Calibrated Hot Box Tests on Several Wood Floor Insulation Methods

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ABSTRACT

Several options exist for insulating wood floors and the opportunity to incorporate reflective air spaces. Calibrated hot box tests were performed on an 80 ft^2 wood floor sample to measure the performance of reflective air spaces with R19 insulation. The specimen included 1/2 in. plywood subfloor supported on 2 by 10 joists. All tests were performed for heat flow down, which simulates winter conditions.

Tests were first conducted on the uninsulated sample. Insulation (R19) was then added and tests were conducted for four different reflective air space/insulation location combinations. The performance of the air spaces is compared with values from the ASHRAE tables. The reflective air spaces increase the system R-value by 1.0 to 5.

Additional tests were made with floor anomalies of cross braces and missing insulation in combination with reflective air spaces. Results of these tests are discussed in the paper. Potential installation problems are discussed.

INTRODUCTION

Heat transfer across horizontal, unvented reflective air spaces is reduced if the heat flow direction is down. In this configuration, convection is minimized and the heat transfer across the air approaches that of conduction. For houses with floors over crawl spaces, the heat transfer is generally downward from the house to the crawl space. Two methods can be used for insulating these types of floors. One is to install the floor batts directly against the subflooring. Another is to install the floor batts flush with the bottom of the floor joists, thus creating an air space between the top of the batts and the subflooring. If a reflective surface is added to this air space, performance should be improved (Yarbrough 1983). In both installations, the possibility exists to add a reflective surface to the bottom of the batts facing the crawl space. This would reduce the radiative heat transfer across the crawl space and, if the crawl space air were stagnant and unvented (no air infiltration), would create a higher R-value. The critical assumptions to achieve this are an unvented crawl space and a stagnant air layer.

Figure 1 shows the heat transfer mechanisms in an actual crawl space under winter conditions. Heat is supplied to the crawl space from the house and ducts located in the crawl space. Heat transfer occurs between the crawl space air and the ambient air by either conduction through the crawl space walls or by air exchange between the crawl space and the ambient air. Heat is also exchanged between the crawl space air and the ground. In addition, heat is exchanged between the interiors of all of the surfaces surrounding the crawl space by radiation and convection. When no reflective surfaces are present, radiation is the dominant mode of heat transfer and, with the exception of venting, determines the performance of the crawl space. However, if a reflective surface is added to the bottom of the insulation, the performance of a crawl space is determined by the presence of either convection or venting.

The performance of a reflective air space in this type of application depends on maintaining an enclosed air space, in this case the crawl space. If outdoor air leaks into the crawl space, it will cool the crawl space air, and reduce the reflective air space performance.

Even if the air space remains enclosed, it will be impossible to maintain a stagnant air layer. This is due to convection loops driven by the cool sidewalls of the crawl space. Figure 2 shows a possible convective pattern. The convective loops increase the heat transfer between the bottom of the insulation and the other surfaces of the crawl space. While the author is not aware of any data directly pertaining to the convective heat transfer coefficients in a crawl space, a review of the literature for convective heat transfer in an enclosure shows that it is on the order of R3. This limits the performance of a crawl space to approximately R3.

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This analysis is important since it is impossible to simulate in a calibrated hot box (CHB) the same boundary conditions that occur in a crawl space (specifically the crawl space sidewall temperatures or the air exchange between the crawl space and the ambient air). In order to simulate the crawl space air space in a CHB, the thickness between the bottom of the joists and the lower piece of plywood must be limited to a couple of inches. Otherwise, since the CHB tests will simulate a stagnant air space that will not occur in a real crawl space, the CHB tests will overstate the crawl space performance with a reflective surface.

This paper discusses tests that were performed in a CHB to investigate the effect of reflective air spaces on the thermal performance of standard wood floor residential construction. A floor construction utilizing 2 by 10 joists was insulated with R19 fiberglass batt insulation and reflective air spaces. Surface-to-surface R-values were measured and compared with calculated R-values using the ASHRAE parallel path method (ASHRAE 1985).

TEST METHOD

All tests were performed in a calibrated hot box per ASTM C-976. The CHB is 10 ft wide by 8 ft high and was rotated so that the heat flow was down. This simulates winter conditions. All tests but one were conducted at 45°F mean temperature with 70°F on the warm side and 20°F on the cold side. One test was conducted at 75°F mean temperature with a 50°F temperature difference.

In addition to the CHB tests, the thermal properties of all components of the sample were measured using ASTM C 518 at 75°F mean temperature. The thermal resistance of the fiberglass batts was adjusted to 45°F mean temperature. These data were then used in the calculations comparing the measured R-values with calculated R-values.

SAMPLE CONSTRUCTION

The test specimen consists of 1/2 in. plywood subflooring supported by 2 in. by 10 in. joists on 16 in. centers, representing 10% of the total area. Another layer of plywood is installed 1 3/4 in. below the bottom of the 2 in. by 10 in. joists. This represents the bottom of the crawl space with the air space between the bottom of the 2 in.by 10 in. joists and the plywood "simulating" the crawl space air space. The choice of a 1 3/4 in. is arbitrary and may overstate the actual performance for a crawl space under field conditions.

The R19 insulation was installed in two different locations. For one set of tests it was installed flush with the plywood subflooring (Figure 3). For another set, the insulation was installed flush with the bottom of the 2 in. by 10 in. joists (Figure 4). This provides an air space between the top of the insulation and the subflooring. For both installations, an air space exists between the bottom of the insulation and the bottom plywood which represents the crawl space air space.

Foil was installed in appropriate locations to create one or two reflective air spaces. In addition, two tests were run with anomalies; one with gaps present between the batts and one with 2 by 10 blocking installed. The exact details are described under "Tests and Results."

CALCULATIONS

Using the standard ASHRAE parallel path calculation procedure, the calculated R value for each test configuration is compared with the measured R value. Measured properties of the materials used in calculations are given in Table 1 and air space properties from ASHRAE are given in Table 2. The following equation was used for the calculations:

$$R = \frac{f_J}{R_J} + \frac{(1-f_J)}{R_I} \qquad (1)$$

where

$$R_J = R_P + R_W + R_C + R_P \qquad (2)$$

$$R_I = R_P + R_A + R_I + R_C + R_P \qquad (3)$$

TESTS and RESULTS

Eight configurations of R19 insulation/reflective air spaces were tested. Each test is described, the results given, and a brief interpretation made. All R-values are surface-to-surface R-values for the sample and do not include the film coefficients. The results are summarized in Table 3.

Test #1 -- The first test simulated an uninsulated floor. Note that none of the tests includes the effects of carpet or pad. The uninsulated case resulted in a measured R-value of 3.0 and a calculated R-value of 2.9.

Test #2 -- The second test added R19 insulation flush with the bottom of the subfloor. No reflective air spaces were present. At 45°F mean temperature, the measured R-value was 20.0. The calculated R-value was 21.0. At 75°F mean temperature, the measured R-value was 18.2 and the calculated R value was 19.3. The calculations used an effective joist depth of 6.75 in. for this configuration only.

Test #3 -- The R19 insulation was installed flush with the bottom of the 2 in. by 10 in. joists. An air space was present between the top of the insulation and the subfloor. No reflective air spaces were present. The measured and calculated R-values were 20.5 and 22.8, respectively.

Tests 4 through 8 use the same configuration as Test #3 but with reflective air spaces.

Test #4 -- Foil was installed on top of the insulation creating a reflective air space between the insulation and the subflooring. The measured R-value was 21.5. Using the ASHRAE data for reflective air spaces resulted in a calculated R-value of 27.8, which substantially overstates the performance of the assembly.

Test #5 -- Foil was installed on the bottom of the insulation but not on the joists. This simulates a reflective crawl space. The measured R-value was 23.9 while the calculated R-value is 26.2.

Test #6 -- This was the same as Test #5 but with foil covering the bottom of the joists. This increased the R-value of the assembly to 25.5. Calculations resulted in a predicted R-value of 28.0.

Test #7 -- This was the same as Test #6 but with 1 1/2 in. gaps at each end of the batts. The gaps represented 2.8% of the total area. This simulates flaws that might occur from poor installation. The measured R-value was 22.8 while the calculated R-value was 22.1. Note that for the calculations, the sections with no insulation or foil were included in the calculations.

Test #8 -- This was the same as Test #6 but with one 2 by 10 blocking added between each joist space. The blocking represented 1.4% of the total area. The measured and calculated R-values were 25.3 and 27.9, respectively.

DISCUSSION

Adding a reflective surface to R19 insulation increases the R-value by 1 to 5 R-values for the systems reported here. For Tests 1 and 2 at 45°F mean temperature without a reflective surface, the calculated R-values are within 5%. For Test 2 at 75°F mean temperature, the calculated values are within 6%. The difference between calculated and measured values for Test 3 is 11.5%. For Test 4, with a reflective air space bounded by the joists, the calculated R-value overstate the system performance by 30%. This is probably due to the fact that the reflective air space values used in the calculations are for plane parallel air spaces from ASHRAE. This has been observed by Hollingsworth (1983) and Greason (1983) for walls and ceilings. For Tests 5 through 8, which contained a plane, parallel air space, the agreement is within 10%.

CONCLUSIONS

Adding a reflective surface to a floor/crawl space construction increases the system R-values by 1 to 5. The effect of blocking was minimal for the case investigated here. However, poor installation of the insulation/reflective air space, resulting in 2.8% gaps, decreased the system R-value by 2.7 or 11%. Installation anomalies, which resulted in unsealed air spaces, would probably result in poorer field performance than the tests performed here indicate.

The tests with a simulated reflective crawl space assume an unvented and stagnant crawl space. These assumptions may not be valid for real crawl spaces. Until actual crawl space performance is better understood, the results reported here should be used with caution.

NOMENCLATURE

R = Thermal Resistance $(h{\cdot}ft^{2}{\cdot}{}^{\circ}F)/Btu$
f = area fraction for component

Subscripts
J = joist path
I = insulation path
P = plywood
W = 2 by 10 wood joist
C = crawl space
A = air space between insulation and wood subfloor

REFERENCES

ASHRAE. 1985. ASHRAE handbook - 1985 fundamentals, chapter 23, "Design Heat Transmission Coefficients." Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engieers, Inc.

ASTM. 1987. ASTM C 976, "Standard test method for thermal performance of buildings assemblies by means of a calibrated hot box." In Annual Book of ASTM Standards. Philadelphia: Amercian Society for Testing and Materials.

Greason, D.M. 1983. "Calculated versus measured thermal resistances of simulated building walls incorporating airspaces." ASHRAE Transactions, Vol. 89, Part 1.

Hollingsworth, M. 1983. "Experimental determination of the thermal resistance of reflective insulations." ASHRAE Transactions, Vol. 89, Part 1.

Robinson, H.E.; Cosgrove, L.A.; and Powell, F.J. 1957. "Thermal resistance of airspaces and fibrous insulations bounded by reflective surfaces." U.S. Department of Commerce NBS Building Materials and Structures Report 151, November 14.

Yarbrough, D.W. 1983. "Assessment of reflective insulations for residential and commercial applications." ORNL/TM-8891 October.

TABLE 1

Properties of Materials and Air Spaces for Calculations

Material	Thermal Property, 75°F Mean Temperature
Plywood	R=0.71 hr ft^2°F/Btu
Insulation	R=20.0 hr ft^2°F/Btu at 45°F mean temperature
	R=17.9 hr ft^2°F/Btu at 75°F mean temperature
2 by 10's	R=13.8 hr ft^2°F/Btu

TABLE 2

Thermal Resistance of Air Spaces for Calculations

	Thermal Resistance		
Test #	Airspace #A	Airspace #B	Temperature Mean/Diff
1	---	1.22	50/30
2	---	1.22	50/30
3	1.24	1.15	50/10
4	7.58	1.15	50/10
5	1.24	4.50	50/10
6	1.24	6.32	50/10
7	1.24	6.32	50/10
8	1.24	6.32	50/10

Notes:
1. All values are from the ASHRAE Handbook of Fundamentals at the mean temperature and temperature difference indicated.
2. Values for reflective air spaces were interpolated from the ASHRAE table.
3. Reflective air space values based on E(as defined in the table) of 0.05. Non-reflective air spaces based on E=0.82.

Table 3.

R Values for Floor Insulation Options Tested

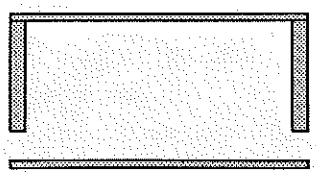
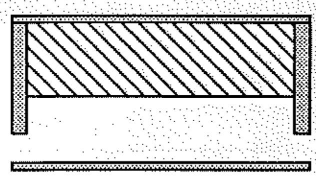
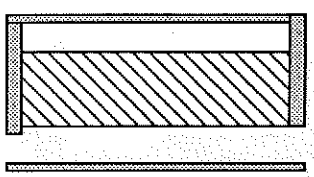
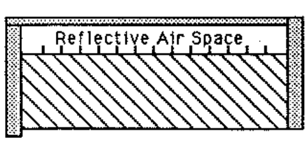
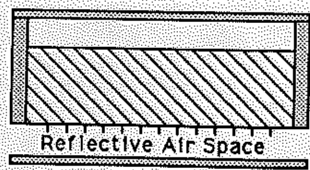
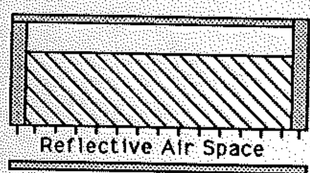
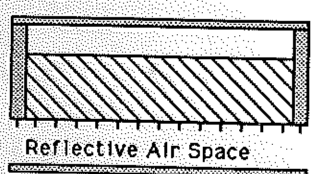
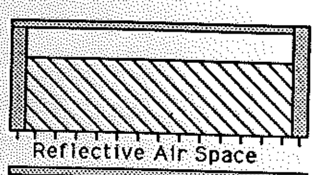
Test Number	Configuration	R Values Measured	R Values Calculated
Test 1 	No Insulation	3.0	2.9
Test 2 	R19 Insulation No Foil	20.0	21.0
Test 3 	R19 Insulation No Foil	20.5	22.8
Test 4 	R19 Insulation One Reflective Air Space	21.5	27.8

Table 3. Continued

Test Number	Configuration	R Values Measured	R Values Calculated
Test 5 	R19 Insulation One Reflective Air Space, No Foil on Bottom of Joists	23.9	26.2
Test 6 	Same as Test 5 but with Foil on Bottom of Joists	25.5	28.0
Test 7 	Same as Test 6 with 1 1/2" Gaps at the ends of each batt.	22.8	22.1
Test 8 	Same as Test 6 with 2x10 blocking between each joist	25.3	27.9

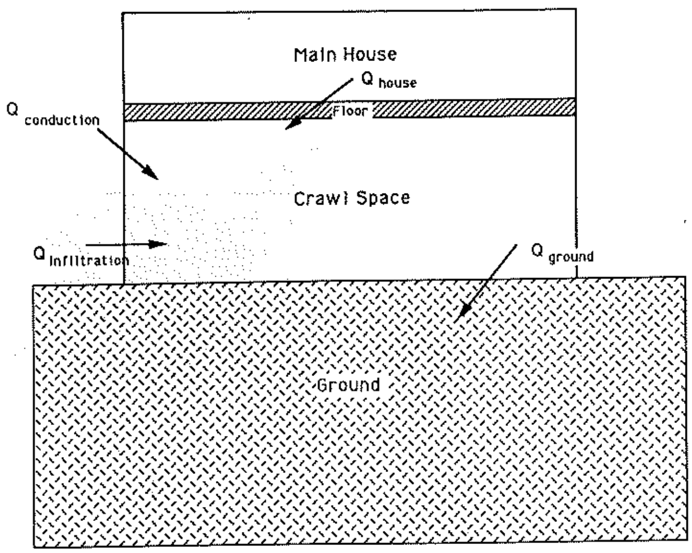


Figure 1. Heat transfer mechanisms for a crawl space

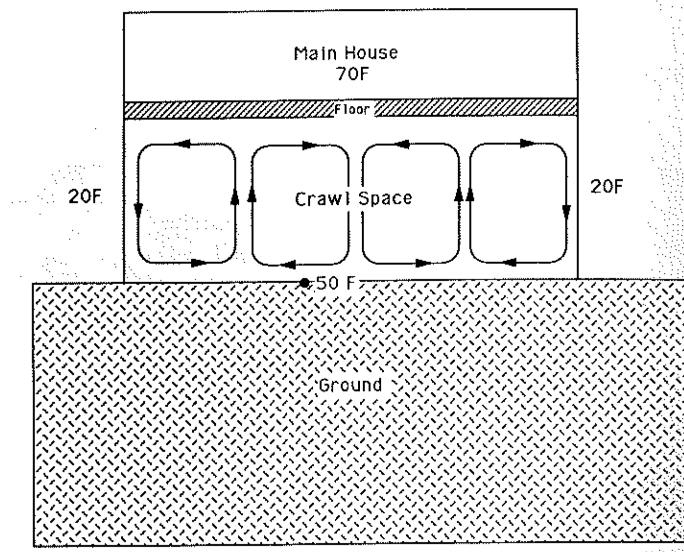


Figure 2. Possible convection cells in a crawl space

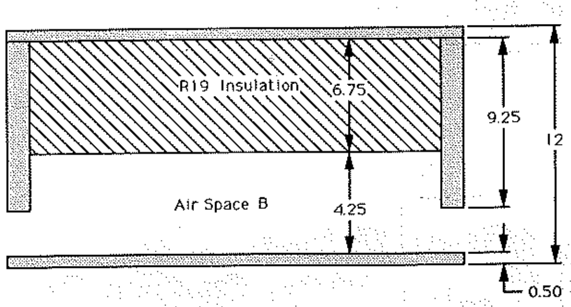


Figure 3. Arrangement for tests 1 and 2

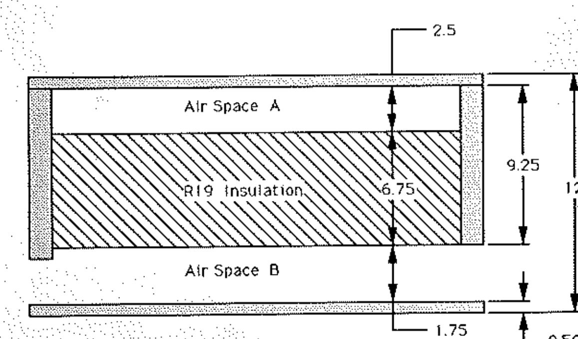


Figure 4. Arrangement for tests 3 to 8