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INSULATING CONCRETE MASONRY THEORETICAL MAXIMUM "R" VALUES

Thomas A. Holm, PE

In keeping with well known natural laws, the movement of heat, water, electricity . . . is determined by the path of least resistance. Should an electrical network have parallel resistance paths (Fig 1) where one resistance R_1 is extremely large in comparison to the other resistance R_2, the the current flow in the high resistance path will approach zero and virtually all current flows will pass through the low resistance path . . . a "shunt" is developed.

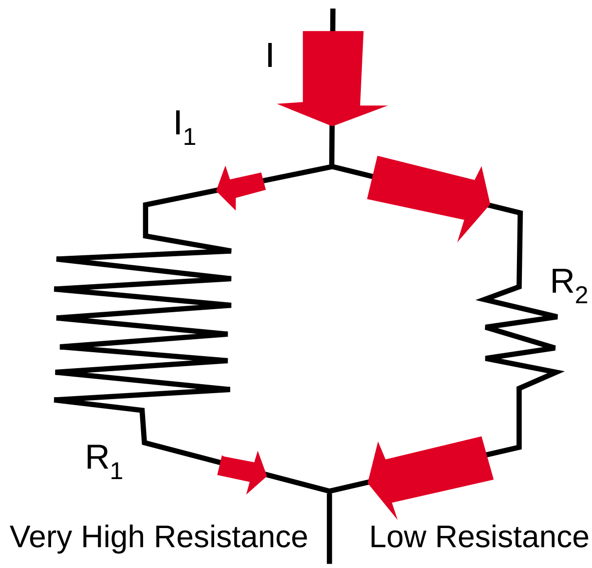

Figure 1. *Current flow in an electric network*

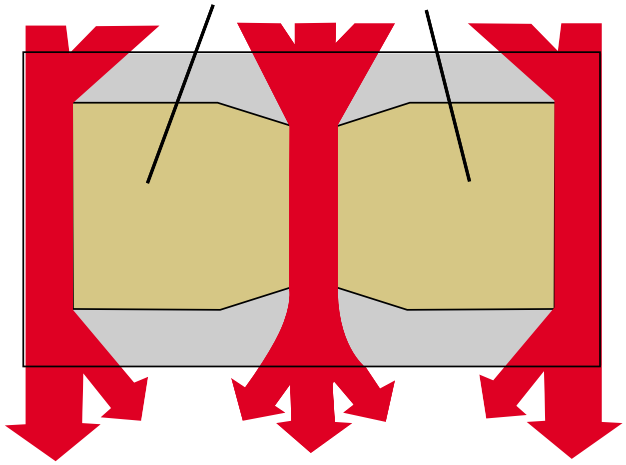

Figure 2. *Heat flow in an insulated concrete masonry unit*

This situation is replicated in a standard commercially available ASTM C90 concrete masonry unit with full depth webs when **all core spaces are filled with a totally nonconducting, super-insulating material with a thermal resistivity approaching infinity ($r_{fill} \rightarrow \infty$).**

In this case, virtually all heat flow is through the webs and the rate of flow is decisively determined by the thermal resistivity (r_c) of the block concrete.

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Using standard series-parallel (Isothermal Planes) calculations methods as mandated by ASHRAE 90.1 and simple arithmetic concepts, the "limiting" thermal resistance of standard concrete masonry units may be approximated as follows:

LAYER	THERMAL RESISTANCE
1. Thermal Resistance of Surface Films	$(.18 + .67)$
+	+
2. Thermal Resistance of Two Face Shells	$(2 \text{ X } 1.5\text{"} \text{ X } r_c)$
+	+
3. The equivalent thermal resistance of the parallel paths through the webs and the highly insulated cores is approximated by:	$\left[\dfrac{1}{\dfrac{.27}{8.2\, r_c} + \dfrac{.73}{8.2\, r_f}}\right]$

For a standard 12" CMU, 8.2" is the width of the core and webs; .27 and .73 are the percentage face areas of the webs and cores; and r_c and r_f are the resistivities of the block concrete and core insulating materials.

As the resistivity of the insulating material in the core approaches infinity ($r_{fill} \rightarrow \infty$); a totally nonconducting, perfect insulator, then the expression $\frac{.73}{8.2\, r_f}$ will reduce to zero. **From a physical perspective this suggests that all the heat in the face shells will converge on and concentrate in a path through the webs.** With the use of a perfect insulating material, the equivalent path thermal resistance expression will reduce to $\dfrac{1}{\frac{.27}{8.2\, r_c}}$ or $30\, r_c$.

Then the total resistance (R) of a standard commercial 12" ASTM C90 CMU will be approximately as follows:

Total Resistance = Film Resistance + Face Shell Resistance + Equivalent Web and Face Shell Resistance

$$R^{MAX}_{12"} \quad = \quad .85 \quad + \quad 3\, r_c \quad + \quad 30\, r_c \quad = \quad 33\, r_c \ + \ .85$$

When the surface film thermal resistances are not included then the limiting thermal resistance of a standard 12" wide concrete masonry unit filled with a totally non conducting core insulation may be approximated by $33\, r_c$.

In similar fashion, an 8" wide CMU would be approximated as follows:

$$R^{MAX}_{12"} = (2 \text{ x } 1.3\, r_c) + \frac{1}{.22 \text{ X } (4.6\, r_c)} \quad = 24\, r_c$$

Then computation of the theoretical thermal resistance ceiling of integrally insulated concrete masonry requires inputting the value of the thermal resistivity of the block concrete. Thermal resistivity is best obtained by a guarded hot plate laboratory measurement in accordance with the procedures of ASTM C177. An alternative is to use an estimated resistivity obtained from Chapter 22 of the *1993 ASHRAE Handbook of Fundamentals*. For comparative analytical purposes, theoretical maximum thermal resistance R^{MAX} values of integrally insulated single wythe walls built with commercially available standard ASTM C90 concrete masonry units with the cores filled with an insulating material having an infinite thermal resistance (totally nonconducting) is shown in the following table:

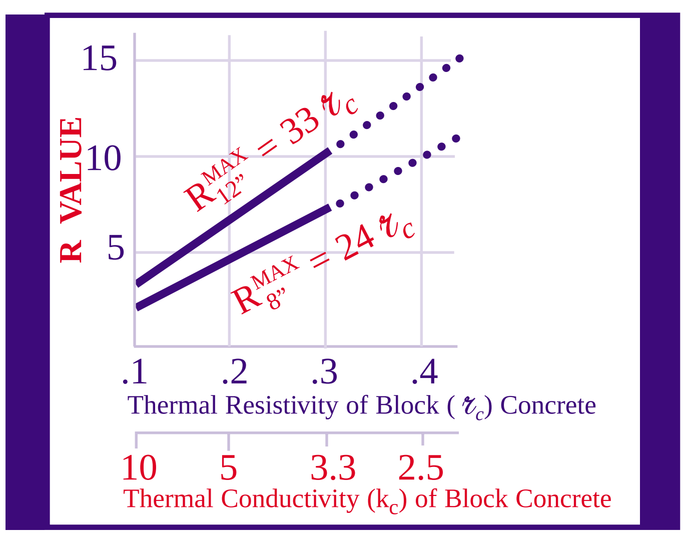
Theoretical Maximum Thermal Resistance RMAX (1) Values of Integrally Insulated Single Wythe Walls Built with Commercially Available, Standard ASTM C90 concrete Masonry Units with Cores Filled with an Insulating material Having an Infinite Thermal Resistance (Totally Nonconducting).

Weight	Heavy Aggregates		Lightweight Aggregates	
Aggregate	Highly Conductive	Moderately Conductive	LWA (Density 105)*	LWA (Density< 90 pcf)*
k_C Thermal Conductivity Used for Purposes of Analysis	10+	8	6	3.3
$r_c = l/k_C$ Thermal Resistivity Used for Purposes of Analysis	.1	.13	.17	.30
$R^{MAX}_{8"} = 24\, r_c$ (Add Film Resistance)	2.4 (3.3)	3.0 (3.9)	4.0 (4.9)	7.3 (8.2)
$R^{MAX}_{12"} = 33\, r_c$ (Add Film Resistance)	3.3. (4.2)	4.1 (5.0)	5.5 (6.4)	9.9 (10.8)

* Concrete block density

(1) Thermal conductivity values shown are for illustrative purposes only. When available use known, tested (ASTM C177) values of thermal conductivity of block concrete, or estimate values from Chapter 22 of *ASHRAE Handbook of Fundamentals.*

***Figure 3.** Thermal Resistance "R" Values of Single Wythe Concrete Masonry Wall (No Surface Films Added)*



It becomes clear that any strategy to increase the thermal resistance (R) of concrete masonry units must recognize the decisive influence of the thermal resistivity of the web block concrete and the thermal bridging effects within a standard commercial unit. One alternate strategy would be to reduce web dimensions while maintaining all of the physical requirements called for in ASTM C90. such configurations are commercially available where the molded polystyrene inserts fit into the cut-down webs. Another strategy is to extend the effective web length by multi-core arrangements.

When thermal conductivity of the block concrete and insulating fills are known from measurements, the thermal resistance of the system may be computed using known series-parallel (Isothermal Planes) methods. Thermal conductivity of dry block concrete may be estimated for lightweight aggregate concrete up to a density of 100 pcf using the Valore equation $k = .5e^{0.02d}$ and then correcting for in-service moisture content. The thermal conductivity of concrete masonry units with densities above 100 pcf cannot be accurately estimated because of the extremely wide range of thermal conductivities of ordinary aggregates that is determined by mineral composition and crystal structure. If, for example the thermal conductivity of block concrete composed entirely of lightweight aggregates (85 pcf) were measured (ASTM C177) to be 3.15 BUT in/sf °F (Resistivity of $\frac{1}{3.15}$ =.32), then the practical limiting thermal resistance of a 12" commercially available CMU made from this block concrete mix would be approximately, 33 X .32 = 10.6. With surface films added (the usual method of reporting in manufacturers literature) the $R^{MAX}_{12"}$ limit of the wall would be approximately 11.5.

Full scale wall tests sponsored by the Expanded Shale, Clay and Slate Institute using concrete masonry units composed entirely of rotary kiln produced expanded shale with cores filled with perlite produced a thermal resistance of 10. The value is less than the computed limiting R^{MAX} value of 11.5 and fully understandable by comparing the thermal resistance of perlite granular fill insulation to that of the infinite thermal resistivity ($r_f \rightarrow \infty$) used in the theoretical derivation.

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