TEK 6-16: HEAT CAPACITY (HC) VALUES FOR CONCRETE MASONRY WALLS

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Introduction

Heat capacity (HC) is defined as: (1) the amount of heat necessary to raise the temperature of a given mass one degree[1]; or more simply, (2) the product of a mass by its specific heat.

Heat capacity is important because energy standards and codes are beginning to provide guidance to designers on how to incorporate the benefits of massive wall assemblies in the design of energy efficient buildings. These benefits are attributed to a property known as thermal mass.

Thermal mass is defined as: materials with mass heat capacity and surface area capable of affecting building loads by storing and releasing heat as the interior and/or exterior temperature and radiant conditions fluctuate.[2] Wall thermal mass tends to decrease both heating and cooling loads in a given building, thus saving costly energy. The amount of savings realized by incorporating thermal mass into a building's design is a function of several variables. These include local climate, wall heat capacity, fenestration (window) area, fenestration orientation, fenestration solar gain, building occupancy load and other internal gains such as lights and office equipment. The most manageable approach to account for energy savings due to thermal mass is to relate the savings to the wall heat capacity and local climate. [2,3,4]

Because less energy is consumed by a building with massive walls, such as concrete masonry, than by one with lightweight frame walls, wood or steel studs for example, the R-value requirements for a massive wall are less than those for a frame wall. In order to achieve an R-value reduction for massive walls, the HC of the wall must be greater than a certain value. This value is not a constant in all codes and standards, because the underlying assumptions that were made in their development are not necessarily the same. Depending upon which code or standard is used, and how it is used, the minimum HC varies but will usually be 5,6,7,10 or 15 (Btu/ºF·ft^2).

This publication is intended for use by engineers and designers as a guide in determining the heat capacity (HC) of concrete masonry walls. Examples are provided which demonstrate how the values in the tables were derived. The use of these tables eliminates the need for lengthy and time consuming calculations.

How to Calculate HC (Rule-of-Thumb)

For the purposes of the energy codes and standards, heat capacity, as discussed thus far in this TEK, actually implies wall heat capacity which is defined as: the sum of the products of the mass of each individual material in the wall per unit area times its individual specific heat. [2] As indicated previously, HC is equal to the mass, or wall weight, multiplied by the specific heat. Therefore, for example, a single wythe concrete masonry wall weighing 34 lb/ft^2 has an HC of 7.14 (Btu/ft^2·ºF)).

HC = wall weight (lb/ft^2) x specific heat (Btu/lb ºF)

HC = 34 (lb/ft^2) x 0.21 (Btu/lb·ºF)

HC = 7.14 (Btu/ft$^{2}\cdot$°F)

This simple calculation is based on a rule-of-thumb that the specific heat of most concretes is very close to 0.21 (Btu/lb·°F). The actual value depends on the aggregate type used in the block manufacture. Blocks produced using sandgravel aggregates tend to have specific heat values of approximately 0.22 (Btu/lb·°) while most other block have a specific heat of 0.21 (Btu/lb·°F). [5]

How to Use HC Values in Codes and Standards

Although the minimum HC value is dependent upon the code being used, the 1988 amendments to the 1986 Council of American Building of finials Model Energy Code (CABO/MEC) require an HC of at least 6.7. Hence, the wall from the previous example with an HC = 7.14 can be given an R-value reduction. For example, at 3,000-4,000 heating degree days (HDD), a wall having an HC less than 6.7 may be required to have a U_w of no greater than 0.20, but a massive wall need only have a U_w of 0.26. Expressed in terms of R values, if a frame wall with an HC less than 6.7 must have an R-value of at least 1/0.20 = 5.0, a masonry wall having an HC equal to 7.14 needs only to have an R-value of at least 1/0.26 = 3.85 (hr·ft$^{2}\cdot$°F/Btu).

ASHRAE proposed standard 90.1, Energy Efficient Design of New Buildings Except Low-Rise Residential, and the Mandatory Interim Guide For All New Federal Buildings Except Low-Rise Residential, have four (4) minimum HC values. The alternate component package (ACP) tables in the prescriptive section have three levels of R-value reduction, expressed in the table as U-value increases. Generally, the greater the HC, the lower the R-value requirement for a wall.

The fourth HC minimum is 7 and is used as the minimum value permitted to make trade-offs for increasing glass area. Glass areas are permitted to be larger when there is adequate mass to provide the necessary storage for the increased heat gains due to solar radiation transmittance. This section allows the designer the flexibility of exploring, via a PC-based computer program, different wall designs to see their effect on the overall energy budget for a given building.

Theory

The values in Tables 1 and 2 are calculated according to the following equation:

$HC_w = HC_b + HC_m + HC_g + HC_f$ -- Eqn.1

where:

HC_w = total heat capacity of finished wall (Btu/ft$^{2}\cdot$°F)
HC_b = heat capacity of block (Btu/ft$^{2}\cdot$°F)
HC_m = heat capacity of mortar (Btu/ft$^{2}\cdot$°F)
HC_g = heat capacity of grout (Btu/ft$^{2}\cdot$°F)
HC_f = heat capacity of finish materials (Btu/ft$^{2}\cdot$°F)
(brick veneer, plaster, etc.)

Individual items in equation 1 are governed by equation(s) 2.

$HC_{b,m,g}$ = V x D x Sp. Ht. x 1.125/sq. ft. -- Eqn.2
HC_f = V x D x Sp. Ht.

where:

V = volume = ft^3
D = density = lb/ft^3
Sp. Ht. = Btu/lb·°F
1.125 = Number of block

Sample Calculations

1. What is the heat capacity of a single wythe wall constructed of standard 8 x 8 x 16 in. unite, 52 % solid, consisting of 90 pcf concrete?

HC_w	HC_b + HC_m
HC_b	= (.52)V x D x Sp. Ht. x 1.125/ft^2
	= (.52)(7.625 x 7.625 x 15.625/1728) x 90 x 0.21 x 1.125
HC_b	= 5.81 (Btu/ft^2·°F)
HC_m	= V x D x Sp. Ht. x 1.125/ft^2
	= 2[(16 x 0.375 x 1.52) + 2(7.625 x 0.375 x 1.52)] x 1/1728 x 120 x 0.20 x 1.125
HC_m	= 0.42 (Btu/lb·°F)
HC_w	= 5.81 + 0.42
	= 6.23 (Btu/ft^2·°F) (check value in Table 1)

2. What is the heat capacity of the wall in Example 1 if it is finished with 1/2" gypsum board glued to the interior surface?

HC_w	= HC_b + HC_m +HC_f
HC_b +HC_m	= 6.23 (From Example 1)
HC_f	= V x D x Sp. Ht.
	= [12 x 12 x 1/2 x (1/1728)] x 50 x 0.26
	= 0.54(Btu/ft^2·°F) (check value in Table 3)
HC_w	= 6.23 + 0.54
	= 6.77(Btu/ft^2·°F)

3. What is the heat capacity of the wall in Example 1 if it is grouted at 24" o. c. (every third core)?

HC_w	= HC_b +HC_m +HC_g
HC_b +HC_m	= 6.23 (From Example 1)
HC_g	= % Grout x V x D x Sp. Ht. x 1.125/ft^2
% Grout	= 1/3(1-.52) = 1/3(0.48) = 0.16
HC_g	= 0.16 x .5257 x130 x 0.20 x 1.125
	= 2.46 (Btu/ft^2·°F)

HC_w	= 6.23 + 2.46
	= 8.69(Btu/ft^2·°F) (check value in Table 2)

Helpful Hints

The preceeding sample calculations illustrate how the values in Tables 1, 2 and 3 were developed. If a wall is made up of any of the masonry units and/or finish materials listed in the tables, simply add the values to get the total wall heat capacity.

If a wall is not made up of the components found in the tables, use equations 1 and 2 to calculate the total wall heat capacity.

TABLE 1. HEAT CAPACITY OF UNGROUTED HOLLOW SINGLE WYTHE WALLS (Btu/ft^2·°F)

Size of CMU and % Solid*	Density of Concrete in CMU (lb/ft^3)						
	80	90	100	110	120	130	140
4" - 65	3.40	3.78	4.17	4.55	4.93	5.56	5.96
78	4.01	4.47	4.94	5.40	5.86	6.60	7.08
100	5.05	5.64	6.23	6.82	7.41	8.37	8.99
6" - 55	4.36	4.87	5.37	5.87	6.38	7.19	7.72
78	6.04	6.76	7.47	8.18	6.90	10.05	10.80
8" - 52	5.57	6.23	6.88	7.52	8.17	9.21	9.89
78	8.17	9.14	10.11	11.08	12.04	13.61	14.63
10" - 48	6.50	7.25	8.01	8.76	9.51	10.60	11.38
78	10.26	11.48	12.71	13.93	15.15	17.13	18.41
12" - 48	7.75	8.66	9.57	10.48	11.39	12.86	13.81
78	12.30	13.77	15.25	16.37	18.20	20.59	22.14

Face Shell Bedding [Density of Mortar = 120 lb/ft^3, Sp. Ht. of Mortar = 0.20 (Btu/lb·°F)]
* % solid based on dimensions in Table 8, "Calculation of U-Values of Hollow Concrete Masonry", by Rudy Valore

TABLE 2. HEAT CAPACITY OF GROUTED SINGLE WYTHE WALLS (Btu/ft^2·°F)

Size of CMU, % Solid* and Spacing	Density of Concrete in CMU (lb/ft^3)						
6" - 55%	80	90	100	110	120	130	140
8"	9.46	9.97	10.47	10.97	11.48	12.29	12.82
16"	6.91	7.42	7.92	8.42	8.93	9.74	10.27
24"	6.06	6.57	7.07	7.57	8.08	8.89	9.42
32"	5.64	6.15	6.65	7.15	7.66	8.47	9.00
40"	5.38	5.89	6.39	6.89	7.40	8.21	8.74
48"	5.21	5.72	6.22	6.72	7.23	8.04	8.57
8" - 52%							
8"	12.97	13.61	14.26	14.90	15.55	16.59	17.27
16"	9.28	9.92	10.57	11.21	11.86	12.90	13.58
24"	8.05	8.69	9.34	9.98	10.63	11.67	12.35
32"	7.44	8.08	8.73	9.37	10.02	11.06	11.74
40"	7.07	7.71	8.36	9.00	9.65	10.69	11.37
48"	6.82	7.46	8.11	8.75	9.40	10.44	11.12
10" - 48%							
8"	16.59	17.34	18.10	18.85	19.60	20.69	21.47
16"	11.55	12.30	13.06	13.81	14.56	15.65	16.43
24"	9.86	10.61	11.37	12.12	12.87	13.96	14.74
32"	9.02	9.77	10.53	11.28	12.03	13.12	13.90
40"	8.52	9.27	10.03	10.78	11.53	12.62	13.40
48"	8.19	8.94	9.70	10.45	11.20	12.29	13.07

8"	19.94	20.85	21.76	22.67	23.58	25.05	27.00
16"	13.85	14.76	15.67	16.58	17.49	18.96	19.91
24"	11.81	12.72	13.63	14.54	15.45	16.92	17.87
32"	10.80	11.71	12.62	13.53	14.44	15.91	16.86
40"	10.39	11.10	12.01	12.92	13.83	15.30	16.25
48"	9.79	10.70	11.61	12.52	13.43	14.90	15.85

Face Shell Bedding [Density of Mortar = 120 lb/ft^3, Sp. Ht. of Mortar = 0.20 (Btu/lb·°F)]
* % solid based on dimensions in Table 8, "Calculation of U-Values of Hollow Concrete Masonry", by Rudy Valore

TABLE 3. HEAT CAPACITY OF MASONRY AND RELATED MATERIALS (Btu/ft²·°F)

Material	Density (lb/ft³)	Specific Heat (Btu/lb·°F)	Heat Capacity (Btu/ft²·°F)	Material	Density (lb/ft³)	Specific Heat (Btu/lb·°F)	Heat Capacity (Btu/ft²·°F)
Mortar	120	0.20	N/A	Clay Brick	135	0.20	8.16
Grout	130	0.20	N/A	Solid 3 5/8"			
Concrete	80	0.21	N/A	Gypsum Board			
	90	0.21	N/A	3/8"	50	0.26	0.41
	100	0.21	N/A	1/2"	50	0.26	0.54
	110	0.21	N/A	5/8"	50	0.26	0.68
	120	0.21	N/A	Plaster and			
	130	0.22	N/A	Stucco			
	140	0.22	N/A	3/8"	120	0.20	1.0
				1/2"	120	0.20	1.5
				5/8"	120	0.20	2.0

References

1. Terminology of Heating, Ventilation, Air Conditioning & Refrigeration published by ASHRAE, 1986

2. ASHRAE 90.1P, Proposed Standard for the Energy Efficient Design of New Buildings, Except Low-Rise Residential

3. ASHRAE 90 2, Proposed Standard for the Energy Efficient Design of New Low-Rise Buildings

4. 1988 Amendments to the 1986 CABO/MEC

5. 1985 ASHRAE Handbook of Fundamentals, Chapter 23