Heat Gains for Thick Walls and Roofs

Simple calculation method extends ASHRAE methodology to heavier constructions

External walls and roofs of buildings gain heat through convection from outside air as well as by radiation from the sun. This heat is transferred to the building interior by conduction through the walls, which also alternately store and release heat. Thus, the process is very complex. To enable design calculations with comparative ease, the *1989 ASHRAE Handbook of Fundamentals*, Chapter 26, provides the following procedure, which is used throughout the industry. Heat gain is calculated by the following formula:

$$q = UA(CLTD) \quad (1)$$

where

q = heat gained by the room, Btuh
A = surface area of wall or roof, sq ft
$CLTD$ = cooling load temperature difference, F
U = overall heat-transfer coefficient, Btuh per sq ft per deg F

Values of *CLTD* for a variety of wall and roof constructions used in commercial buildings have been listed in the *ASHRAE Handbook*. These are limited to about 1 ft thick concrete walls and 6 in. thick concrete roofs. While this range is quite adequate for commercial buildings, much heavier construction is used in some buildings. For example, external walls in nuclear power plants are typically more than 2 ft thick concrete and roofs are 1 ft or more thick concrete. For such constructions, no guidance is provided by the *ASHRAE Handbook*. My research has resulted in a simple calculation procedure that extends the ASHRAE methodology to such heavy constructions. This procedure and its basis are briefly described in the following.

Research

The one-dimensional transient heat conduction equation was numerically solved for solid concrete walls 1.5 to 4 ft thick and solid concrete roofs 1 to 2 ft thick, with and without external insulation. The air on one side of the wall/roof was considered to be at a constant temperature; this temperature was 78

Table 1—Summary of some typical calculations done for determining CLTD for thick concrete walls and roofs.

Type	Thickness, ft: Concrete	Thickness, ft: Insulation	Mean T_{ss}, F	T_r, F	Btuh per sq ft per deg F: h_i	Btuh per sq ft per deg F: h_o	Calculated CLTD, F: Max	Calculated CLTD, F: Min	Calculated CLTD, F: Mean	Mean $(T_{ss} - T_r)$
Roof	1.0	0.083	107	78	1.08	4.0	35.2	23.2	29.2	29.0
Roof	1.0	0.167	107	78	1.08	4.0	34.0	24.5	29.2	29.0
Roof	1.0	None	107	78	1.08	4.0	43.8	15.2	29.5	29.0
Roof	1.5	None	107	78	1.08	4.0	34.6	24.1	29.3	29.0
Roof	2.0	None	107	78	1.08	4.0	31.4	27.3	29.3	29.0
Wall	1.5	None	100	78	1.08	4.0	26.0	18.5	22.2	22.0
Wall	2.0	None	115	104	0.50	1.0	11.0	9.9	10.4	11.0
Wall	2.0	None	115	104	1.46	4.0	12.8	9.8	11.3	11.0
Wall	2.0	None	100	78	1.46	4.0	23.8	20.7	22.2	22.0
Wall	2.0	None	115	78	1.46	4.0	39.0	35.6	37.3	37.0
Wall	3.0	None	100	78	1.46	4.0	22.6	22.2	22.4	22.0
Wall	4.0	None	100	78	1.08	4.0	22.4	22.4	22.4	22.0

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Table 2—Calculated CLTD for dark horizontal roofs.

Roof description		Solar time, hr																							
Concrete thickness, in.	Insulation thickness, in.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
12	2	33	33	32	31	31	30	29	28	26	26	25	25	24	25	26	27	28	29	31	32	33	34	34	34
12	1	33	32	31	30	29	27	26	25	24	23	23	24	24	26	27	29	31	32	34	35	35	35	35	34
12	0	36	34	31	28	25	22	20	18	16	15	16	17	20	23	27	31	36	39	42	43	44	43	41	39
18	0	35	35	34	34	33	32	30	29	28	27	25	25	24	24	24	25	26	27	29	30	32	33	34	34
24	0	30	30	31	31	31	31	31	31	31	31	30	30	29	29	28	28	27	27	27	28	28	28	29	30

or 104 F in various runs, thus simulating design room temperatures. The air on the other side of the wall/roof was at the sol-air temperatures listed in Table 1 of the *ASHRAE Handbook* and thus varied with time. In some runs, higher sol-air temperatures were also used. Inside and outside air film heat-transfer coefficients were varied in the range that may be expected in practice. The heat transferred from the wall to the room air was calculated at each instant; the *CLTD* at each instant was then calculated using Equation 1. Computer runs were continued until calculated *CLTD*s were repeated in 24-hr cycles.

In Table 1, a summary of some typical calculations for walls and roofs is presented. The mean sol-air temperatures and mean *CLTD*s are 24-hr mean values. h_i and h_o are inside and outside air film heat-transfer coefficients, respectively.

In Table 2, the calculated *CLTD*s for various horizontal roofs are listed. All of these are for dark roofs and the sol-air temperatures listed in Table 1 in the *ASHRAE Handbook*. Note that all *CLTD*s listed in the *Handbook* for various roofs and walls were also calculated using the sol-air temperatures from this source.

All calculations were done for heavyweight concrete of 140 lb per cu ft density. The insulation considered had a density of 15 lb per cu ft, thermal conductivity of 0.024 Btuh per ft per deg F, and specific heat of 0.17 Btu per lb per deg F.

Results

The results listed in Table 1 show that:

$$\text{Mean } CLTD = \text{Mean } T_{sa} - T_r \quad (2)$$

where

T_{sa} = sol-air temperature
T_r = room air temperature

Thus, the 24-hr mean heat gain can be calculated with Equation 1 using the mean *CLTD* from Equation 2.

Study of Table 1 also shows that for walls 2 ft thick or thicker, the extreme values of *CLTD* do not differ much from the mean *CLTD* given by Equation 2. It should be realized that due to the large thermal lag of these walls, these high *CLTD*s will be reached only if the sol-air temperatures remain at the peak values for more than one day. This will occur only rarely. Hence, the mean *CLTD* from Equation 2 will generally be the maximum *CLTD*.

Footnote 4 of Tables 29 and 31 in the *ASHRAE Handbook* list *CLTD* values to be used for roofs and walls with additional insulation, which takes them beyond the range of those tables. Study of those listed *CLTD* values show that they are exactly in accordance with Equation 2. Thus, the present research has shown that the calculation method given by ASHRAE for lightweight, thickly insulated walls/roofs is also applicable to heavyweight walls/roofs, with or without insulation.

Table 1 also shows that very large changes in the inside and outside film heat-transfer coefficients have comparatively small influence on the *CLTD*. It also shows agreement with the ASHRAE method for correcting for variations of room temperature and outside air temperatures.

Calculation procedure

For heavyweight concrete walls 2 ft thick or thicker, with or without insulation, use the following "uncorrected" *CLTD*s (in accordance with Footnote 4 of Table 31 in the *ASHRAE Handbook*): N, 11; NE, 17; E, 22; SE, 21; S, 17; SW, 21; W, 22; NW, 17 (letters represent wall orientation, numbers are *CLTD*s). These *CLTD*s are to be adjusted for color, latitude, room temperature, and outside air temperature as described in Footnote 2 of that table.

For the horizontal roof constructions listed in Table 2, obtain *CLTD* and then adjust it for color, latitude, room temperature, and outside air temperature as described in Footnote 2 of Table 29 in the *ASHRAE Handbook*.

For horizontal, uninsulated roofs thicker than 2 ft and insulated roofs more than 1.5 ft thick, use 29 F as the uncorrected *CLTD* (according to Footnote 4 of Table 29) and then correct it according to Footnote 2 of that table.

Conclusion

The calculation procedure given for heavy walls and roofs was derived from computerized solutions of the governing heat-transfer equation and is in agreement with ASHRAE's recommended procedure for lightweight walls and roofs with thick insulation. Its use will result in simple, reliable calculations, eliminating the need for guesswork and conservatism, which had to be resorted to until now. Ω