In 2003 Crocker Ltd. was invited to advise in the testing of compressed earth blocks for R-values in an experiment conducted by Sandia National Laboratories in Albuquerque, NM. One of the goals of the experiment was to test "alternative" materials, as determined by Sandia team. Among these were shredded paper and fly ash using various proportions of water and latex as a binder. None of those blocks survived the drying process adequately enough to be tested.

Following is the report, including the testing parameters, as submitted at the end of the project. The compressed earth blocks made with crusher fines from the Santa Fe River valley, west of the city, demonstrated a 3.41 to 3.51 R-value for a 14-inch block.

R-VALUE TESTING OF COMPRESSED EARTH BLOCK

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SUMMARY

This project determined the approximate R-values (thermal transmittance) of three formulations of compressed block. The composition of each formulation is as follows: 1) Concrete mixer truck washout with soil, 2) Engineered Fill No. 1: clay, sand, large aggregate (>3/8"), 3) Engineered Fill No. 2: clay, sand, small aggregate (<1/4").

From published properties of the block components,[1] we predicted R-values for each formulation as follows:

1) Concrete Mixer Truck Washout: R-0.21/inch
2) Engineered Fill No. 1 (large aggregate): R-0.27/inch,
3) Engineered Fill No. 2 (small aggregate), R-0.29/inch

Actual values for the test samples ranged as follows:

1) Concrete Mixer Truck Washout: R-0.24/inch to R-0.44/inch {A-series Blocks}
   Average R-0.35 = 60% of predicted value
2) Engineered Fill No. 1 (large aggregate), R-0.21/inch to R-0.29/inch {B-series Blocks}
   Average R-0.24 = 89% of predicted value
3) Engineered Fill No. 2 (small aggregate): R-0.19/inch to R-0.35/inch {C-series Blocks}
   Average R-0.25 = 86% of predicted value

EQUATIONS

The following equation defines thermal transmittance or R-value of homogenous materials for absolute test methods:

$$R = \frac{A\,(T_h - T_c)}{Q} \qquad \text{\{Equation 1\}}$$

R: material r-value per unit thickness
T*h*: hot side specimen temperature
Q: Watts per hour per unit area
A: specimen surface area
T*c*: cold side specimen temperature

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[1]Energy-10, an energy modeling program, possesses an "R-value calculator" that will calculate R-values of a material when provided with values for density, specific heat capacity, and thermal conductance. Energy-10 contains established values of specific heat capacity and thermal conductance for many common materials (e.g., sand, concrete, wood, etc.). These established values allow the R-value calculator to estimate R-values for untested homogenous materials.

The following equation defines thermal transmittance or R-value of a homogenous material in a comparative test method:

$$R_{test} = \frac{R_{ref}\,[A_{test}(T_{htest} - T_{Ctest})]}{[A_{ref}(T_{href} - T_{Cref})]} \qquad \text{\{EQUATION 2\}}$$

R_{test}: test specimen r-value per unit thickness
R_{ref}: reference specimen r-value per unit thickness
A_{test}: test specimen surface area
A_{ref}: reference specimen surface area
T_{htest}: hot side test specimen temperature
T_{ctest}: cold side test specimen temperature
T_{href}: hot side reference specimen temperature
T_{cref}: cold side reference specimen temperature

TEST METHOD

The test used a comparative measure of heat flow, rather than an absolute measure, to determine the R-value of the three block formulations. A comparative test uses a specimen with known thermal transmission properties to determine thermal transmission properties of unknown specimens by reference. This test used "R-Tech" brand rigid foam insulation (laboratory-tested value of R-6.08 at 21° C for 1.4375 in. thickness) as the reference specimen. This comparative test determined R-values for the unknown specimens by measuring differences in changes to the surface temperature in an environment controlled by a conventional thermostat. An absolute test method directly measures the heat flow per unit time, typically measured in Watts, through an individual specimen in order to determine the heat flow rate, Q. The accuracy of a comparative test depends upon the test accuracy of the referenced material and can be no better than that of the referenced procedure.[2]

Several factors influenced the decision to use a comparative rather than an absolute test method. Absolute heat flow test methods (e.g., ASTM C-177) generally measure steady state heat flux through materials with a "low" thermal conductivity, which commonly are denoted as "thermal insulators".[3] In this test, the test specimens possess high thermal conductivity and are not considered thermal insulators relative to other materials. Furthermore, absolute test methods require specimen geometry with a large ratio of area to thickness. Such a test requires thin slices of the specimens and effective slicing tools are not available to us. In addition to cost and time limitations, these factors suggest that an absolute heat flow test of earth blocks would not produce results significantly different from a comparative test.

We tested three samples each of the first three block formulations. We wrapped each sample on four sides with the "R-Tech" brand insulation. This left two sides open—one for the hot side measurements and one for the cold side measurements. Thus, each sample created a box. We filled each box with ice and turned

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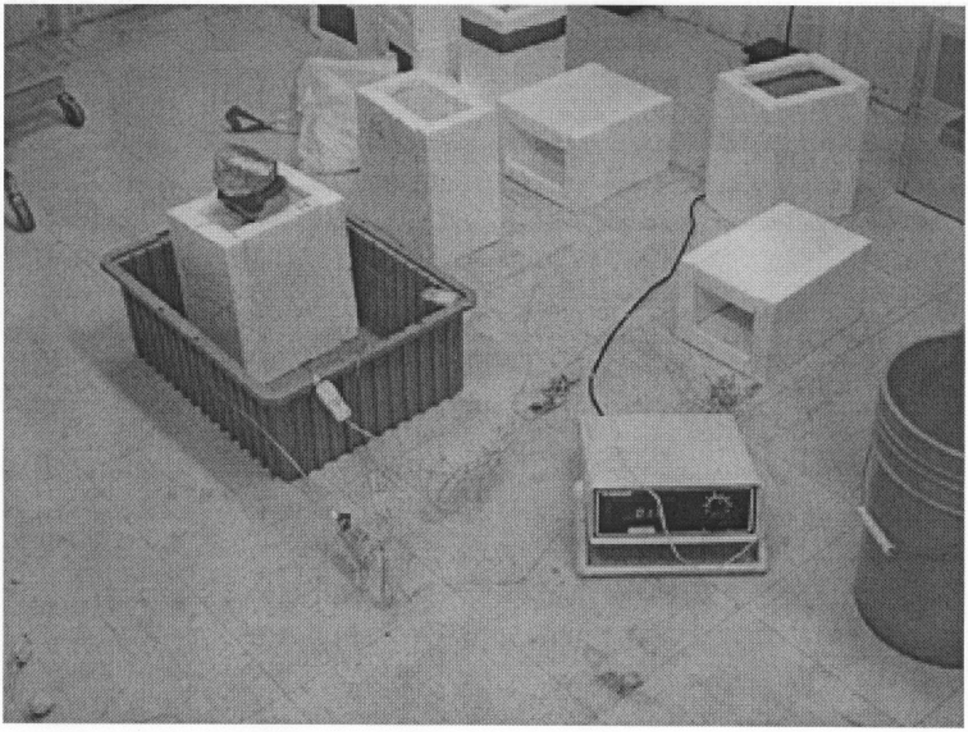
[2] ASTM Designation: C-177-97, Section 5.9 *Standard Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate Apparatus,* ASTM International, 2003.
[3] ASTM Designation: C-177-97, Section 5.1

the box over inside a tub. For each sample, we placed thermocouples on the cold and hot surfaces of the brick and one on the warm side of the rigid insulation. A fourth thermocouple measured the ambient air temperature. The block surface temperatures stabilized after about two hours. We recorded the temperatures and used these values in Equation 2 to calculate the R-value of each sample.



SAMPLE TEST BOXES AND THERMOCOUPLE READER

LIMITING FACTORS

With the exception of one sample set, the test results fall within 20% of the values predicted by the Energy-10 R-value calculator. This supports the conclusion that these tests have accuracy within an order of magnitude (i.e., a margin of error less than +/- 10x actual R-value). However, the variability between samples within a series necessarily excludes any definitive claims to a more precise degree of accuracy. For example, the A-series tests indicate that measured R-values varied by as much as 40%.

Limiting factors in the accuracy of this test method include the small number of samples (three samples per block formulation), non-uniform sample sizes, variations in box construction, unknown moisture content of samples, the thermocouple reader's degree of accuracy (+/- 1 degree C), variability in the test room temperature (6°C), and variation (3%) of the reference specimen R-value due to room temperature variability. Better control of these limiting factors could provide a greater degree of accuracy and a much smaller range of difference measured between samples within a series.

Results for Concrete Mixer Truck Washout----First Run

Test Brick ID#	A1	Temperature (^oC)	
DATE:	2/16/04	Time (Started at 9:20AM)	
TC#	Location	1:03PM	
4	Warm Side, Brick	15	
3	Cold side, Brick	8	
2	Warm Side, styrofoam	15	

room air: varies between 18 and 24°C

R_s= 6.08

Brick thickness: 3.5

Dimensions:

Brick - 6 7/8" x 4 1/8"

Sty - 6 7/8" x 7 7/8"

$R_b=R_s[(A_b*T_b)/(A_s*T_s)]$

A_s= 54.1 in^2

A_b= 28.4 in^2

R_b= 1.49

R_b per inch = 0.43

R_b @ 14" = 5.95

Test Brick ID#	A2	Temperature (^oC)	
DATE:	2/16/04	Time (Started at 9:20AM)	
TC#	Location	1:03PM	
7	Warm Side, Brick	15	
6	Cold side, Brick	8	
5	Warm Side, styrofoam	14	

Brick thickness: 3.875

Dimensions:

Brick - 7 3/16" x 4 1/8"

Sty - 7 3/16" x 7 3/8"

A_s= 53.0 in^2

A_b= 29.6 in^2

R_b= 1.70

R_b per inch = 0.44

R_b @ 14" = 6.13

Test Brick ID#	A3	Temperature (^oC)	
DATE:	2/16/04	Time (Started at 9:20AM)	
TC#	Location	1:03PM	
10	Warm Side, Brick	15	
9	Cold side, Brick	9	
8	Warm Side, styrofoam	14	

Brick thickness: 3.875

Dimensions:

Brick - 6 7/8" x 4 1/8"

Sty - 6 7/8" x 7 5/8"

A_s= 52.4 in^2

A_b= 28.4 in^2

R_b= 1.41

R_b per inch = 0.36

R_b @ 14" = 5.10

Average for A-Series		
	R_b=	1.53
	R_b per inch =	0.41
	R_b @ 14" =	5.73

Results for Concrete Mixer Truck Washout----Second Run

Test Brick ID#	A1	Temperature (^0C)	
DATE:	2/20/04	Time (Started at 7:40AM)	
TC#	Location	10:03PM	
4	Warm Side, Brick	15	
3	Cold side, Brick	9	
2	Warm Side, styrofoam	15	

room air: varies between 18 and 24°C

R_s= 6.08

Brick thickness: 3.5

Dimensions:

Brick - 6 7/8" x 4 1/8"

Sty - 6 7/8" x 7 7/8"

$R_b=R_s[(A_b*T_b)/(A_s*T_s)]$

A_s= 54.1 in^2

A_b= 25.9 in^2

R_b= 1.16

R_b per inch = 0.33

R_b @ 14" = 4.65

Test Brick ID#	A2	Temperature (^0C)	
DATE:	2/20/04	Time (Started at 7:40AM)	
TC#	Location	10:03PM	
7	Warm Side, Brick	15	
6	Cold side, Brick	8	
5	Warm Side, styrofoam	15	

Brick thickness: 3.875

Dimensions:

Brick - 7 3/16" x 4 1/8"

Sty - 7 3/16" x 7 3/8"

A_s= 53.0 in^2

A_b= 27.1 in^2

R_b= 1.45

R_b per inch = 0.37

R_b @ 14" = 5.24

Test Brick ID#	A3	Temperature (^0C)	
DATE:	2/20/04	Time (Started at 7:40AM)	
TC#	Location	10:03PM	
10	Warm Side, Brick	15	
9	Cold side, Brick	9	
8	Warm Side, styrofoam	15	

Brick thickness: 3.875

Dimensions:

Brick - 6 7/8" x 4 1/8"

Sty - 6 7/8" x 7 5/8"

A_s= 52.4 in^2

A_b= 25.9 in^2

R_b= 1.20

R_b per inch = 0.31

R_b @ 14" = 4.34

Average for A-Series		
	R_b=	1.27
	R_b per inch =	0.34
	R_b @ 14" =	4.74

Results for Engineered Fill No. 1 (large aggregate)

Test Brick ID#	B1	Temperature (^oC)		
DATE:	2/12/04	Time (Started at 11:31AM)		
TC#	Location	1:49PM	2:40PM	3:50PM
4	Warm Side, Brick	14	15	15
3	Cold side, Brick	11	11	11
2	Warm Side, styrofoam	16	15	16

room air: varies between 18 and 24°C

R_s= 6.08

Brick thickness: 3.75

Dimensions:

Brick - 7 5/16" x 4 1/16"

Sty - 7 5/16" x 7 9/16"

A_s= 54.7 in^2

A_b= 29.7 in^2

$R_b=R_s[(A_b*T_b)/(A_s*T_s)]$

R_b= 0.88

R_b per inch = 0.23

R_b @ 14" = 3.28

Test Brick ID#	B2	Temperature (^oC)		
DATE:	2/12/04	Time (Started at 11:31AM)		
TC#	Location	1:49PM	2:40PM	3:50PM
7	Warm Side, Brick	16	16	16
6	Cold side, Brick	11	11	11
5	Warm Side, styrofoam	16	16	16

Brick thickness: 4

Dimensions:

Brick - 4 1/8" x 5 5/16"

Sty - 5 5/16" x 6 13/16"

A_s= 36.2 in^2

A_b= 21.9 in^2

R_b= 1.15

R_b per inch = 0.29

R_b @ 14" = 4.02

Test Brick ID#	B3	Temperature (^oC)		
DATE:	2/12/04	Time (Started at 11:31AM)		
TC#	Location	1:49PM	2:40PM	3:50PM
10	Warm Side, Brick	17	16	16
9	Cold side, Brick	12	12	12
8	Warm Side, styrofoam	16	16	16

Brick thickness: 4.125

Dimensions:

Brick - 5 3/8" x 4 1/8"

Sty - 5 3/8" x 7 1/4"

A_s= 39.0 in^2

A_b= 22.2 in^2

R_b= 0.86

R_b per inch = 0.21

R_b @ 14" = 2.93

Average for B-Series

R_b= 0.96

R_b per inch = 0.24

R_b @ 14" = 3.41

Results for Engineered Fill No. 2 (small aggregate)

Test Brick ID#	C1	Temperature (^0C)		
DATE:	2/10/04	Time (Started at 10:00AM)		
TC#	Location	1:35PM	2:22PM	
4	Warm Side, Brick	17	17	
3	Cold side, Brick	14	13	
2	Warm Side, styrofoam	17	18	

Room air: varies between 18 and 24°C

R_s = 6.08

Brick thickness: 4.375

Dimensions:

Brick - 7 1/8" x 4 1/8"

Sty - 7 1/8" x 6 7/8"

A_s = 49 in^2

A_b = 29.4 in^2

$R_b = R_s[(A_b * T_b)/(A_s * T_s)$

R_b = 0.81

R_b per inch = 0.19

R_b @ 14" = 2.59

Test Brick ID#	C2	Temperature (^0C)		
DATE:	2/10/04	Time (Started at 10:00AM)		
TC#	Location	1:35PM	2:22PM	
7	Warm Side, Brick	15	16	
6	Cold side, Brick	12	11	
5	Warm Side, styrofoam	18	19	

Brick thickness: 4.875

Dimensions:

Brick - 4" x 4 1/4"

Sty - 4 1/4" x 6"

A_s = 25.5 in^2

A_b = 17 in^2

R_b = 1.07

R_b per inch = 0.22

R_b @ 14" = 3.06

Test Brick ID#	C3	Temperature (^0C)		
DATE:	2/10/04	Time (Started at 10:00AM)		
TC#	Location	1:35PM	2:22PM	
10	Warm Side, Brick	16	16	
9	Cold side, Brick	10	9	
8	Warm Side, styrofoam	16	18	

Brick thickness: 4

Dimensions:

Brick - 8 1/2" x 4 1/8"

Sty - 8 1/2" x 7"

A_s = 59.5 in^2

A_b = 35.1 in^2

R_b = 1.39

R_b per inch = 0.35

R_b @ 14" = 4.88

Average Values for C-Series

R_b =	1.09
R_b per inch =	0.25
R_b @ 14" =	3.51