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VIEWPOINT

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DENSITY-RELATED PROPERTIES OF CONCRETE MASONRY

INTRODUCTION

Concrete masonry is a versatile, durable material for the construction of building walls that provide load-bearing strength, fire resistance, a high degree of resistance to sound penetration and other desirable features. The density of the concrete mix design used to create a concrete masonry unit (CMU or commonly called block) can vary greatly. This Viewpoint addresses the effects that density has on the physical, aesthetic, engineering and economic characteristics of concrete masonry walls.

Concrete masonry offers a variety of color and texture to the designer

Throughout North America, a wide variety and blends of aggregate materials are used to manufacture concrete masonry units. Concrete block density can range from less than 85 pcf to more than 140 pcf. Table 1 shows a range of concrete densities and approximate resulting weights for typical concrete masonry units. ASTM C 90 (Ref. 1) concrete masonry units must be made with aggregates that meet either ASTM C 33 "*specification for concrete aggregates*" or ASTM C 331 "*specification for lightweight aggregates for concrete masonry*".

Nominal Thickness	Specified Thickness	% Solid	Gross Volume CF	Absolute Volume CF	Oven Dry Density of Block Concrete					
					85	95	105	115	125	135
4	3.63	74	.250	.185	16	18	19	21	23	25
6	6.63	61	.388	.237	20	23	25	27	30	32
8	7.63	52	.526	.273	22	25	28	30	33	36
10	9.63	50	.664	.332	28	32	36	38	42	48
12	11.63	48	.802	.385	33	37	40	44	48	52

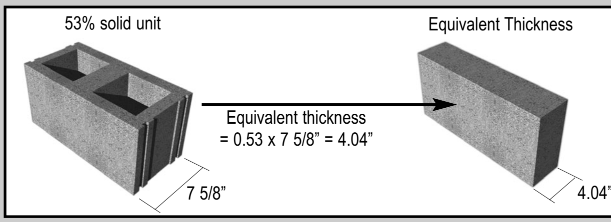
Table 1 - Approximate weight (lbs) of oven dry concrete masonry units as a function of concrete density

PHYSICAL PROPERTIES

Fire Resistance

The fire resistance of concrete masonry walls depends on the geometry of the concrete masonry units, and the density of the concrete block. The unit geometry affects the effective or "equivalent" unit thickness. For a given unit configuration, the fire resistance of a concrete masonry wall increases as the concrete density decreases.
(See NCMA TEK 7-1A Ref. 4).

Extensive testing has established a relationship between the fire resistance and the equivalent solid thickness for concrete masonry walls as shown in Figure 1. Equivalent thickness is essentially the solid thickness that would be obtained if the same amount of masonry contained in a hollow unit were recast 100% solid without core holes. The equivalent thickness of a hollow unit is equal to the percentage solid times the



Aggregate Type in the Concrete Masonry Unit	Minimum required equivalent thickness for fire resistance rating, in. (mm)[1]						
	4 hours	3 hours	2 hours	1.5 hours	1 hour	0.75 hrs	0.5 hrs
Calcareous or siliceous gravel	6.2 (157)	5.3 (135)	4.2 (107)	3.6 (91)	2.8 (71)	2.4 (61)	2.0 (51)
Limestone, cinder or slag	5.9 (150)	5.0 (127)	4.0 (102)	3.4 (86)	2.7 (69)	2.3 (58)	1.9 (48)
Expanded clay, shale or slate	5.1 (130)	4.4 (112)	3.6 (91)	3.3 (84)	2.6 (66)	2.2 (56)	1.8 (46)
Expanded slag or pumice	4.7 (119)	4.0 (102)	3.2 (81)	2.7 (69)	2.1 (53)	1.9 (48)	1.5 (38)

1. Fire resistance rating between the hourly fire resistance rating periods listed may be determined by linear interpolation based on the equivalent thickness value of the concrete masonry assembly.
2. Minimum required equivalent thickness corresponding to the hourly fire resistance rating for units made with a combination of aggregates shall be determined by interpolation based on the percent by volume of each aggregate used in the manufacture.

Figure 1 - Fire Resistance Rating Period of Concrete Masonry Assemblies (Ref. 4)

actual thickness of the unit. The percentage solid is determined in accordance with ASTM C 140 (Ref 9). Table 2 shows the relationship between fire resistance and equivalent thickness for concrete masonry units of varying densities.

Equivalent Thickness (based on trend lines)				
Conc. Density (pcf)	Fire Endurance (hours)			
	1	2	3	4
< 95	2.5-2.7	3.5-3.7	4.4-4.6	5.4-5.6
95-105	2.7-2.9	3.7-3.9	4.6-4.8	5.6-5.7
105-125	2.9-3.0	3.9-4.1	4.7-4.9	5.7-5.9
>125	2.9-3.1	4.1-4.3	5.3-5.5	6.6-6.7

Table 2 - Approximate Equivalent Thickness in Inches by Density (Ref 7)

Thermal Resistance (R-Values)

R-Values of concrete masonry are correlated to concrete density, since thermal conductivity of concrete increases with increasing density. Table 3 shows the R-Values for a typical 8" CMU of various densities with and without insulated cores. The R value of 12" insulated and reinforced cmu for various densities is listed in Fig 5.

Density (PCF)	Cores Empty	Cores Insulated with Perlite	Cores Insulated with Foam
85	2.5	7.1	8.0
105	2.2	5.2	5.6
135	1.9	3.3	3.4

Table 3 - R Value of 8" CMU (Ref. 6)

Thermal Mass

The effect of thermal mass (also known as thermal inertia) on walls is well documented. High thermal inertia walls, such as concrete masonry, have the ability to delay and reduce the impact of outdoor temperature changes on conditioned indoor environments, improving energy efficiency. The International Energy Conservation Code (1994) recognizes most masonry walls that weigh more than 25 lb per square foot as mass walls. For example, this wall weight is attained with a 90 pcf 8" un-reinforced cmu.

Load Bearing Properties

All concrete masonry units, regardless of density, must conform to ASTM C 90. ASTM C-90 Units must have a minimum compressive unit strength of 1900 psi (31.1Mpa). If required, compressive strengths considerably higher than ASTM C 90 minimum are readily achieved with low and high density aggregates.

Structural and Seismic Loading

Lower density units reduce the dead load on supporting beams, columns and foundations of a structure. This is especially important in mid-rise or high-rise structures. Lower density units also reduce the inertia of a masonry wall, which improves the building's seismic performance and makes masonry a more structurally efficient material.

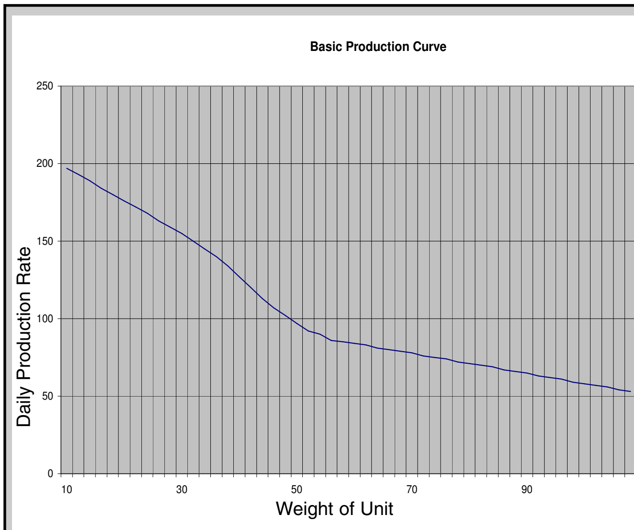


Figure 2 - CMU Weight vs. Daily Production (ref. 2)

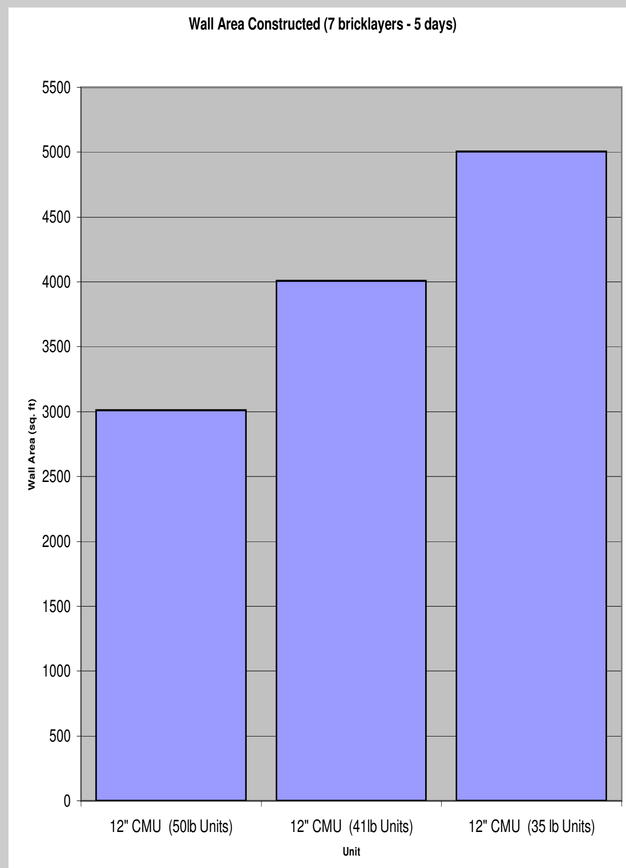


Figure 3 - Area of 12" CMU laid by 7 man crew in 5 days vs. Block Weight

Weight of 1 Unit	35lbs.	41lbs	50lbs
Installed Cost	$11.53	$13.43	$15.89

Table 4 - Initial Costs by Unit Weight of 12" CMU (ref. 3)

Economic Characteristics

In estimating masonry construction, a common method employed by mason contractors is the production rate method. The production rate of a given unit is expressed in the total units a mason can lay in one work day (8 hours). Figure 2 shows the relationship of CMU weight to daily production of concrete masonry units. The figure shows that productivity increases as the weight of the CMU goes down. Figure 3 shows the amount of wall area that a typical crew of 7 people can build in 5 days using 12" CMU of varying densities.

Initial Wall Costs and Density

The initial cost of a concrete masonry wall is a function of material cost, labor cost and contractor's overhead and profit. The largest single factor is the cost of labor required to construct the wall.

Many experienced estimators and project managers recognize the relationship between the density of the concrete masonry units and the labor cost. This relationship is reflected in the cost data obtained through market research in Illinois (Table. 4).

Wall Construction:	Location:
Single wythe 12" CMU reinforced 48" vertically with foamed in place core insulation	Chicago, Illinois Winter 2005-06

R Value Data	CMU Density				
	135 lb / ft^3	125 lb / ft^3	115 lb / ft^3	105 lb / ft^3	90 lb / ft^3
R value[1]	3.65	4.17	4.74	5.41	6.62
Calculate: U value	0.274	0.240	0.211	0.185	0.151

R value in (hr · ft^2 · ^{o}F) / BTU. U value in BTU / (hr · ft^2 · ^{o}F)

The following analysis caclulates annual heating and cooling costs for the concrete masonry wall. All units are conventional 12" x 8" x 16" size.

	CMU Density				
	135 lb / ft^3	125 lb / ft^3	115 lb / ft^3	105 lb / ft^3	90 lb / ft^3
Heating Cost Calculations					
Natural Gas Cost[2] per mcf	$10.00	$10.00	$10.00	$10.00	$10.00
Furnace efficiency	0.80	0.80	0.80	0.80	0.80
Calculate: $ Cost per Btu output	1.25E-05	1.25E-05	1.25E-05	1.25E-05	1.25E-05
Heating Degree Days for This Location[3]	6459	6459	6459	6459	6459
Calculate: Energy Cost: $ / sq ft / yr	$0.5309	$0.4647	$0.4088	$0.3582	$0.2927
Calculate: Energy Cost: $ / block / yr	$0.4719	$0.4131	$0.3634	$0.3184	$0.2602
Present Worth of Heating Savings					
n (years)	30	30	30	30	30
i (nominal rate - energy and money)[4]	2.00%	2.00%	2.00%	2.00%	2.00%
Calculate: Present Worth of Wall Heating Costs, $ / block	*$10.57*	*$9.25*	*$8.14*	*$7.13*	*$5.83*
Cooling Cost Calculations					
Electricity Cost[2] per kwh	$0.1050	$0.1050	$0.1050	$0.1050	$0.1050
SEER	10	10	10	10	10
Cooling Degree Hours for This Location[3]	6606	6606	6606	6606	6606
Calculate: Energy Cost: $ / sq ft / yr	$0.0190	$0.0166	$0.0146	$0.0128	$0.0105
Calculate: Energy Cost: $ / block / yr	$0.0169	$0.0148	$0.0130	$0.0114	$0.0093
Present Worth of Cooling Savings					
n (years)	30	30	30	30	30
i (nominal rate - energy and money)[4]	2.00%	2.00%	2.00%	2.00%	2.00%
Calculate: Present Worth of Wall Cooling Costs, $ / block	*$0.38*	*$0.33*	*$0.29*	*$0.26*	*$0.21*
Calculate: Present Worth of Total Wall Heating and Cooling Cost, $ / block	*$10.95*	*$9.58*	*$8.43*	*$7.39*	*$6.04*

(1) R-values for Single Wythe Concrete Masonry Walls, TEK 6-2A, National Concrete Masonry Association, 1996. The R value is interpolated for 90 pcf. (2) Natural Gas and Electricity Costs: Illinois Masonry Institute. Current for Winter 2005-06.
(3) Appendix A, Climactic Data for the US and Canada, ASHRAE 90.2, 1993.
(4) The 2% nominal discount rate was chosen as appropriate for this analysis because it represents the typical long term two percent difference between short term US T-bill rates and the CPI inflation rate. See Office of Management and Budget Circular A-94 Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs.

Calculations are based on Expanded Shale, Clay & Slate Institute (ESCSI) Information Sheet No. 3530.

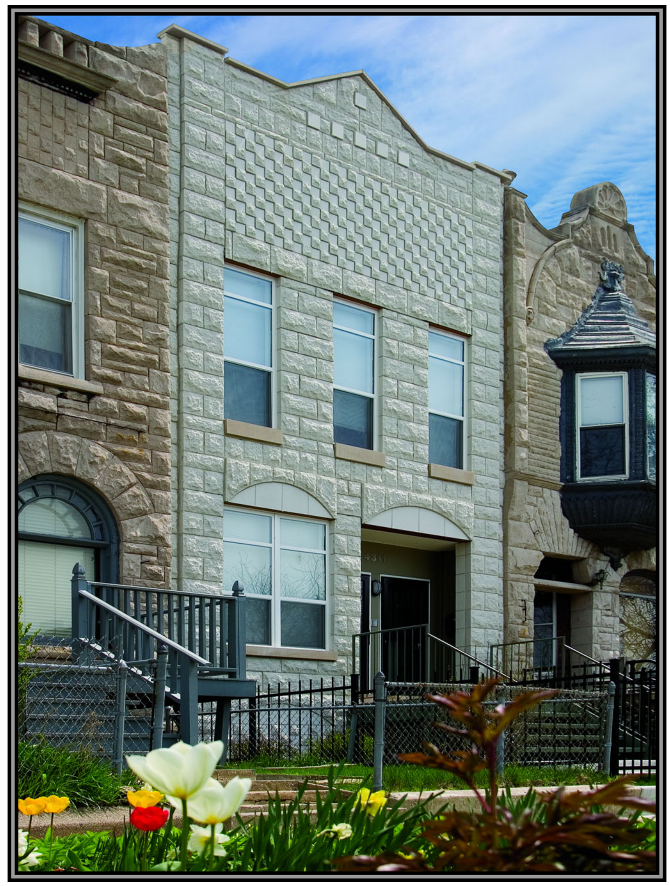
Table 5 - Life Cycle Energy Cost Analysis Over 30 Year Period(ref. 5)

Based on steady state analysis - 5/01/2006

AESTHETIC CONSIDERATIONS

One of the most significant architectural benefits of designing with concrete masonry is its versatility in the finished appearance of a concrete masonry wall can be varied with the unit size and shape, color of units and mortar, bond pattern, and surface finish of the units. The term ”architectural concrete masonry units” typically is used to describe units displaying any one of several surface finishes that affects the texture of the unit, allowing the structural wall and finished surface to be installed in a single step.

Architectural concrete masonry units are used for interior and exterior walls, partitions, terrace walls, and other enclosures. Some units are available with the same treatment or pattern on both faces, to serve as both exterior and interior finish wall material, increasing both the economic and aesthetic advantages. Architectural units ranging in density from 85 to 140 pcf comply with the same quality standards as conventional concrete masonry, ASTM C 90.



1 ASTM C 90-06b, Standard Specification for Load Bearing Concrete Masonry Units, ASTM International, Inc. 2006
2 Kolkoski Rynold V.,Masonry Estimating. The Aberdeen Group, 1995
3 Masonry Cost Guide, Masonry Advisory Council, 2007
4 NCMA TEK 7-1A. Fire Resistance Rating of Concrete Masonry Assemblies, National Concrete Masonry Association.
5 ESCSI Information Sheet 3530, Life Cycle Energy Cost Analysis, Expanded Shale, Clay and Slate Institute, 2000
6 NCMA TEK 6-2A, R-Values of Single Wythe Concrete Masonry Walls, National Concrete Masonry Association.
7 Compilation of data from NCMA Library FPD00123, Fire Resistance of Concrete Masonry Walls, NCMA technical Committee Task Group on Concrete Masonry Fire Resistance.
8 Thermal Mass, The International energy Conservation Code (IEEC), International Code Council, Country Club Hills, Ill, 2004
9 ASTM C 140, Standard Method of Sampling and Testing Concrete Masonry Units, ASTM International, Inc.