	15	13	11

**Table 10 CLTD table for roof (°C) based on second set of weather data**

Roof No.	Hour																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1(CL)	17	15	14	12	11	10	9	9	12	16	21	27	32	36	39	41	41	39	36	32	28	25	22	19
1(NC)	8	7	6	5	4	3	4	7	13	19	26	32	37	39	40	39	36	31	26	21	17	14	12	10
2(CL)	25	24	22	21	20	19	18	17	17	17	18	19	22	24	26	28	30	31	31	31	30	29	28	26
2(NC)	19	17	15	14	13	11	10	10	11	12	15	18	22	25	28	30	32	32	31	29	27	25	22	20
3(CL)	15	14	12	11	10	9	9	11	15	20	26	32	36	39	41	42	40	36	32	29	25	22	19	17
3(NC)	8	7	6	5	4	4	5	9	15	21	27	32	36	37	38	36	32	27	23	19	16	13	11	9

Note: CL=ceiling, NC=no ceiling, inside air temperature 25°C

The comparison of the cooling load is shown in Fig. 5. The cooling load values calculated from the first set and the second set of weather data are quite close together with the values calculated from the second set of weather data larger. The maximum value of the east wall cooling load occurs in the morning while the maximum value of the west wall cooling load occurs in the afternoon. The magnitudes of the cooling load on the west wall are greater than the cooling load on east wall, especially the cooling load calculated from the first set of weather data. The smaller value of the east wall cooling load is due to the lower value of the direct normal radiation of the first set of weather data in the morning compared to the radiation data in the afternoon as shown in Fig. 1. The direct normal radiation data of the second set of weather data are rather symmetrical around 12 o'clock

noon. Therefore, the maximum value of the east wall and west wall cooling load calculated from the second set of weather data are quite close together.

Then the CLTD values from ASHRAE (1997), with some adjustment as suggested by ASHRAE (1997), to correct for the outside air temperature, inside air temperature, and daily range to suit the first set and second set of weather data shall be used to obtain the cooling load of the similar envelopes considered. Wall number 3 and roof number 3, which according to ASHRAE (1997), have characteristics closest to wall number 5 and roof number 1 in this study are selected for finding the CLTD values. The results are shown with the previous results in Fig. 6. As for the roof, the values of the cooling load calculated from CLTD values based on ASHRAE according to the first set and second set of weather data are

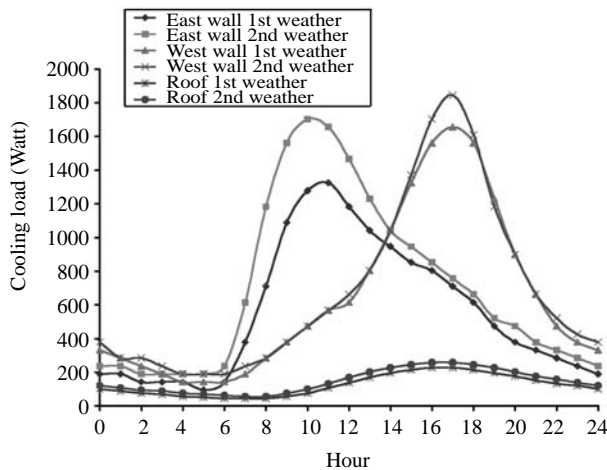


Fig. 5 The comparison between cooling load of specified walls and roof calculated from CLTD values based on 1<sup>st</sup> weather data set and ones calculated from CLTD values based on 2<sup>nd</sup> weather data set

quite close together, almost the same line as shown in Fig. 6. Fig. 6 shows the comparison of the cooling load calculated from the developed CLTD values based on the first set and the second set of weather data and the cooling load calculated from CLTD values based on ASHRAE. Some discrepancy in cooling load values between ones calculated from CLTD values based on ASHRAE and the developed CLTD values can be obviously seen. The cooling load calculated from CLTD values based on ASHRAE according to the first set of weather data is higher on the east wall, west wall, and roof when compared to the load calculated from the developed CLTD values. The discrepancy in cooling load values calculated from the second set of weather data have a similar pattern to the ones calculated from the first set of weather data except that the maximum value of the east wall cooling load calculated from ASHRAE is lower than the cooling load calculated from the developed CLTD values. From Fig. 6, one can clearly see that though some adjustment can be applied to correct the CLTD values generated by ASHRAE due to local weather data which are different from the generated weather data, some large errors in the cooling load calculated from the corrected values still exist. Therefore, it would be more appropriate to use CLTD values that are developed from local weather data and based on materials commonly used in local buildings for calculating building cooling load rather than using CLTD values generated from ASHRAE.

## VI. CONCLUSION

This article describes the development of cooling load temperature differential values for building

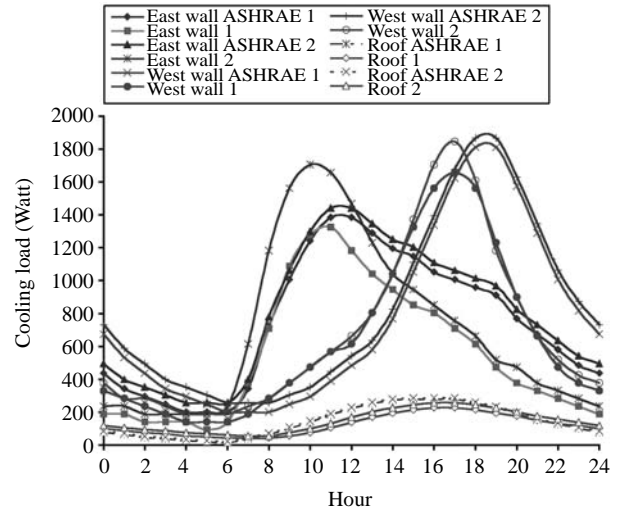


Fig. 6 The comparison between cooling load of specified walls and roof calculated from CLTD based on 1<sup>st</sup> and 2<sup>nd</sup> weather data sets and ones calculated from CLTD values from ASHRAE corrected to the condition of 1<sup>st</sup> and 2<sup>nd</sup> weather data sets

envelopes in Thailand made of materials commonly used in Thailand and using Bangkok weather data. With these CLTD values, the cooling load of the building envelopes can be easily and manually performed. The CLTD values based on the first set of weather data are suitable for predicting the cooling load for general usage while the CLTD values based on the second set of weather data will be more suitable when the designers emphasize the peak cooling load and the size of the air conditioning equipment. The study also shows the discrepancy when one uses CLTD values with some adjustment from ASHRAE which are more suitable for building in North America. With more accurate values of CLTD, the cooling load calculation can be easily and manually performed and yields a more accurate result. This will allow the air conditioning systems design in Thailand to be performed more easily and more effectively.

## NOMENCLATURE

$a$	amplitude
$A$	area of surface, m <sup>2</sup>
<i>ASHRAE</i>	American Society of Heating, Refrigerating and Air Conditioning Engineers
<i>CLTD</i>	cooling load temperature differential
$d$	time delay
$Dr$	mean daily range
$i$	index
$q_t$	hourly heat gain at time $t$ , W
$q_{max}$	maximum heat gain of magnitude 1 watt
$Q$	cooling load, W

$T_o$	hourly dry bulb temperature, °C
$T_d$	maximum dry bulb temperature, °C
<i>TFM</i>	transfer function method
$U$	overall head transfer coefficient for surface, W/m <sup>2</sup> -°C
$v_i, w_i$	coefficient of room transfer function or weighting factors
$X$	percentile of daily variation of dry bulb temperature
$\phi$	phase lag, radians

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