TECHNICAL NOTES on Brick Construction
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Technical Notes 4B Revised- Energy Code Compliance of Brick Masonry Walls
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Abstract: All buildings designed today must comply with energy code requirements. Building energy performance requirements may be embodied in a model building code or in a separate energy standard. These documents typically contain requirements for the building envelope, including walls, windows, doors, roofs and floors. Brick masonry, as a high mass building material, has the inherent energy saving feature of thermal storage capacity (thermal mass). This *Technical Notes* describes how to quantify thermal mass and calculate the heat capacity of several brick masonry walls. The procedure for addressing thermal mass in residential and commercial construction when determining building envelope compliance with widely used energy standards and codes is also described.

Key Words: brick, building codes, building envelope, energy, heat capacity, standards, thermal mass.

INTRODUCTION

All buildings designed today must comply with energy code requirements. Energy performance requirements may be found in such documents as the 2000 *International Residential Code* [8], the 2000 *International Energy Conservation Code* [7], and the ASHRAE/IES Standard 90.1-1999: *Energy Efficient Design of New Buildings Except New Low-Rise Residential Buildings* [4]. These standards and codes specify energy efficient design through overall building performance criteria or by a component prescriptive approach. The element in overall building performance discussed in this *Technical Notes* is the building envelope. Brick masonry walls provide a uniquely energy efficient envelope due to their high thermal mass. Thermal mass is the characteristic of heat capacity and surface area capable of affecting building thermal loads by storing heat and releasing it at a later time. Materials with high thermal mass react more slowly to temperature fluctuations and thereby reduce peak energy loads. Economic, energy efficient designs may be achieved by recognizing this inherent aspect of brick masonry and incorporating it in the building envelope design.

The benefits of thermal mass have been known for a long time. Research in 1975-76 during the energy crisis, sponsored by the Masonry Industry Committee, led to the development of a simplified method for quantifying thermal mass benefits [10]. This method, called the M Factor, was developed for use by designers to compare wall systems with respect to energy performance during the heating cycle. The M Factor was not intended for sizing of mechanical equipment, but rather as a comparative analysis tool. By knowing the weight of a wall and the annual heating degree days (HDD), a designer could determine the correction factor (M Factor) to convert the calculated U- or R-value of a wall to an equivalent U- or R-value accounting for thermal mass and its effect of slowing heat transmittance. The U- and R-values are measures of steady-state heat transmittance. The corrected U- or R-value was then used to comply with prescribed energy requirements. At that time codes and standards did not incorporate thermal storage concepts when prescribing limits on heat transfer.

Today, energy codes and standards specify energy requirements as a function of wall type. Adjustment factors are included for masonry and other high mass walls as well as for walls built with steel studs that create thermal bridges. In the case of masonry walls, a higher maximum permissible value for the coefficient of thermal transmittance (U-value) for the building envelope is given depending upon where the insulation is located relative to the wall mass. Some codes additionally specify a maximum overall thermal transfer value for walls ($OTTV_W$) of mechanically cooled spaces. The $OTTV_W$ is also a measure of heat transmittance and is a function of the wall temperature difference (TD_{EQ}) which is also related to wall weight.

This *Technical Notes* instructs the user on the methods for determining compliance of various brick masonry walls with the building envelope requirements of several energy standards and codes. Those included are the 1999 ASHRAE/IES Standard 90.1, the 2000 International Residential Code [8], and the 2000 International Energy Conservation Code [7]. The methods by which these energy standards and codes criteria reflect thermal mass properties of brick masonry are explained.

The user of this *Technical Notes is* assumed to have a working knowledge of heat transmittance and familiarity with the energy codes and standards listed. Procedures for calculating the actual U-values for walls can be found in *Technical Notes* 4 Revised, Section 8.4 of ASHRAE/IES Standard 90.1, and in the ASHRAE *Handbook of Fundamentals* [5].

Because of the possible confusion inherent in showing dual unit systems in calculations, metric (SI) units are not given in the data, equations, or examples in this *Technical Notes.* Table 1 provides metric (SI) conversion factors for the more commonly used energy units.

TABLE 1
Conversion Factors

Dimension	Customary	Metric (SI)
Length	1 in.	= 25.4 mm
	1 ft	= 0.305 m
Area	1 in.^{2}	= 645.2 mm^2
	1 ft^2	= 0.0929 m^2
Volume	1 ft^3	= 0.0283 m^3
Volume (liquid)	1 gal	= 3.79 L
Mass (weight)	1 lb	= 0.454 kg
Mass per Unit Area	1 lb/ft^2	= 4.88 kg/m^2
Density	1 lb/ft^3	= 16.0 kg/m^3
Temperature Interval	1 °F	= 0.556 K
Equivalent Temperature	($t_{°F}$ + 459.67)/1.8	= t_K
Conductance	1 Btu/(hr-ft^2-°F)	= 5.68 W/(m^2-K)
Conductivity	1 (Btu-in.)/(hr-ft^2-°F)	= 0.144 W(m-K)
Resistance	1 (hr-ft^2-°F)/(Btu)	= 0.176 (m^2-K)/W
Resistivity	1 (hr-ft^2-°F)/(Btu-in.)	= 6.93 (m-K)/W
Heat Flow	1 Btu/(hr-ft^2)	= 3.15 W/m^2
Rate of Heat Flow	1 Btu/hr	= 0.293 W
Tons of Refrigeration	1 Ton (12,000 Btu/hr)	= 3.52 kW

NOTATION

A_d door area, ft^2

A_f fenestration area, ft^2

A_g glazing area, ft^2

A_o gross wall area above grade, ft^2

A_w opaque wall area, ft^2

c specific heat, Btu/(lb -°F)

dt temperature difference between exterior and interior design conditions, °F

HC heat capacity, Btu/(ft^2-°F)

HDD annual heating degree days

HDD65 annual Fahrenheit heating degree days, 65 °F base

$OTTV_w$ overall thermal transfer value - walls, Btu/(hr-ft^2)

SC shading coefficient of the fenestration, dimensionless

SF solar factor value, Btu/(hr-ft^2)

TD_{EQ} temperature difference value, °F

U_d thermal transmittance of the door area, Btu/(hr-ft^2-°F)

U_f thermal transmittance of the fenestration area, Btu/(hr-ft^2-°F)

U_g thermal transmittance of the glazing area, Btu/(hr-ft^2-°F)

U_o average thermal transmittance of the gross wall area, Btu/(hr-ft^2-°F)

U_{ow} overall thermal transmittance of the wall assembly, Btu/(hr-ft^2-°F)

U_w thermal transmittance of the opaque wall area, Btu/(hr-ft^2-°F)

w weight, lb/ft^2

HEAT CAPACITY

In most energy codes, the thermal characteristics of high mass walls are quantified by measuring the heat capacity of the wall. Heat capacity represents the amount of thermal energy which may be stored by a material. For walls constructed of multiple materials, total heat capacity is calculated as the sum of the heat capacities of the individual components. In most energy codes and standards in the United States, heat capacity (HC) of a wall is calculated as the product of weight per unit area and specific heat (HC = w x c). Since the specific heats of most building materials are roughly equal, the heat capacity of a wall is directly proportional to its weight. Those materials which are relatively lightweight, such as insulation, do not have a significant effect on heat capacity and are often ignored when determining heat capacity. Use of the adjustment factors for mass walls in the 2000 International Residential Code [8] and the 2000 International Energy Conservation Code [7] is limited to walls having a heat capacity greater than or equal to 6 Btu/ft^2. Sample calculations of heat capacity for several brick walls are provided in Figure 1. Brick walls with a nominal thickness or 4 in. or greater have heat capacities greater than or equal to 6 Btu/ft^2.

ENERGY CODE COMPLIANCE

Each energy code and standard is slightly different in scope and criteria for compliance. The ASHRAE/IES Standard 90.1 is only applicable to *non*-residential buildings. Both residential and non-residential criteria may be found in the model building codes or the *International Energy Conservation Code* [7]. Each code and standard is discussed individually below.

ASHRAE/IES Standard 90.1

The ASHRAE/IES Standard 90.1 covers the energy performance design of new buildings *except* residential buildings of three stories or less. Compliance with this standard may follow one of two paths: the Building Energy Cost Budget Method or the System/Component Method.

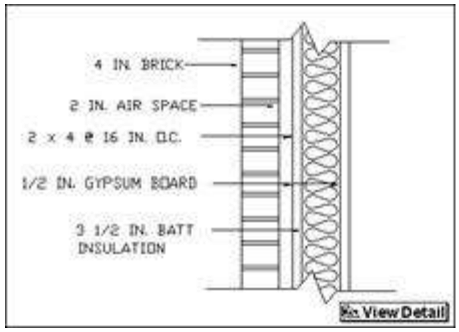
The Building Energy Cost Budget Method (BECBM) is to be used with innovative design concepts which cannot be accommodated by the System/Component Method or when a design fails the System/Component approach. The BECBM requires a detailed energy analysis to determine the estimated design energy cost. The BECBM permits any design whose design energy cost does not exceed the specified energy cost budget and meets the other requirements of the method. A complete description of this method can be found in Section 13 of the ASHRAE/IES Standard 90.1.

The System/Component Method can be divided into two compliance paths for the building envelope: *Prescriptive Criteria* found in Section 8.5 and *System Performance Criteria* found in Section 8.6. These methods give minimum requirements to satisfy both heating and cooling cycle conditions. As the use of the ASHRAE/IES Standard 90.1 may be somewhat confusing, the National Codes and Standards Council of the Concrete and Masonry Industries has published a handbook which discusses the benefits of thermal mass and the design provisions of ASHRAE/IES Standard 90.1 [2]. In addition to the examples given in this *Technical Notes,* the reader is also urged to refer to this handbook.

FIG. 1

Heat Capacities of Several Brick Walls

(a) 4 IN. BRICK AND WOOD STUD WALL



4 IN. BRICK w = (130 lb/ft^3) x [(0.75)(3.63 in.) / 12in./ft] = 29.5 lb/ft^2

(>75% SOLID) c = 0.20 Btu/(lb-°F)

HC = 29.5 x 0.20 = 5.9 Btu/(ft^2-°F)

4 IN. STUD w = 45 lb/ft^3 x [(3.5 in. x 1.5 in.) / (144 in.^{2}/ft^2)] x (12 in./ft / 16 in.)

= 1.23 lb/ft^2

c = 0.30 Btu/(lb-°F)

HC = 1.23 x 0.30 = 0.4 Btu/(ft^2-°F)

(2) 1/2 IN. w = 50 lb/ft^3 x [(2)(0.5 in.) / 12 in./ft] = 4.2 lb/ft^2

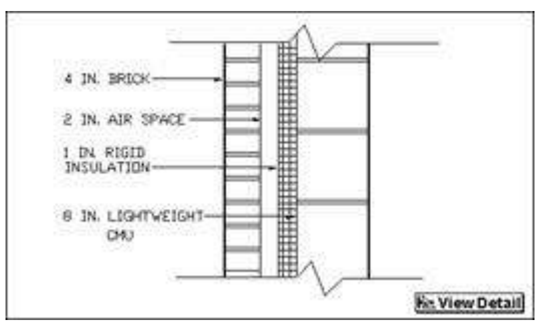
GYPSUM BOARD c = 0.26 Btu/(lb-°F)

HC = 4.2 x 0.26 = 1.1 Btu/(ft^2-°F)

INSULATION NEGLIGIBLE

TOTAL HC = 5.9 + 0.4 + 1.1 = 7.4 Btu/(ft^2°F)

(b) 4 IN. BRICK AND 8 IN. LIGHTWEIGHT CMU WALL



4 IN. BRICK HC = 5.9 Btu/(ft^3°F) (from Fig. 1a)

8 IN. LIGHTWEIGHT CMU w = 90 lb/ft^3 x [(0.52)(7.63 in.) / 12in./ft] = 29.7 lb/ft^2

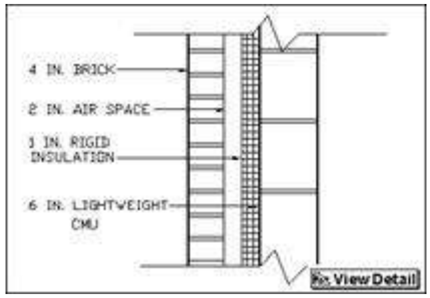
(52% SOLID) c = 0.21 Btu/(lb-°F)

HC = 29.7 x 0.21 = 6.2 Btu/(ft^2-°F)

INSULATION NEGLIGIBLE

TOTAL HC = 5.9 + 6.2 = 12.1 Btu/(ft^2-°F)

(c) 4 IN. BRICK AND 6 IN. LIGHTWEIGHT CMU WALL



4 IN. BRICK HC = 5.9 Btu/(ft2-°F) (from Fig. 1a)

6 IN. LIGHTWEIGHT CMU   w = 90 lb/ft3 x [(0.55)(5.63 in.) / 12 in./ft] = 23.2 lb/ft2

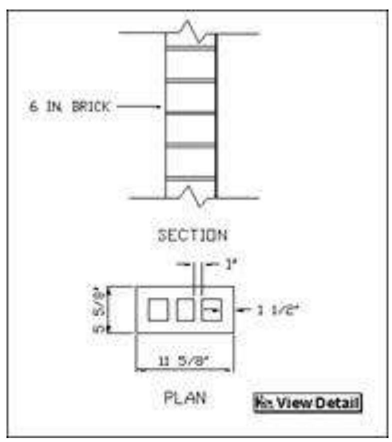
(55% SOLID)   c = 0.21 Btu/(lb-°F)

HC = 23.2 x 0.21 = 4.9 Btu/(ft2-°F)

INSULATION   NEGLIGIBLE

TOTAL HC = 5.9 + 4.9 = 10.8 Btu/(ft2-°F)

(d) 6 IN. HOLLOW BRICK WALL



6 IN. BRICK   w = 130 Ib/ft3 x [(0.60)(5.63 in.) / 12 in./ft] = 36.6 Ib/ft2

(60% SOLID)   c = 0.20 Btu/ (Ib-°F)

TOTAL HC = 36.6 x 0.20 = 7.3 Btu/(ft2-°F)

IF GROUTED, HC WOULD BE EVEN GREATER

Prescriptive Criteria. Section 8.5 of the ASHRAE/IES Standard 90.1 provides precalculated Alternate Component Package (ACP) tables based on the System Performance Criteria in Section 8.6 for a set of climate ranges. These ACP tables list the maximum permissible percentage of fenestration in a wall area, maximum thermal transmittance U-values, and minimum thermal resistance R-values as a function of the building's internal energy load, type and characteristics of fenestration and wall construction. The many climatic variables which influence the building envelope are grouped together in each ACP table for a range of climates. Thus, the criteria found in the ACP tables address a worst case condition and may be more stringent than the System Performance Criteria in Section 8.6.

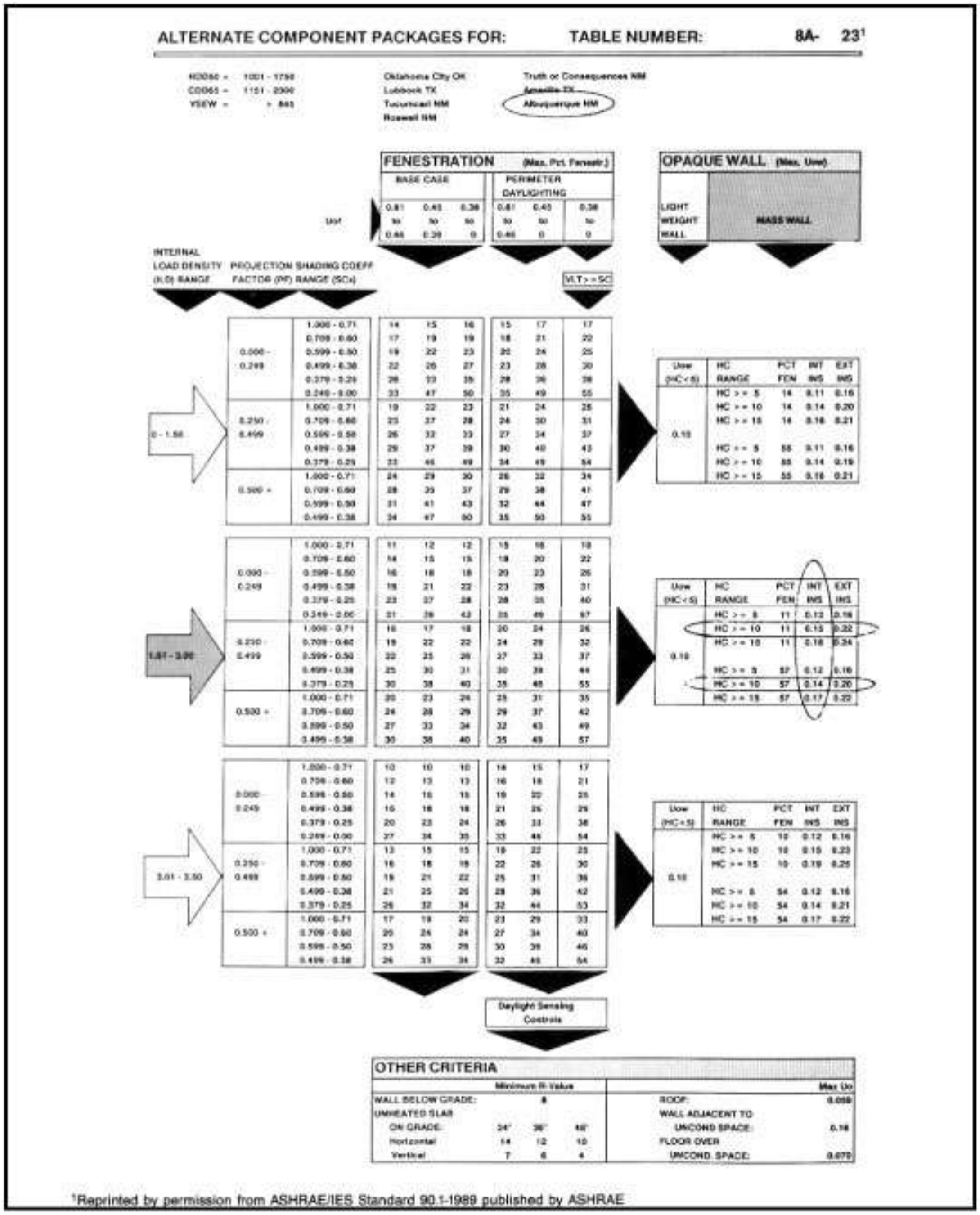
The maximum permissible overall thermal transmittance value of an opaque wall (U_{ow}) using the prescriptive envelope criteria and the appropriate ACP table. The following example illustrates the benefits of using a thermal mass wall by comparing the maximum permissible U_{ow}-value of a lightweight and a high mass wall. The U_{ow}-value is a function of the wall weight (represented by HC); the building's internal cooling loads due to heat generated by lights, equipment, and people (ILD); the placement of the insulation either internal to or integral with the wall mass (INT INS) or outside the wall mass (EXT INS); and the percentage of total wall area consisting of doors, windows and other glazing (PCT FEN). Refer to Fig. 2 of this *Technical Notes* and Section 8.6 of the ASHRAE/IES Standard 90.1 for the tables and terms used in this example.

EXAMPLE 1: ASHRAE/IES Standard 90.1— Prescriptive Criteria

Office Building

Determine the maximum permissible overall wall thermal transmittance value (U_{ow}) of a 12,000 ft^2 office building located near Albuquerque, NM. The building is constructed of 4 in. nominal brick veneer with 8 in. nominal concrete masonry loadbearing walls with insulation as shown in Fig. 1b. The building's fenestration is 30 percent of the total wall area. To determine the maximum permissible U_{ow}-value, use the following steps.

Step 1: To use the Prescriptive Envelope Criteria, first determine the appropriate ACP table from the locations listed in Table 8A-0 in Attachment 8A of the Standard. Find Albuquerque, NM in Table 2 of this *Technical Notes.* From Table 2, determine that the appropriate ACP table is Table 8A-23 of the Standard. The ACP table for Albuquerque, NM (8A-23) is shown in Fig. 2 of this *Technical Notes.*



ALTERNATE COMPONENT PACKAGES FOR: TABLE NUMBER: 8A- 23[1]

HDD65 = 1001 - 1750
CDD65 = 1151 - 2000
VSEW = > 845

Oklahoma City OK
Lubbock TX
Tucumcari NM
Roswell NM
Truth or Consequences NM
~~Amarillo TX~~
Albuquerque NM

FENESTRATION (Max. Pct. Fenestr.) / **OPAQUE WALL** (Max. Uow)

INTERNAL LOAD DENSITY (ILD) RANGE	PROJECTION FACTOR (PF) RANGE	SHADING COEFF RANGE (SCx)	Base Case Ubf 0.81 to 0.46	Base Case Ubf 0.45 to 0.39	Base Case Ubf 0.38 to 0	Perimeter Daylighting Ubf 0.81 to 0.46	Perimeter Daylighting Ubf 0.45 to 0	Perimeter Daylighting Ubf 0.38 to 0 (VLT>=SC)
0 - 1.50	0.000 - 0.249	1.000 - 0.71	14	15	16	15	17	17
		0.709 - 0.60	17	19	19	18	21	22
		0.599 - 0.50	19	22	23	20	24	25
		0.499 - 0.38	22	26	27	23	28	30
		0.379 - 0.25	26	33	35	28	36	38
		0.249 - 0.00	33	47	50	35	49	55
	0.250 - 0.499	1.000 - 0.71	19	22	23	21	24	25
		0.709 - 0.60	23	27	28	24	30	31
		0.599 - 0.50	26	32	33	27	34	37
		0.499 - 0.38	29	37	39	30	40	43
		0.379 - 0.25	33	46	49	34	49	54
	0.500 +	1.000 - 0.71	24	29	30	26	32	34
		0.709 - 0.60	28	35	37	29	38	41
		0.599 - 0.50	31	41	43	32	44	47
		0.499 - 0.38	34	47	50	35	50	55
1.51 - 3.00	0.000 - 0.249	1.000 - 0.71	11	12	12	15	16	18
		0.709 - 0.60	14	15	15	18	20	22
		0.599 - 0.50	16	18	18	20	23	26
		0.499 - 0.38	18	21	22	23	28	31
		0.379 - 0.25	23	27	28	28	35	40
		0.249 - 0.00	31	39	42	35	49	57
	0.250 - 0.499	1.000 - 0.71	16	17	18	20	24	26
		0.709 - 0.60	19	22	22	24	29	32
		0.599 - 0.50	22	25	26	27	33	37
		0.499 - 0.38	25	30	31	30	39	44
		0.379 - 0.25	30	38	40	35	48	55
	0.500 +	1.000 - 0.71	20	23	26	25	31	35
		0.709 - 0.60	24	28	29	29	37	42
		0.599 - 0.50	27	33	34	32	43	49
		0.499 - 0.38	30	38	40	35	49	57
3.01 - 3.50	0.000 - 0.249	1.000 - 0.71	10	10	10	14	15	17
		0.709 - 0.60	12	13	13	16	18	21
		0.599 - 0.50	14	16	15	19	22	25
		0.499 - 0.38	16	18	18	21	26	29
		0.379 - 0.25	20	23	24	26	33	38
		0.249 - 0.00	27	34	35	33	46	54
	0.250 - 0.499	1.000 - 0.71	13	15	15	19	22	25
		0.709 - 0.60	16	18	19	22	26	30
		0.599 - 0.50	19	21	22	25	31	36
		0.499 - 0.38	21	25	26	28	36	42
		0.379 - 0.25	26	32	34	32	44	53
	0.500 +	1.000 - 0.71	17	19	20	23	29	33
		0.709 - 0.60	20	24	24	27	34	40
		0.599 - 0.50	23	28	29	30	39	46
		0.499 - 0.38	26	33	34	32	46	54

Daylight Sensing Controls

OPAQUE WALL (Max. Uow): LIGHT WEIGHT WALL / MASS WALL

ILD RANGE	Uow (HC<5)	HC RANGE	PCT FEN	INT INS	EXT INS
0 - 1.50	0.10	HC >= 5	14	0.11	0.16
		HC >= 10	14	0.14	0.20
		HC >= 15	14	0.16	0.21
		HC >= 5	55	0.11	0.16
		HC >= 10	55	0.14	0.19
		HC >= 15	55	0.16	0.21
1.51 - 3.00	0.10	HC >= 5	11	0.12	0.16
		HC >= 10	11	0.15	0.22
		HC >= 15	11	0.18	0.24
		HC >= 5	57	0.12	0.16
		HC >= 10	57	0.14	0.20
		HC >= 15	57	0.17	0.22
3.01 - 3.50	0.10	HC >= 5	10	0.12	0.16
		HC >= 10	10	0.15	0.23
		HC >= 15	10	0.19	0.25
		HC >= 5	54	0.12	0.16
		HC >= 10	54	0.14	0.21
		HC >= 15	54	0.17	0.22

OTHER CRITERIA

	Minimum R-Value				Max Uo
WALL BELOW GRADE:		8		ROOF:	0.059
UNHEATED SLAB				WALL ADJACENT TO	
ON GRADE:	24"	36"	48"	UNCOND SPACE:	0.16
Horizontal	14	12	10	FLOOR OVER	
Vertical	7	6	4	UNCOND. SPACE:	0.079

[1]Reprinted by permission from ASHRAE/IES Standard 90.1-1989 published by ASHRAE

1Table 8A-0, reprinted by permission from ASHRAE/IES Standard 90.1-1989 published by ASHRAE

FIG. 2

Step 2: Calculate the heat capacity (HC) of the wall in question. The HC of the brick and concrete masonry wall shown in Fig. 1b has already been calculated to be 12.1 Btu/(ft2-°F) .

Step 3: Calculate internal load density (ILD) of the building. Section 8.5.5.2 of the Standard defines ILD as the sum of Lighting Power Density (LPD), Equipment Power Density (EPD) and Occupant Load Adjustment (OLA). Values for LPD are found in Table 6-5 of the Standard. (Note that Unit Lighting Power Allowance (ULPA) equals LPD.) For this office building example, LPD equals 1.81 W/ft2. The EPD can be selected from Table 8-4 of the Standard. For an office, EPD equals 0.75 W/ft2. OLA is a measure of the heat generated by living objects and is discussed in Section 8.5.5.2 of the Standard. For this example, assume OLA equals 0.0 W/ft2. Therefore,

$$ILD = LPD + EPD + 0LA = 1.81 + 0.75 + 0.0 = 2.56 \text{ W/ft}^2.$$

Using the ACP table for Albuquerque, NM shown in Fig. 2, enter the appropriate row based on the ILD of the building. Since ILD for this example is 2.56 W/ft^2, enter the row for ILD 1.51 - 3.00.

Step 4: The ACP tables contain criteria for both fenestration and opaque portions of the building envelope. This example addresses only the opaque wall requirements. Therefore, to determine the maximum permissible U_{ow}-value for the wall assembly in this example, move to the far right to the box under the heading OPAQUE WALL. Since HC of the wall in question is greater than 5 Btu/(ft^2-F), go to the subheading MASS WALL and find the box corresponding to the ILD row found in Step 3.

Step 5: The maximum U_{ow}-value is also a function of the location of insulation in the wall assembly. The insulation in this example is placed between or integral with the wall mass. Therefore, select the column for interior or integral insulation, INT INS. See Section 8.5.5.3 of the Standard for a complete discussion of insulation location.

Step 6: Find the appropriate rows under MASS WALL corresponding to the HC of the wall in question. In this example, HC equals 12.1 Btu/(ft^2-F), so use the rows HC greater than or equal to 10. Follow these rows to where they intersect the INT INS column. There are two possible values of U_{ow} based on the percentage of fenestration (PCT FEN) in the envelope.

Step 7: Follow the rows for HC greater than or equal to 10 to PCT FEN equal to 11 and PCT FEN equal to 57. Recall that the building's fenestration (PCT FEN) equals 30 percent of the wall area in this example. The U_{ow}-value corresponding to 11 percent equals 0.15 Btu/(hr-ft^2-°F), and U_{ow}-value corresponding to 57 percent equals 0.14 Btu/(hr-ft^2-F). Linearly interpolate for PCT FEN equal to 30 or use the lower of the two values. Using the lower value as the maximum permissible value, U_{ow} must be less than or equal to 0.14 Btu/(hr-ft^2-F).

Step 8: To comply with the Standard, the calculated U_{ow}-value of the wall in question may not exceed the maximum permissible value as determined from the ACP table. Using the steps found in *Technical Notes* 4 Revised or the ASHRAE *Hand/book of Fundamentals,* the thermal transmittance of the wall in Fig. 1b is calculated to be 0.10 Btu/(hr-ft^2-F). Since the calculated U_{ow}-value is less than the maximum permissible value of 0.14 Btu/(hr-ft^2-F), the wall construction complies with the Building Envelope Requirements of ASHRAE/IES Standard 90.1.

Compare the maximum permissible U_{ow}-value of the thermal mass wall in this example with the maximum permissible U_{ow}-value for a lightweight wall with HC less than 5 Btu/(ft^2-F). The box under the heading OPAQUE WALL shows that the maximum U_{ow}-value is only 0.10 Btu/(hr-ft^2-°F) for a lightweight wall. In terms of R-values, this thermal mass wall must have a minimum R-value of 7.1 (hr-ft^2-F)/Btu, whereas a lightweight wall must have an R-value of at least 10.0 (hr-ft^2-F)/Btu.

System Performance Criteria. A system approach for compliance with envelope requirements is provided in Section 8.6 of the ASHRAE/IES Standard 90.1. This method is more flexible than the Prescriptive Criteria when considering thermal mass for several reasons. The external wall criteria are based on annual energy calculations for a specific location, rather than for a group of climates. Calculations allow for variations in internal loads and wall heat capacity by separating the building into zones. Furthermore, wall assemblies with HC greater than or equal to 7 Btu/(ft^2-°F) do not have limits on the permissible U_{ow}-value as they do in the ACP tables. Compliance with the System Performance Criteria is achieved if the calculated energy loads do not exceed the criteria specified in Section 8.6. The System Performance Criteria approach requires numerous mathematical calculations by hand or a computer program. Information on an acceptable computer program, ENVSTD, is part of Appendix D of the ASHRAE/IES Standard 90.1. The program models the building envelope's performance and fully accounts for the effects of thermal mass. For this reason, ENVSTD is recommended for use with the System Performance Criteria when determining energy compliance of brick masonry walls, particularly when passive solar technologies are employed in the design.

International Residential Code

The 2000 *International Residential Code* (IRC) covers all aspects of residential design and construction. Section N1102 of Chapter 11 - *Energy Efficiency* contains prescriptive requirements for energy compliance of the building envelope. This Code is only applicable for climates with Heating Degree Days (HDD) of less than 13,000. Further restrictions on the use of this Code limit the glazing area of Type A-1 Residential buildings to 15 percent or less and 25 percent or less for Type A-2 Residential buildings. Thermal performance criteria in the form of minimum required insulation R-values and maximum permissible U-factors are specified for each element in the building envelope. This *Technical Notes* covers the requirements for exterior walls only.

Section N1102.1.1 contains tables with minimum R-values for walls, ceilings, floors, etc. based on the climates Heating Degree Days (HDD). Two tables are included specifically for mass walls. The first, Table N1102.1.1.1(1), specifies the minimum R-values for mass walls. The requirements vary depending upon the location of insulation and HDD. Walls with insulation placed on the exterior of the entire masonry mass are considered to have exterior insulation. An example of this type of construction is EIFS with a masonry backup. Walls that have insulation sandwiched between two roughly equal layers of masonry or mixed with the mass materials are considered to have integral insulation. Examples of this type of construction include masonry cavity walls and concrete masonry walls with insulated cores. Log walls are also considered to have integral insulation. Walls with interior insulation have the entire mass material on the exterior side of the insulation, such as in the case of brick veneer walls.

The required R-values found in Table N1102.1.1.1(1) for mass walls with exterior or integral insulation are the same. Mass walls that do not meet the definitions for exterior or integral insulation are grouped into the "Other mass walls" category. The R-value requirements are lowest for walls having exterior or integral insulation. However, even "Other mass walls" reflect a considerable reduction in R-value as compared with non-mass walls. This savings is shown in Example 2(a).

The second Table in this section provides a listing of the R-values of common mass wall assemblies. To comply with the minimum R-value requirements of Table N1102.1.1.1(1), find the R-value of the mass assembly from Table N1102.1.1.1(2) and add to it the R-value of any insulation or other layers in the wall assembly. See Example 2(b).

EXAMPLE 2: 2000 International Residential Code - Mass Wall Requirements

Determine the required amount of insulation for the walls of a single family home in Raleigh, North Carolina framed with wood construction and a brick veneer. The glazing area is 12 percent. What is the required insulation R-value with vinyl siding instead of brick veneer? What is the required insulation R-value if the house is built with loadbearing brick masonry cavity walls?

Ex. 2a: Determine the required R-values for brick veneer wall, a vinyl sided wall, and a loadbearing brick masonry cavity wall with integral insulation.

> **Step 1:** Determine the Climate Zone and annual Fahrenheit Heating Degree Days (HDD) for the location given. Climate Zones are listed in Table N1101.2 of the IRC. The Climate Zone for Raleigh, North Carolina which is located in Wake County is Zone 7.
>
> **Step 2:** Brick veneer construction is considered to have interior insulation. On Table N1102.1.1.1(1), Mass Wall Prescriptive Building Envelope Requirements, find Zone 7 and the column for "Other mass walls". The required mass wall assembly (insulation and masonry) R-value is 10.8 ($hr\bullet ft^2\bullet °F$)/Btu.
>
> **Step 3:** For the vinyl-sided wall, use Table N1102.1. Zone 7 corresponds to HDD 3,000 - 3,499. From the walls column determine that R-13 insulation is required for the non-mass wall system.
>
> **Step 4:** For the loadbearing brick masonry cavity wall, use Table N1102.1.1.1(1). Under the column for integral insulation, find that the mass wall assembly (insulation and masonry) R-value must be R-8.9 ($hr\bullet ft^2\bullet °F$)/Btu.

Ex. 2b: Determine the required insulation values for the brick veneer wall and the loadbearing brick masonry cavity wall.

> **Step 1:** For the brick veneer wall, From Table N1102.1.1.1(2) determine that brick veneer alone has an R-value of 2.0($hr\bullet ft^2\bullet °F$)/Btu. The required insulation R-value is calculated as 10.8 - 2.0 = 8.8($hr\bullet ft^2\bullet °F$)/Btu
>
> **Step 2:** For the brick masonry cavity wall, assume ungrouted cells are not insulated and the only insulation is located in the cavity. From Table N1102.1.1.1(2) determine that the mass assembly R-value is equal to 3.7 ($hr\bullet ft^2\bullet °F$)/Btu. Calculate the required insulation R-value as 8.9 - 3.7 = 5.2 ($hr\bullet ft^2\bullet °F$)/Btu.

2000 International Energy Conservation Code

The 2000 *International Energy Conservation Code* (*IECC*) prepared by the International Code Council, Inc. is applicable to residential dwellings as well as commercial, institutional and other buildings. This code sets limits on the permissible thermal transmission (U-value) of the building envelope. Residential buildings may comply with this code by adhering to one of three chapters *:* Chapter 4 - Residential Building Design by Systems Analysis and Design of Buildings Utilizing Renewable Energy Sources; Chapter 5 - Residential Building Design by Component Performance Approach; or Chapter 6 - Simplified Prescriptive Requirements for Residential Buildings, Type A-1 and A-2.

<u>RESIDENTIAL REQUIREMENTS - Chapters 4, 5, and 6</u>

Chapter 4 - Systems Analysis and Renewable Energy Source Analysis. Chapter 4, as its title implies, is separated into two sections: Systems Analysis and Renewable Energy Source Analysis. Both sections require an analysis of the annual energy usage of the proposed system. Requirements and procedures for analysis are specified. Compliance is achieved if annual energy consumption is not greater than that of a similar residential building designed according to *IECC Component Performance Approach* found in Chapter 5.

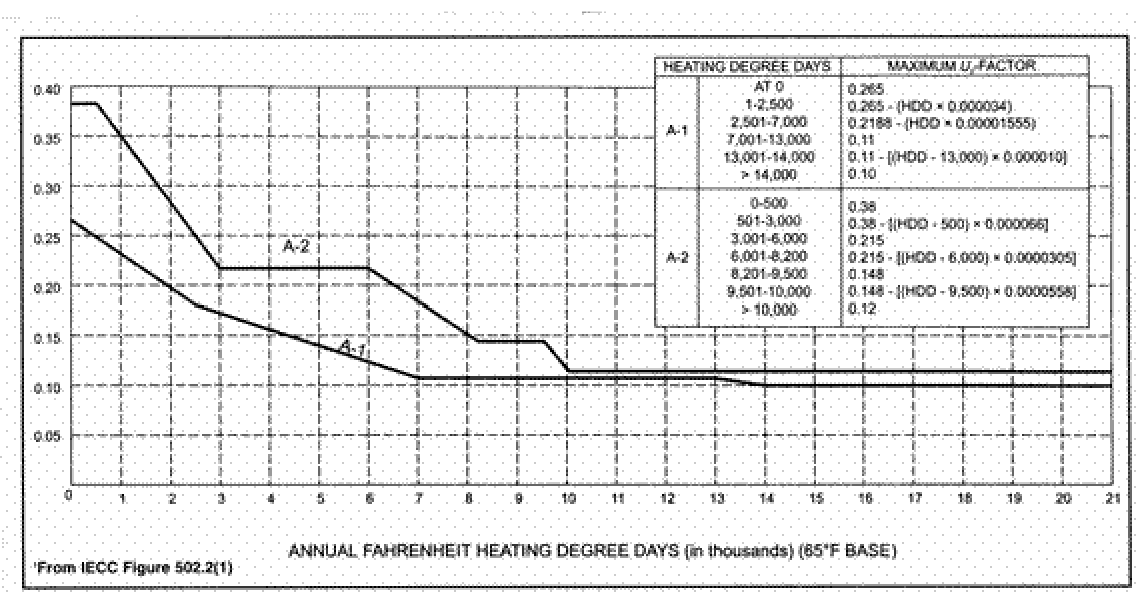
Chapter 5 - Component Performance Approach. The component performance approach presented in Chapter 5 of the *IECC* has requirements for residential building envelope (Section 502) as well as building mechanical systems, water heating, and electrical power and lighting. Residential requirements of Section 502 are divided into two types of residential construction, A-1 and A-2. Type A-1 are buildings with glazing areas that do not exceed 15 percent of the gross area of exterior walls. Detached one- and two-family dwellings are commonly Type A-1 buildings. Type A-2 have glazing areas that do not exceed 25 percent of the gross area of the exterior walls. Section 502.2, “Heating and Cooling Criteria”, specifies the maximum thermal transmission U-value for each building component (walls, roof, slab on grade, etc.). In residential construction, the maximum permissible U_W-value for walls is a function of the heat capacity of the wall in question. The example that follows illustrates how the maximum permissible U_{OW}-value may be increased if the HC of the wall in question is greater than or equal to 6 Btu/(ft^2-°F). All 4 in. brick veneer walls have a HC of at least 6 Btu/(ft^2-°F). This example utilizes the Compliance by Performance on an Individual Component Basis found in Section 502.2.1. Other provisions in this section contain criteria for compliance using Acceptable Practices (Section 502.2.3) and Prescriptive Criteria (502.2.4).

EXAMPLE 3: International Energy Conservation Code — Component Performance Criteria

Single Family Home

Determine the maximum permissible thermal transmittance of the opaque wall area (U_W-value) of a 2,000 ft^2 two-story single family home located in a suburb of Washington, D.C. The house is brick veneer over wood frame constructed as shown in Fig. 1a. The home's fenestration is 20% of the total wall area: 15% glazing, 5% doors. Thermal transmittance values for the fenestration are: U_g = 0.48 and U_d = 0.48. The following steps are suggested to determine the maximum permissible U_W-value.

Step 1: Determine the annual Fahrenheit heating degree days (HDD, 65 °F base) for the location given. For Washington, D.C., HDD equals 4224. HDD for many U.S. cities can be found in the 2000 *International Energy Conservation Code* [7]. Other resources include Table B7.1 of *Building Control Systems* [1] or in the 1981 ASHRAE *Handbook of Fundamentals* [5]. A single family home with a glazing area of 20% is classified by *IECC* Section 101.3.1 as building Type A-2. Using this information, determine the maximum U_O-value for the gross wall area from Fig. 3 of this *Technical Notes* to be 0.215 Btu/(hr-ft^2-°F).



U_O Walls—Type A-1 and A-2 Residential Buildings—Heating'

FIG. 3

Step 2: Calculate U_W using Eq. 1 and knowing the U-values of the glazing and door areas and the gross wall area (U_O). Equation 1 in this *Technical Notes* is Eq. 5-1 found in Section 502 of the IECC, solved for U_W.

$$U_w = \frac{U_o A_o - U_g A_g - U_d A_d}{A_w} \qquad \text{Eq. 1}$$

U_w = 0.118 Btu/(hr-ft^2-°F) or R ⩾ 8.42 (hr-ft^2-°F)/Btu. This U_w-value is the maximum permissible value for wall constructions having a heat capacity less than 6 Btu/(ft^2-F).

Step 3: Determine the HC of the wall in question. The HC of the brick veneer and wood stud wall has already been calculated to be 7.4 Btu/(ft^2-°F), see Fig. 1a. The maximum permissible U_w-value for a wall having a HC of 6 Btu/(ft^2-°F) or greater may be increased to account for the effects of thermal mass using Tables 3a-3c in this *Technical Notes.* The values in these tables, taken from the *IECC,* are a function of climate (represented by HDD65); wall construction (HC greater than or equal to 6 Btu/(ft^2-°F)); and the placement of insulation outside the thermal wall mass (Table 3a), on the interior of the wall mass (Table 3b) or integral with the wall mass (Table 3c).

In this example, the insulation in the wall shown in Fig. 1a is placed interior of the wall mass. Therefore, Table 3b should be used. Enter the row in Table 3b for HDD equal to 4001-5500 and the column for U_w equal to 0.118 Btu/(hr-ft^2-°F). U_w equal to 0.118 is between the columns in the table labeled 0.10 and 0.12. Linearly interpolate the table to determine the maximum permissible thermal transmittance, U_w, to be 0.137 Btu/(hr-ft^2-°F). This U-value corresponds to an R-value greater than or equal to 7.30 (hr-ft^2-°F)/Btu.

TABLE 3a

Required U_w for Wall With a Heat Capacity

Equal to or Exceeding 6 Btu/(ft^2 ^{o}F)

With Insulation Placed on the Exterior of the Wall Mass

HEATING DEGREE DAYS	U_w REQUIRED FOR WALLS WITH A HEAT CAPACIY LESS THAN 6 Btu/ft^2·°F AS DETERMINED BY USING EQUATION 5-1 AND FIGURE 502.2(1)										
	0.24	0.22	0.20	0.18	0.16	0.14	0.12	0.10	0.08	0.06	0.04
0-2,000	0.33	0.31	0.28	0.26	0.23	0.21	0.18	0.16	0.13	0.11	0.08
2,001-4,000	0.32	0.30	0.27	0.25	0.22	0.20	0.17	0.15	0.13	0.10	0.08
4,001-5,500	0.30	0.28	0.25	0.23	0.21	0.18	0.16	0.14	0.11	0.09	0.07
5,501-6,500	0.28	0.26	0.23	0.21	0.19	0.17	0.15	0.12	0.10	0.08	0.06
6,501-8,000	0.26	0.24	0.22	0.19	0.17	0.15	0.13	0.11	0.09	0.07	0.05
>8001	0.24	0.22	0.20	0.18	0.16	0.14	0.12	0.10	0.08	0.06	0.04

From IECC Figure 502.2.1.1.2(1)

TABLE 3b

Required U_w for Wall With a Heat Capacity

Equal to or Exceeding 6 Btu/(ft^2 ^{o}F)

With Insulation Placed on the Interior of the Wall Mass

HEATING DEGREE DAYS	U_w REQUIRED FOR WALLS WITH A HEAT CAPACIY LESS THAN 6 Btu/ft^2·°F AS DETERMINED BY USING EQUATION 5-1 AND FIGURE 502.2(1)										
	0.24	0.22	0.20	0.18	0.16	0.14	0.12	0.10	0.08	0.06	0.04
0-2,000	0.29	0.27	0.25	0.22	0.20	0.17	0.15	0.12	0.09	0.07	0.04
2,001-4,000	0.28	0.26	0.24	0.21	0.19	0.16	0.14	0.12	0.09	0.07	0.04
4,001-5,500	0.27	0.25	0.23	0.21	0.17	0.16	0.14	0.11	0.09	0.07	0.04
5,501-6,500	0.26	0.24	0.22	0.20	0.17	0.15	0.13	0.11	0.09	0.06	0.04
6,501-8,000	0.25	0.23	0.21	0.19	0.17	0.14	0.12	0.10	0.08	0.06	0.04
>8001	0.24	0.22	0.20	0.18	0.16	0.14	0.12	0.10	0.08	0.06	0.04

From IECC Figure 502.2.1.1.2(2)

TABLE 3c

Required U_w for Wall With a Heat Capacity

Equal to or Exceeding 6 Btu/(ft^2 ^{o}F)

With Integral Insulation (Insulation and Mass Mixed, Such as a Log Wall)

HEATING DEGREE DAYS	U_w REQUIRED FOR WALLS WITH A HEAT CAPACIY LESS THAN 6 Btu/ft^2·°F AS DETERMINED BY USING EQUATION 5-1 AND FIGURE 502.2(1)										
	0.24	**0.22**	**0.20**	**0.18**	**0.16**	**0.14**	**0.12**	**0.10**	**0.08**	**0.06**	**0.04**
0-2,000	0.33	0.31	0.28	0.25	0.23	0.20	0.17	0.15	0.12	0.09	0.07
2,001-4,000	0.32	0.30	0.27	0.24	0.22	0.19	0.17	0.14	0.11	0.09	0.06
4,001-5,500	0.30	0.28	0.26	0.23	0.21	0.18	0.16	0.13	0.11	0.08	0.06
5,501-6,500	0.28	0.26	0.24	0.21	0.19	0.17	0.14	0.12	0.10	0.08	0.05
6,501-8,000	0.26	0.24	0.22	0.20	0.18	0.15	0.13	0.11	0.09	0.07	0.05
>8001	0.24	0.22	0.20	0.18	0.16	0.14	0.12	0.10	0.08	0.06	0.04

From IECC Figure 502.2.1.1.2(3)

Step 4: To determine if the wall in question complies with Section 502 of the *IECC,* compare the maximum permissible thermal transmittance, U_w-value, determined in Step 3 with the calculated U_w-value. The calculated U_w-value, determined using the procedures contained in *Technical Notes* 4 Revised or the ASHRAE *Handbook of Fundamentals,* is 0.071 Btu/(hr-ft^2-°F). Since the calculated U_w-value is less than the maximum U_w-value (0.157 Btu/(hr-ft^2-°F)), this wall construction meets the requirements of the *IECC* Section 502.

For comparison, in this example the maximum permissible U_w-value for a lightweight wall is 0.118 Btu/(hr-ft^2-°F), but for a thermal mass wall, the maximum U_w-value is 0.137 Btu/(hr-ft^2-°F). The allowable U_w-value for the thermal mass wall is 16 percent greater.

Chapter 6 - Simplified Prescriptive Requirements for Residential Buildings, Type A-1 and A-2

Chapter 6 contains a simplified prescriptive approach that does not reflect different percentages of glazing or trade-offs between building envelope components. It does, however, allow for decreased R-value requirements for mass walls similar to those found in Chapter 5.

COMMERCIAL CONSTRUCTION - Chapters 7 and 8

Chapter 7 - Building Design for All Commercial Buildings. Chapter 7 of the *IECC* simply references the requirements of ASHRAE/IES *Energy Code for Commercial and High-Rise Residential Buildings*. All commercial buildings must meet the requirements of the ASHRAE/IES *Energy Code* or the requirements of Chapter 8 of the IECC.

Chapter 8 - Design by Acceptable Practice for Commercial Buildings. Chapter 8 of the *IECC* is applicable to buildings that have a window and glazed door area not greater than 50 percent of the gross wall area. Buildings with glazing areas over 50 percent must comply with the ASHRAE/IEC *Energy Code*. Chapter 8 contains requirements for individual building components (walls, roof, floors). If any of these requirements are not met, the ASHRAE/IEC *Energy Code* can be used for that portion of the building envelope. Differences for mass walls are reflected in the required values for all but the warmest climates.

SUMMARY

This *Technical Notes* continues the discussion of the energy efficiency of thermal mass brick masonry walls. Direction is provided on how to treat thermal mass when considering the envelope requirements of several energy codes or standards. Methods for complying with these requirements are described in detail. Sample calculations quantifying thermal mass as heat capacity (HC) are given.

The information and suggestions contained in this *Technical Notes* are based on the available data and the experience of the engineering staff of the Brick Industry Association. The information contained herein must be used in conjunction with good technical judgment and a basic understanding of the properties of brick masonry. Final decisions on the use of the information contained in this *Technical Notes* are not within the purview of the Brick Industry Association and must rest with the project architect, engineer and owner.

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