Technical Report

R-values for Hybrid Insulation Assembly for Ceiling Above Garage

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Background

R-values for an advanced hybrid insulation assembly designed for the space below conditioned living space and above unconditioned garage space have been calculated using well-established correlations.1,2 The hybrid assembly includes a layer of conventional insulation and HY-Fi manufactured by Fi-Foil Company.3 HY-Fi is installed to form three enclosed reflective air spaces as shown in Figure 1. The total thermal resistance (R-value) of the hybrid insulation assembly is the sum of the R-value for the conventional insulation and the R-value for the reflective insulation. The R-value for the reflective insulation consisting of three enclosed reflective air spaces depends on the heat-flow direction which is controlled by the season. Summertime conditions result in heat-flow up from the garage to the conditioned space while winter conditions result in heat-flow down from the conditioned space to the garage. The difference between winter and summer performance is the result of free convection in the enclosed reflective air space. The free-convection component is included in the calculations that have been made for the report.

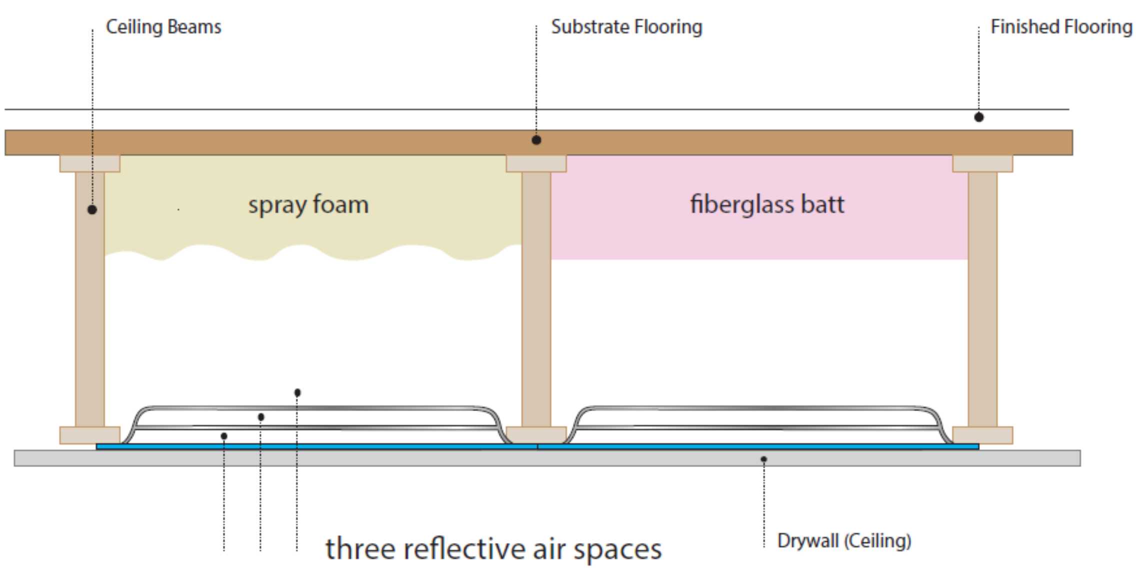

Figure 1. Diagram of Region Containing the Hybrid Insulation Assembly

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Procedure for R-value Calculation

The thermal resistances of the air spaces shown in Figure 1 depend on several factors of which is the temperature difference across the air space. The temperature difference across an individual element depends on the total temperature difference and the R-values of all of the components. As a result, an iterative procedure is required as described in the literature.[1] The iteration involves the selection of a set of R-values for the reflective air spaces. The selected R-values are then used to calculate temperature differences. New R-values are calculated using the temperature differences. These R-values are compared with the initially selected R-values. If there are differences between the selected R-values and calculated R-values, then the calculated R–values become the selected R-value and the process is repeated until the difference is eliminated. Table 1 contains the primary input data used in the calculations.

Table 1. Input for Hybrid R-value Calculation

Item	Value
Temperature at upper surface of region	70°F
Temperature at lower surface of region	100°F (summer) 40°F (winter)
Emittance for reflective surfaces	0.034
non-reflective surfaces	0.90
Total space for the hybrid assembly	12.0 (inches)
R-value for conventional component	selected ($ft^2 \cdot h \cdot °F/Btu$)
HY-Fi thickness	1.0 (inch)
Enclosed reflective air space thickness	11.0 (thickness of conventional insulation)

R-values for the Hybrids listed in Table 2 have been calculated for heat-flow up and heat- flow down. The calculated R-values are compared with the requirement R 22 to identify code-compliant combinations.

Table 2. Assemblies Evaluated

Assembly Number	Description
1	R 7 fiberglass batt – thickness 2.25 inches
2	R 11 fiberglass batt – thickess 3.5 inches
3	R 13 fiberglass batt – thickess 3.5 inches
4	R 7.6 open-cell cellular plastic foam – thickness 2.0 inches
5	R 11.4 open-cell cellular plastic foam – thickness 3.0 inches
6	R 15.2 open-cell cellular plastic foam – thickness 4.0 inches

Calculated R-values

Table 3 contains the calculated thermal resistances for the six assemblies described in Table 2.

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Table 3. Calculated R-values (ft^2·h·°F/Btu)

Assembly Number	R-value for Heat Flow Up	R-value for Heat Flow Down
1	15.1	18.1
2	19.4	23.4
3	21.5	25.5
4	15.8	19.7
5	19.8	23.8
6	23.7	27.9

The results contained in Table 3 are shown in Figure 2 with a horizontal line at R 22. The designation R* in Table 3 identifies thermal resistivity or R-per- inch of thickness (ft^2·h·°F/Btu·in.) of the conventional insulation component. The calculated R-values form two distinct groups: heat-flow up and heat-flow down. The line through the two groups is a function of the R for the conventional components and independent of the type of conventional insulation. This is due in large to the limited range of R*-values considered: 3.14 to 3.80. Figure 3 shows the data viewed as two sets with a statistically significant least-square characterization of each set.

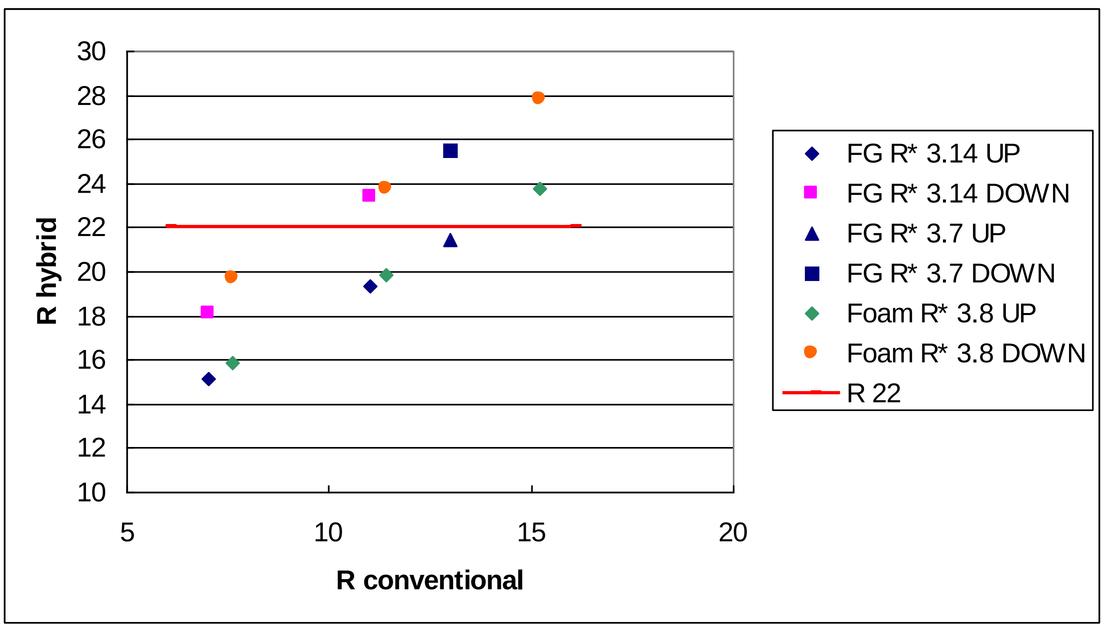

Figure 2. Calculated R-values for Six Hybrid Insulation Combinations

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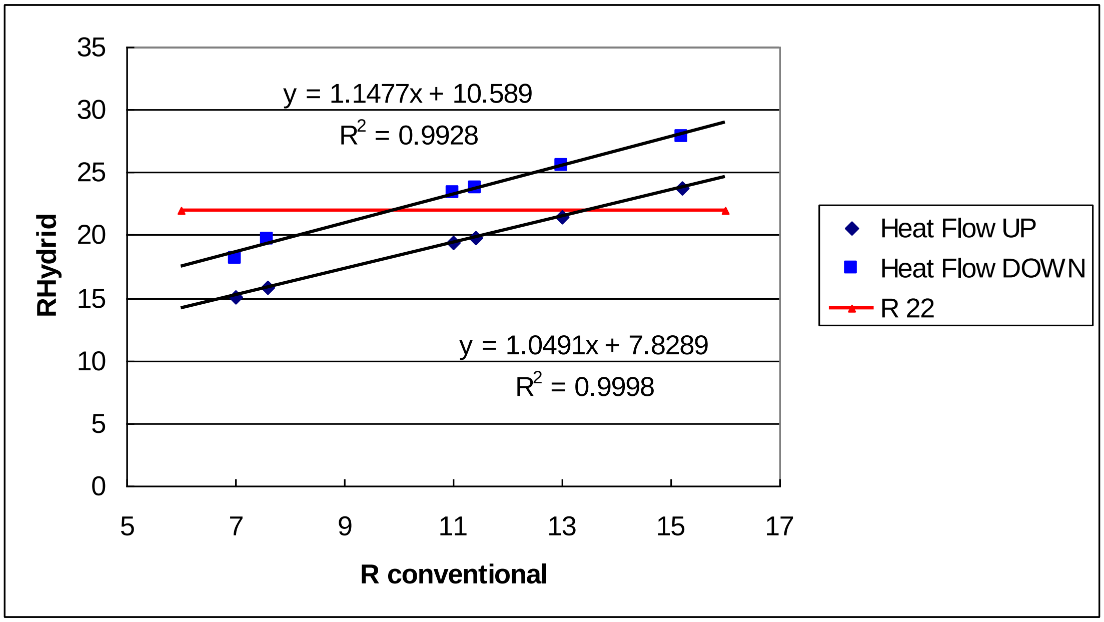

Figure 3. Calculated R-values Grouped for Heat-Flow Up and Heat-Flow Down

The equation for Hybrid R-values as a function of the conventional contribution to the R-value of the hybrid insulation for heat flow up is given by Equation 1 while the R-values for heat flow down are given by Equation 2. The equations are for $3 < R^*_{CONVENTIONAL} < 4$.

Heat-Flow Up

$$R_{HYBRID} = 7.8289 + 1.0491 \cdot R_{CONVENTIONAL} \quad (1)$$

Heat-Flow Down

$$R_{HYBRID} = 10.589 + 1.1477 \cdot R_{CONVENTIONAL} \quad (2)$$

Equations 1 or 2 can be solved for the value of $R_{CONVENTIONAL}$ needed to achieve R_{HYBRID} of 22. The results are $R_{CONVENTIONAL}$ =10 for heat flow-down and $R_{CONVENTIONAL}$ =13.5 for heat flow-up. Equation (3) shows the relationship between $R_{CONVENTIONAL}$ and thickness $t_{CONVENTIONAL}$ for conventional insulation having R-per-inch of $R^*_{CONVENTIONAL}$.

$$t_{CONVENTIONAL} = R_{CONVENTIONAL}/R^*_{CONVENTIONAL} \quad (3)$$

If cellular plastic foam insulation with R*=3.8 is used to achieve R_{HYBRID} 22 for heat flow up, then $t_{CONVENTIONAL}$ is 3.55 inches. Table 4 contains R_{HYBRID} for various thicknesses (t_{FOAM}) of R* 3.8 foam for heat-flow up and heat-flow down along with "rounded R-values".

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Table 4. R_{HYBRID} for Various Thicknesses of R* 3.8 Foam and HY-Fi Reflective Assembly

T_{foam} (in.)	R_{HYBRID} ($ft^2 \cdot h \cdot °F/Btu$)			
	Heat Flow Up	(Rounded)	Heat Flow Down	(Rounded)
2.5	17.80	18	21.49	21
3.0	19.79	20	23.67	24
3.5	21.78	22	25.85	26
4.0	23.78	24	28.03	28
4.5	25.77	26	30.21	30
5.0	27.76	28	32.40	32

Summary

R-value calculations have been completed for a range of insulation combinations. The results can be correlated against the R-value of the conventional insulation component. The HY-Fi component R-value is added to the conventional component to arrive at R_{HYBRID} . This permits selection of components to achieve a specific target hybrid insulation R-value and information needed to evaluate the cost associated with various combinations of HY-Fi and fiberglass or open-cell foam insulation.

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December 2, 2014

References

[1] Desjarlais, A.O. and David W. Yarbrough, "Prediction of the Thermal Performance of Single and Multi-Airspace Reflective Insulation Materials", *Insulation Materials: Testing and Applications*, 2nd Volume, ASTM STP 1116, R.S. Graves and D.C. Wysocki, Eds., American Society for Testing and Materials (1991) pp. 24-43.

[2] Glicksman, Leon R., "Two-Dimensional Heat Transfer Effects on Vacuum and Reflective Insulations", *Journal of Thermal Insulation* 14 (1991) pp.281-294.

[3] *Fi-Foil Company*, 612 Bridgers Ave W., Auburndale, FL 33823