Cooling Load Temperature Differential Values For Buildings In Ghana

Felix A. Uba, Emmanuel A. Sarsah

Abstract: Wrong sizing of equipment is often the result of inaccurate procedures employed to estimate the cooling load of the air conditioned space. Long term weather information was used to develop cooling load temperature differential (CLTD) values made of materials commonly used in Ghana. The CLTD are produced from ASHRAE mathematical models and weather information of Accra, Ghana. The CLTD was obtained for each wall and roof type after dividing the results from the Transfer Function Method, TFM by the overall heat transfer coefficient of the envelope material. This method makes hand calculation of cooling load possible and gives satisfactory results when compared with complex cooling load tools.

Key Terms: Cooling Load, Building, Transfer Function Method, CLTD.

1 INTRODUCTION

The use of air conditioners is becoming a standard feature in occupied spaces such as offices, shops and private houses today in Ghana and correct calculation of heating and cooling loads is the essential first step for successful HVAC system design. As has been thoroughly documented, properly sized systems, compared to over-sized systems, have lower installation cost, perform better, operate more efficiently, and impose less demand on utilities [1]. The cause of over-sizing is lack of confidence in load calculation methods. That is, practitioners do not know (or do not believe) the accuracy of the procedures and thus use conservative assumptions and/or apply safety factors to calculate loads. Most air-conditioning equipment breakdowns can be attributed to the vast error between actual space load and the equipment capacity; these identify weaknesses at the side of service providers. In fact, it is surprisingly difficult to make rigorous comparisons of calculated and actual building cooling loads [2] but the error of difference can be reduced. For accurate estimation of cooling load which is the first requirement for correct sizing of cooling equipment, computer-based load estimation programs are available on the market today. This kind of computer program usually requires local annual weather data (8760 hours) and requires a complex and lengthy data input [3].

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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 [4]. 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. [5] has developed the CLTD values for exterior walls and roofs based on solar radiation 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 [6,7]. The accuracy of the CLTD values could be in question when the location of the building is not at 40°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 [3]. 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 Ghana and using Accra (Latitude 5.6°N) weather data. With these values, the cooling load calculation of buildings in Ghana can be easily and manually performed with more accuracy and also for tuition purposes.

2 MATERIALS AND METHODS

2.1 Sol-Air Temperature

Sol-air temperature, T_{sol}, is the fictitious temperature of the outdoor air which, in the absence of radiative exchanges on the outer surface of the roof or wall, would give the same rate of heat transfer, *Q*, through the wall or roof as the actual combined heat transfer mechanism between the sun, the surface of the roof or wall, the outdoor air and the surroundings [8]. T_{sol}, is the outdoor temperature increased by an amount to account for the effect of solar radiation. If the surrounding environment can be characterized by a single temperature to account for the radiative flux, *αI/A*, the sol-air temperature, is defined as;

$$T_{sol} = T_0 + \frac{\alpha I}{h_0} - \frac{\Delta qir}{h_0} \quad (1)$$

where

h_o = surface heat transfer coefficient for radiation and convection, W/ (m^2.K)

I = global solar irradiance on surface, W/m^2

T_o = out-door temperature, K

Δqir = correction to infrared radiation transferred between surface and environment if the sky temperature is different from T_o, W/m^2

α = absorptance

A = area of wall, m^2

In practice, one assumes that $\Delta qir/ho$ varies from zero for vertical surfaces to 3.9 K for upward-facing surfaces and the values of $\alpha I/ho$ range from 0.026-0.052; value is 0.026 for light-coloured surface, whiles 0.052 represents maximum value for dark-surfaces [8].

2.1.2 Insolation on surfaces

The amount of radiation incident on an inclined surface is the algebraic sum of the direct radiation reflected from the ground and diffuse sky radiation incident on a surface and usually called global radiation [9,10]. From [11] if unshaded flat surface is titled at an angle θ_p, the global irradiance, on the tilted plane is

$$I_{glo,p} = I_{dir}\cos\theta_i + I_{dif}\frac{1+\cos\theta_p}{2} + I_{glo,hor}\rho g\frac{1-\cos\theta_p}{2} \quad (2)$$

and on a horizontal plane is

$$I_{glo,hor} = I_{dir}\cos\theta_s + I_{dif} \quad (3)$$

where

θ_p = zenith angle, angle of tilt from the horizontal surface

I_{dir} = direct radiation, W/m^2

θ_i = incidence angle (an angle between normal of plane and line from sun)

θ_s = zenith angle for any latitude, λ

I_{dif} = diffuse irradiance on a horizontal surface, W/m^2

ρg = reflectivity of the ground, [10]

For vertical surfaces, the angle θ_p = 90° and "(2)" simply reduces to;

$$I_{glo,vert} = I_{dir}\cos\theta_i + \frac{I_{dif}}{2} + \frac{I_{glo,hor}\rho g}{2} \quad (4)$$

According to [10]

$$I_{dir} = I_0\left[a_0 + a_1\exp\left(-\frac{k}{\cos\theta_s}\right)\right] \quad (5)$$

I_0 is the extraterrestrial radiation. The coefficients; a_0, a_1 and k depend on the state of the atmosphere; they are listed in [10] for 23 km and 5km visibility. The correction factors r_o, r_1, and r_k depend on the time of the year and climate. From [12] the diffuse irradiance on a horizontal surface can be estimated from a relation

$$I_{dif} = \left(0.271I_0 - 0.2939I_{dir}\right)\cos\theta_s \quad (6)$$

2.1.3 Conductive heat across external surfaces

If the temperature follows a periodic pattern, day after day, heat gain conducted will follow a periodic pattern. Once heat gain conducted has been calculated, the CLTD can be defined as the temperature difference that gives the same cooling when multiplied by UA. Thus the conductive cooling load is

$$\dot{Q}_{cond,t} = UA\left(CLTD_t\right) \quad (7)$$

where

$\dot{Q}_{cond,t}$ = conductive heat gain at time t.

$CLTD$ = Cooling Load Temperature Difference

t = time in hour of the day

U = overall heat transfer coefficient, (W/m^2.K)

A = area, (m^2)

The CLTD values are obtained from transfer functions.

This approach was developed by [8]

In the TFM, two elements are identified: the driving elements and the response elements. The TFM calculates the response of a system by the following basic assumptions: discrete time steps, linearity and causality (the response at time t can depend only on the past, not on the future) This method includes these steps:

- Calculation of the conductive heat gain for each distinct component of the envelope from "(8)" below.
- Calculation of the load of the room at constant temperature, based on this conductive heat gain as well as any other heat source in the room from "(9)".

The Cooling Load Temperature Difference method is a simplified method of TFM for direct one step calculation of cooling load. The conductive transfer defined in TFM form by [8]

$$\dot{Q}_{cond,t} = -\sum_{n\geq 1} d_n \dot{Q}_{cond,t-n\Delta t} + A\left(\sum_{n\geq 0} b_n \dot{T}_{sol,t-n\Delta t} - T_i \sum_{n\geq 0} c_n\right) \quad (8)$$

where

$\dot{Q}_{cond,t}$ = conductive heat gain at time *t*.

A = area of roof or wall, m^2

Δt = time step = 1 h

$T_{sol,t}$ = sol-air temperature of outside surface at time *t.*

b_n, c_n, d_n= coefficient of conductive transfer function [4]

The load of the room at constant temperature is expressed as;

$$\dot{Q}_{load,t} = v_0 \dot{Q}_{gain,t} + v_1 \dot{Q}_{gain,t-\Delta t} + v_2 \dot{Q}_{gain,t-2\Delta t} + ... - w_1 \dot{Q}_{load,t-\Delta t} - w_2 \dot{Q}_{load,t-2\Delta t} \quad (9)$$

Where

$\dot{Q}_{gain}$ = heat gain , W

$\dot{Q}_{load}$ = cooling load, W

v_n, w_n = transfer function coefficients

t = time, h

The coefficients in "(8)" and "(9)" stand for properties of building envelope. In this paper some of the assumptions taken are; there is no heat pocket in the envelope, and sol-air temperatures of external surfaces are uniformly distributed on the surface.

3 RESULTS, DISCUSSION AND VALIDATION

Insolation values from the ASHRAE models were used to produce the sol-air temperatures for walls of different orientations. As shown in Fig. 1 the wall temperature for east facing wall increases to its peak around 10:00 hours and starts to fall to meet the air temperature. At mid-day the west facing wall picks up some isolation and consequently an increase in temperature till its gets to its peak around 15:00 hours then it falls back in line with the air temperature. The east and west walls are presumed to be symmetrical and supposed to have the same peak/amplitude in temperature but the opposite occurred with the east having a lower amplitude compared to the west wall because of the effect of dew/moisture in the atmosphere in the morning. This applies to the other symmetric wall orientations; SE, SW and NE, NW. The deviations of the wall temperatures from the air temperatures when the sun is at the opposite side are accounted for by the diffuse part of the radiations.

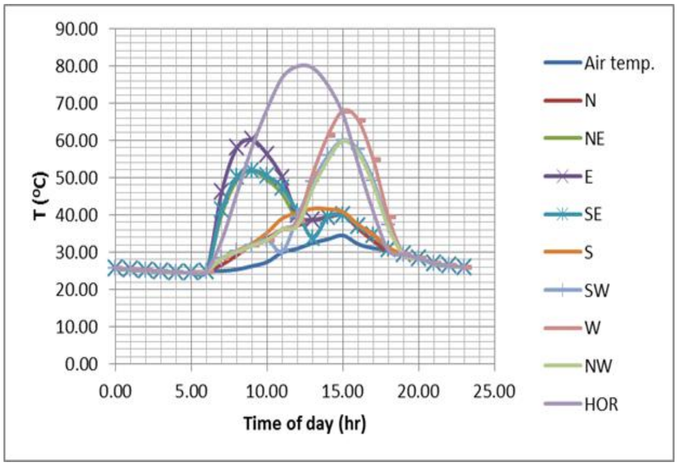

Fig. 1. Sol-Air temperature for different orientations of surfaces

Fig. 2 shows cooling load temperature difference of a 4-in light weight concrete wall against solar time for a typical material and Tables 1 and 2 (in the appendix) show factors of CLTD with time for various construction types.

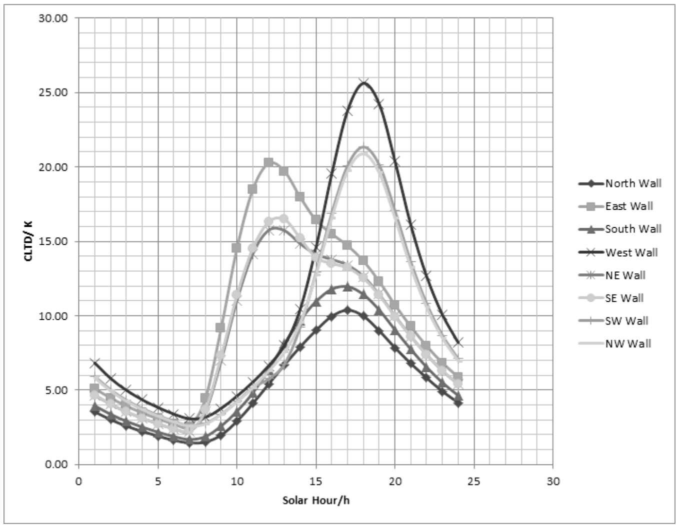

Fig. 2. Cooling Load Temperature Difference of a 4-in light weight concrete wall against solar time.

The heavier the construction the smaller the amplitude and later the peak. The calculation needs to be done for the hour when the peak occurs. That hour can be guessed if a single load dominates, because in that case it is the hour with the largest value of CLTD. If several loads with non-coincident peaks are of comparable importance, the hour of the combined peak may not be entirely obvious, and the calculation may have to be repeated several times. In most buildings, peak cooling loads occur in the afternoon or early evening. Fig. 2 gives an indication when the components of the cooling load are likely to reach their peak. The scale of deviation of the cooling load obtained from some installations shows that it estimations are satisfactory. An example is the results obtained when it was used at the Check-in hall and the Meeters & Greeters hall of the Terminal building at the Kotoka International Airport [13]. The air conditioning system was designed and supplied by

York Air Conditioning Company of the United Kingdom. The design data of the air conditioning system in the two spaces are tabulated in [13].

4 CONCLUSION

This article describes the development of cooling load temperature differential values for building envelopes in Ghana made of materials commonly used, ASHRAE models and using long term weather data. With these CLTD values, the cooling load of the building envelopes can be easily and manually performed. 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 air-condition simulation, tuition for academic purposes, and systems design in Ghana to be performed more easily and more effectively.

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APPENDIX: TABLE OF CLTDs VALUES

Table 1. CLTDs of Selected Roof Construction

CLTDs table for sunlite roofs (K) based on lat. 5.6°N

Description of construction	U valve, W/(m^2.K)	Solar time, h																								Hour of max. CLTD	Min. CLTD	Max. CLTD	Differ-ence CLTD
		0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400				
4-in. light weight deck with false ceiling	0.817632	7.58	6.20	5.05	4.06	3.20	2.46	1.94	2.40	4.46	8.12	12.84	18.08	23.09	27.25	30.06	31.21	30.27	27.41	23.41	19.53	16.27	13.49	11.15	9.21	1600	1.94	31.21	29.27
4-in. light weight concrete roof	0.760852	8.95	6.86	5.09	3.59	2.31	1.22	0.32	-0.18	0.45	2.75	6.72	11.92	17.76	23.43	28.27	31.69	33.21	32.49	29.70	25.66	21.46	17.65	14.31	11.42	1700	-0.18	33.21	33.40
4-in. heavy weight concrete floor deck	1.936198	9.34	7.98	6.78	5.72	4.76	3.92	3.40	3.88	5.73	8.79	12.67	16.95	21.01	24.41	26.77	27.76	27.06	24.91	22.02	19.29	16.83	14.61	12.63	10.89	1600	3.40	27.76	24.36
6-in. heavy weight concrete roof	0.499664	14.89	14.49	14.09	13.67	13.25	12.81	12.39	11.97	11.63	11.45	11.49	11.77	12.29	12.99	13.77	14.55	15.27	15.81	16.11	16.19	16.07	15.87	15.59	15.25	2000	11.45	16.19	4.74

Table 2. CLTDs of Selected Wall Construction

CLTDs table for wall (K) based on lat. 5.6°N

Wall facing	Solar time, h 0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400	Hour of max. CLTD	Min. CLTD	Max. CLTD	Difference CLTD
Wall number 1 (4-in. light weight concrete wall)																												
N	3.55	3.02	2.59	2.23	1.92	1.64	1.46	1.52	1.99	2.92	4.11	5.41	6.70	7.91	9.03	9.96	10.38	9.98	8.99	7.84	6.79	5.82	4.92	4.16	1700	1.46	10.38	8.92
NE	4.67	4.05	3.55	3.12	2.74	2.41	2.24	3.55	7.00	11.04	14.17	15.75	15.73	14.84	14.13	13.78	13.41	12.64	11.44	9.99	8.62	7.39	6.30	5.40	1200	2.24	15.75	13.51
E	5.11	4.47	3.93	3.48	3.08	2.73	2.57	4.45	9.20	14.55	18.48	20.23	19.72	17.96	16.43	15.50	14.72	13.68	12.30	10.72	9.27	7.97	6.83	5.89	1200	2.57	20.23	17.66
SE	4.67	4.06	3.55	3.12	2.76	2.42	2.25	3.68	7.30	11.39	14.54	16.30	16.48	15.21	13.91	13.52	13.22	12.52	11.37	9.95	8.60	7.39	6.31	5.41	1300	2.25	16.48	14.23
S	3.95	3.38	2.91	2.52	2.18	1.89	1.69	1.89	2.60	3.58	4.82	6.40	8.13	9.71	10.97	11.79	11.96	11.44	10.39	9.05	7.74	6.55	5.51	4.64	1700	1.69	11.96	10.27
SW	5.93	5.03	4.33	3.77	3.31	2.91	2.63	2.77	3.39	4.24	5.17	5.76	6.74	9.24	12.92	16.90	20.09	21.35	20.14	17.05	13.63	10.83	8.69	7.11	1800	2.63	21.35	18.72
W	6.83	5.79	4.99	4.36	3.84	3.40	3.08	3.19	3.78	4.61	5.54	6.65	8.00	10.44	14.57	19.55	23.79	25.63	24.23	20.37	16.09	12.65	10.07	8.20	1800	3.08	25.63	22.55
NW	5.82	4.95	4.26	3.71	3.26	2.86	2.59	2.73	3.36	4.21	5.17	6.29	7.55	9.53	12.76	16.58	19.73	20.89	19.60	16.55	13.25	10.57	8.50	6.97	1800	2.59	20.89	18.30
SHADED	2.61	2.19	1.83	1.53	1.28	1.04	0.88	0.82	0.82	0.94	1.24	1.82	2.64	3.53	4.44	5.30	5.83	5.87	5.67	5.33	4.87	4.30	3.67	3.10	1800	0.82	5.87	5.05

Wall facing	Solar time, h 0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400	Hour of max. CLTD	Min. CLTD	Max. CLTD	Difference CLTD
Wall number 2 (4-in. h. w. concrete wall)																												
N	4.45	3.92	3.45	3.03	2.66	2.32	2.08	2.06	2.35	2.99	3.81	4.77	5.78	6.79	7.76	8.63	9.04	8.91	8.40	7.76	7.09	6.38	5.68	5.03	1700	2.06	9.04	6.98
NE	5.99	5.31	4.71	4.18	3.71	3.29	3.09	4.28	6.76	9.50	11.68	12.97	13.27	13.17	13.13	13.17	12.99	12.49	11.62	10.59	9.57	8.56	7.61	6.75	1300	3.09	13.27	10.18
E	6.61	5.87	5.23	4.65	4.14	3.68	3.52	5.25	8.68	12.30	15.06	16.53	16.58	16.01	15.52	15.19	14.70	13.95	12.89	11.70	10.54	9.42	8.37	7.44	1300	3.52	16.58	13.06
SE	6.00	5.32	4.72	4.19	3.72	3.30	3.12	4.40	6.99	9.76	11.99	13.44	13.87	13.37	13.08	13.11	12.95	12.45	11.60	10.58	9.56	8.56	7.61	6.76	1300	3.12	13.87	10.75
S	5.03	4.43	3.91	3.44	3.02	2.65	2.39	2.49	2.92	3.57	4.47	5.69	7.01	8.28	9.37	10.17	10.49	10.34	9.78	8.99	8.14	7.28	6.45	5.70	1700	2.39	10.49	8.10
SW	7.88	6.90	6.06	5.33	4.69	4.14	3.73	3.70	4.00	4.47	5.04	5.40	6.40	8.48	11.30	14.32	16.76	17.87	17.32	15.61	13.69	11.92	10.37	9.03	1800	3.70	17.87	14.16
W	9.18	8.03	7.04	6.20	5.47	4.83	4.36	4.27	4.51	4.95	5.53	6.33	7.42	9.55	12.84	16.62	19.81	21.31	20.67	18.53	16.14	13.99	12.12	10.53	1800	4.27	21.31	17.04
NW	7.73	6.77	5.95	5.24	4.61	4.07	3.67	3.65	3.94	4.43	5.05	5.88	6.87	8.63	11.22	14.17	16.54	17.55	16.93	15.24	13.38	11.67	10.15	8.85	1800	3.65	17.55	13.90
SHADED	3.08	2.71	2.37	2.06	1.78	1.52	1.33	1.20	1.14	1.18	1.38	1.81	2.39	3.06	3.78	4.48	4.91	5.07	5.08	4.95	4.70	4.33	3.90	3.48	1900	1.14	5.08	3.94

Wall facing	Solar time, h 0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400	Hour of max. CLTD	Min. CLTD	Max. CLTD	Difference CLTD
Wall number 3 (4-in. common brick)																												
N	4.71	4.14	3.63	3.19	2.79	2.43	2.14	2.01	2.16	2.64	3.38	4.29	5.30	6.32	7.33	8.27	8.92	9.06	8.73	8.14	7.47	6.75	6.02	5.33	1800	2.01	9.06	7.05
NE	6.29	5.57	4.93	4.36	3.87	3.42	3.08	3.59	5.50	8.16	10.66	12.43	13.24	13.34	13.27	13.27	13.17	12.81	12.10	11.12	10.08	9.04	8.03	7.11	1400	3.08	13.34	10.26
E	6.93	6.14	5.45	4.84	4.30	3.82	3.47	4.27	6.95	10.54	13.78	15.95	16.73	16.45	15.91	15.48	15.04	14.38	13.45	12.29	11.09	9.93	8.82	7.82	1300	3.47	16.73	13.26
SE	6.30	5.57	4.94	4.37	3.87	3.43	3.09	3.66	5.68	8.40	10.94	12.83	13.80	13.74	13.33	13.21	13.12	12.76	12.06	11.10	10.06	9.03	8.03	7.11	1300	3.09	13.80	10.71
S	5.32	4.67	4.11	3.61	3.17	2.77	2.45	2.38	2.66	3.20	3.99	5.08	6.38	7.70	8.90	9.87	10.44	10.51	10.15	9.45	8.60	7.72	6.85	6.04	1800	2.38	10.51	8.14
SW	8.39	7.30	6.37	5.59	4.90	4.31	3.83	3.62	3.77	4.17	4.72	5.18	5.85	7.45	9.94	12.91	15.71	17.51	17.79	16.62	14.76	12.88	11.16	9.66	1900	3.62	17.79	14.17
W	9.77	8.50	7.41	6.49	5.71	5.03	4.47	4.20	4.30	4.65	5.18	5.89	6.84	8.47	11.25	14.86	18.41	20.80	21.23	19.79	17.48	15.16	13.07	11.28	1900	4.20	21.23	17.03
NW	8.22	7.16	6.26	5.49	4.82	4.23	3.76	3.56	3.72	4.12	4.69	5.44	6.36	7.75	9.98	12.80	15.52	17.24	17.42	16.23	14.42	12.59	10.92	9.46	1900	3.56	17.42	13.86
SHADED	3.27	2.88	2.52	2.19	1.89	1.61	1.39	1.24	1.14	1.13	1.25	1.58	2.10	2.73	3.44	4.17	4.75	5.04	5.12	5.06	4.86	4.54	4.13	3.69	1900	1.13	5.12	3.99

Table 2. CLTDs of Selected Wall Construction *(Continued)*

Wall facing	Solar time, h 0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400	Hour of max. CLTD	Min. CLTD	Max. CLTD	Differ-ence CLTD
Wall number 4 (4-in. heavy weight concrete block wall)																												
N	3.45	2.95	2.54	2.18	1.87	1.60	1.46	1.64	2.24	3.27	4.48	5.77	7.02	8.19	9.26	10.11	10.28	9.67	8.60	7.51	6.53	5.59	4.74	4.04	1700	1.46	10.28	8.81
NE	4.56	3.97	3.48	3.06	2.69	2.37	2.37	4.45	8.28	12.10	14.68	15.74	15.30	14.45	13.94	13.71	13.24	12.35	11.04	9.61	8.31	7.13	6.11	5.26	1200	2.37	15.74	13.37
E	5.00	4.38	3.86	3.42	3.03	2.69	2.76	5.69	10.91	15.89	19.08	20.08	19.00	17.27	16.03	15.31	14.49	13.37	11.89	10.34	8.96	7.71	6.63	5.74	1200	2.69	20.08	17.40
SE	4.56	3.98	3.49	3.07	2.70	2.38	2.40	4.63	8.61	12.44	15.09	16.36	16.06	14.55	13.66	13.48	13.09	12.26	10.99	9.58	8.30	7.13	6.11	5.27	1200	2.38	16.36	13.98
S	3.85	3.30	2.85	2.47	2.14	1.85	1.71	2.09	2.90	3.93	5.23	6.89	8.57	10.05	11.18	11.84	11.79	11.11	9.97	8.64	7.41	6.29	5.31	4.50	1600	1.71	11.84	10.12
SW	5.79	4.94	4.27	3.72	3.27	2.87	2.66	2.96	3.67	4.54	5.41	5.87	7.27	10.23	14.07	17.91	20.56	21.06	19.16	15.84	12.70	10.21	8.31	6.88	1800	2.66	21.06	18.41
W	6.67	5.70	4.93	4.31	3.80	3.36	3.11	3.38	4.06	4.90	5.83	6.99	8.48	11.46	15.98	20.88	24.50	25.34	23.01	18.85	14.94	11.90	9.63	7.94	1800	3.11	25.34	22.22
NW	5.69	4.86	4.20	3.66	3.21	2.83	2.62	2.92	3.63	4.50	5.46	6.63	7.94	10.32	13.83	17.59	20.20	20.59	18.62	15.39	12.37	9.98	8.13	6.75	1800	2.62	20.59	17.97
SHADED	2.51	2.11	1.78	1.49	1.23	1.01	0.89	0.84	0.85	1.02	1.38	2.06	2.89	3.78	4.67	5.48	5.83	5.77	5.54	5.18	4.71	4.12	3.51	2.98	1700	0.84	5.83	5.00

Wall facing	Solar time, h 0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400	Hour of max. CLTD	Min. CLTD	Max. CLTD	Differ-ence CLTD
Wall number 5 (4-in. hollow block)																												
N	3.58	3.05	2.62	2.25	1.94	1.65	1.46	1.51	1.95	2.84	4.02	5.32	6.62	7.85	8.97	9.93	10.39	10.06	9.11	7.96	6.90	5.91	5.00	4.22	1700	1.46	10.39	8.93
NE	4.71	4.08	3.57	3.13	2.76	2.43	2.25	3.46	6.72	10.73	13.96	15.70	15.82	15.01	14.26	13.86	13.47	12.73	11.56	10.12	8.73	7.49	6.38	5.46	1300	2.25	15.82	13.57
E	5.16	4.51	3.96	3.50	3.10	2.75	2.58	4.30	8.81	14.14	18.23	20.20	19.88	18.22	16.63	15.62	14.81	13.78	12.43	10.86	9.38	8.06	6.90	5.94	1200	2.58	20.20	17.62
SE	4.71	4.10	3.58	3.15	2.77	2.44	2.26	3.57	7.00	11.08	14.34	16.24	16.57	15.41	14.09	13.59	13.27	12.60	11.48	10.08	8.71	7.48	6.38	5.46	1300	2.26	16.57	14.30
S	3.99	3.41	2.93	2.54	2.20	1.90	1.69	1.87	2.54	3.51	4.73	6.29	8.02	9.62	10.92	11.77	12.00	11.53	10.52	9.19	7.86	6.65	5.58	4.70	1700	1.69	12.00	10.31
SW	5.99	5.07	4.36	3.79	3.33	2.93	2.65	2.75	3.33	4.18	5.10	5.73	6.69	9.07	12.66	16.63	19.91	21.35	20.34	17.39	13.96	11.08	8.85	7.21	1800	2.65	21.35	18.70
W	6.89	5.83	5.02	4.39	3.86	3.42	3.10	3.17	3.72	4.55	5.48	6.58	7.92	10.29	14.29	19.21	23.54	25.59	24.48	20.81	16.52	12.96	10.27	8.31	1800	3.10	25.59	22.49
NW	5.88	4.98	4.29	3.73	3.27	2.88	2.60	2.71	3.30	4.15	5.10	6.21	7.47	9.41	12.54	16.33	19.55	20.89	19.81	16.89	13.58	10.80	8.66	7.06	1800	2.60	20.89	18.29
SHADED	2.65	2.22	1.85	1.55	1.29	1.05	0.89	0.82	0.82	0.93	1.21	1.77	2.58	3.47	4.38	5.25	5.81	5.90	5.71	5.38	4.92	4.35	3.72	3.15	1800	0.82	5.90	5.08

Wall facing	Solar time, h 0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400	Hour of max. CLTD	Min. CLTD	Max. CLTD	Differ-ence CLTD
Wall number 6 (frame, partition with $^{3}/_{4}$-in. gypsum board)																												
N	2.06	1.74	1.48	1.24	1.01	0.87	1.09	1.92	3.34	4.98	6.44	7.84	8.98	10.00	10.82	10.96	9.72	7.94	6.31	5.26	4.38	3.53	2.91	2.45	1600	0.87	10.96	10.10
NE	2.96	2.59	2.27	1.98	1.71	1.53	3.37	9.29	14.95	17.95	18.17	16.45	13.92	12.88	12.84	12.71	11.64	10.03	8.11	6.68	5.60	4.63	3.93	3.40	1100	1.53	18.17	16.64
E	3.33	2.94	2.60	2.29	2.00	1.80	4.38	12.54	19.96	23.47	23.27	20.33	16.27	14.21	13.74	13.44	12.27	10.61	8.66	7.19	6.07	5.08	4.35	3.80	1100	1.80	23.47	21.67
SE	2.97	2.60	2.28	1.99	1.72	1.53	3.53	9.78	15.44	18.33	18.83	17.47	14.36	11.86	12.31	12.54	11.59	10.03	8.12	6.70	5.61	4.65	3.94	3.41	1100	1.53	18.83	17.29
S	2.34	2.00	1.72	1.47	1.23	1.07	1.49	2.78	4.19	5.67	7.58	9.68	11.23	12.26	12.67	12.30	10.96	9.25	7.39	5.91	4.83	3.89	3.23	2.74	1500	1.07	12.67	11.60
SW	3.48	3.07	2.72	2.41	2.11	1.90	2.27	3.50	4.73	5.86	6.36	6.91	10.70	15.93	20.81	23.92	23.76	20.10	14.36	9.55	7.00	5.50	4.59	3.97	1600	1.90	23.92	22.02
W	4.03	3.59	3.20	2.86	2.53	2.30	2.65	3.84	5.06	6.17	7.39	8.95	11.81	17.76	24.23	28.78	29.03	24.48	17.16	11.08	7.98	6.25	5.24	4.57	1700	2.30	29.03	26.73
NW	3.43	3.02	2.68	2.36	2.07	1.87	2.24	3.46	4.69	5.83	7.07	8.51	10.69	15.23	20.15	23.48	23.23	19.44	13.83	9.29	6.87	5.42	4.53	3.92	1600	1.87	23.48	21.62
SHADED	1.38	1.10	0.87	0.67	0.47	0.36	0.42	0.48	0.69	1.15	1.96	3.14	4.15	5.13	6.00	6.40	5.89	5.29	4.76	4.14	3.44	2.68	2.12	1.71	1600	0.36	6.40	6.04