Systems Evaluation:
Effects of a Radiant Barrier on Roof Cavity Temperature
ReVISION Home, Las Vegas, NV

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1. Introduction

The ReVision Las Vegas house is a research and training platform intended to demonstrate cost-effective, market-ready methods for achieving near-net-zero energy consumption in deep-energy retrofit projects. Significant building envelope upgrades were combined with efficient mechanical systems and renewable energy systems. The thermal envelope improvements (walls, roof, windows, etc.) were performed primarily from the exterior, leaving the interior building finishes largely intact. Added to the deep energy-efficiency measures were significant levels of renewable energy in the form of a solar PV system and a solar-thermal hot-water system.

Since this was intended to be a demonstration project, there were several innovative products installed, one of which was a radiant barrier in combination with a reflective, vented, standing-seam, metal roof. This paper focuses on the effects of that radiant barrier on the cooling and heating loads of the home as compared to the same assembly without the radiant barrier.

2. Design of Roof Assembly

The roof insulation retrofit for this home presented some unique challenges and opportunities. Before renovation, the cooling load from the roof assembly was immense with poorly installed insulation, plenty of air-leakage paths (over a dozen non-sealed can-lights), and ineffective venting. The insulation was less effective than the wood studs as indicated in infrared images taken during the initial audit (see Figure 1). Because this is a one story home, the cooling and heating loads associated with the roof are a substantial portion of the overall loads. Retrofitting this assembly was one of the highest priorities if the net zero energy goal was to be achieved.

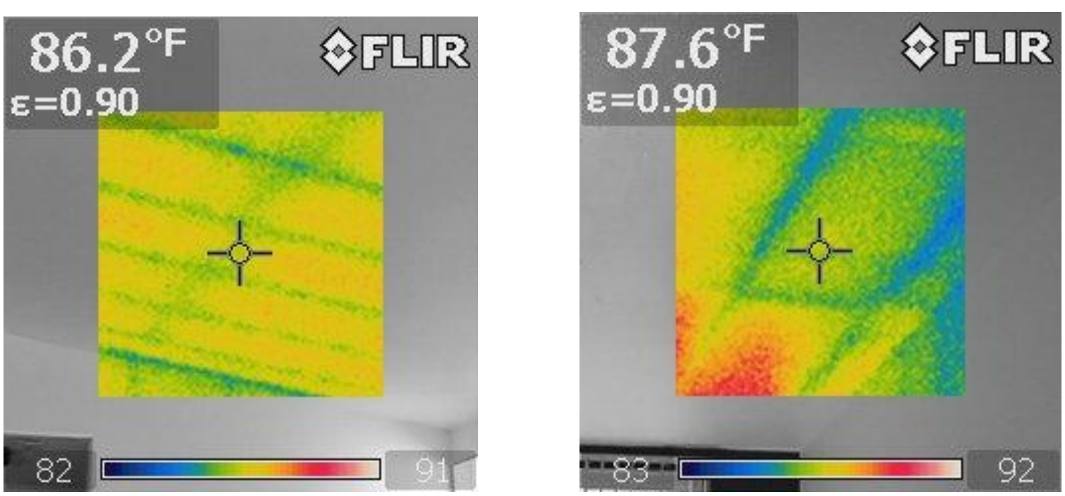

Figure 1. Interior infrared images of the roof before retrofit work. Exterior temperature was approximately 110°F.

Gutting the interior or drilling holes into the roof bays to insulate from inside the conditions space was undesirable, because another goal of this project was to demonstrate how a deep energy retrofit could be conducted without the occupants being displaced during the construction process. Since the roof needed replacement anyway, it was decided to blow foam insulation into the roof cavity from the outside, once the sheathing was removed.

In addition to 8.5" inches of closed cell foam (approximately R-58), the design team decided to install a reflective or "cool" metal roof. In a hot-dry climate like Las Vegas, with its extreme summer heat and solar radiation levels near the highest in the nation, roofs are exposed to high levels of ultra violet radiation (UV) shortening life spans. These reflective metal roofs are more durable than asphalt shingles and rubberized coatings and keep the whole assembly cooler due to their reflective coatings. The product specified had a factory applied paint coating with a solar reflectance (SR) of over 0.46, and a solar Reflectance Index (SRI) of 53 or higher. When installed with a vent space directly underneath, they have the potential to keep the roof even cooler.

In addition to deterioration of roofing and increased cooling loads, it should be noted that the performance of many types of insulation is negatively affected when exposed to extreme hot or cold temperatures. Figure 2 demonstrates how polyurethane insulation is affected by temperature.

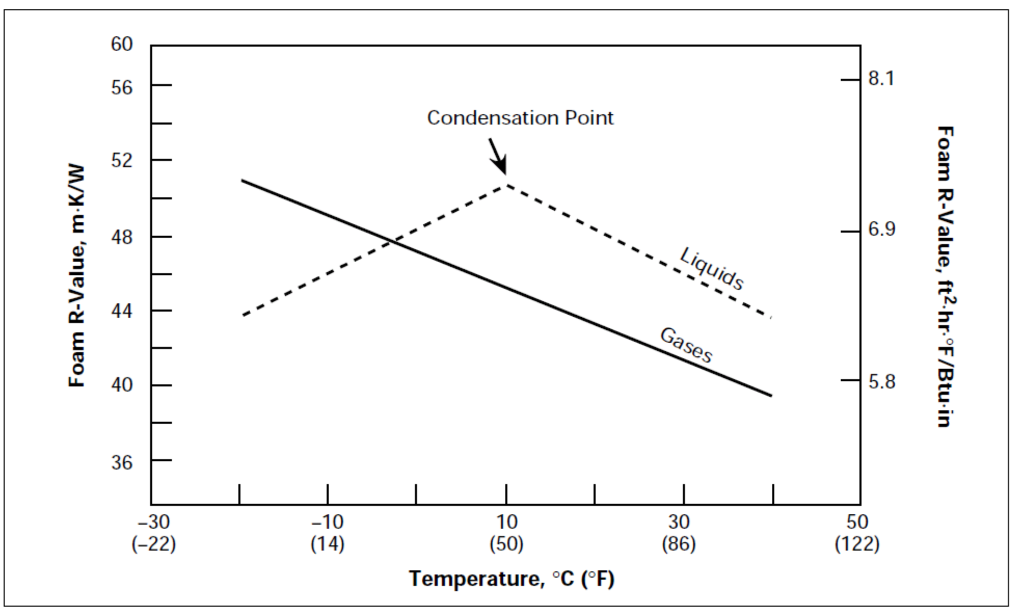

Figure 2. Foam Insulation Value vs. Temperature for Liquid and Gaseous Blowing Agents[1]

For liquid blowing agents, performance is optimum at approximately 50°F and degrades as the temperature rises or falls. For foam applied with a gas blowing agent, the colder the temperature, the better the performance. This was just one more reason to keep the roof cavity as cool as possible.

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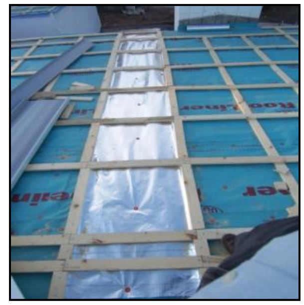
[1] DupontFormacel – "Temperature Effect on the Insulation Value of Polyurethane Foams", Technical Information ABA-14.

Although the roof assembly decided upon was extremely efficient, CARB was interested in evaluating the performance if a radiant barrier was also installed on top of the roof sheathing under the metal roof. Would this have any substantial affect on the overall performance of the roof assembly, especially considering it was already so efficient? To answer this question, one bay of the roof was covered with a radiant barrier before the metal roof was installed. Temperature sensors were placed inside the bay on top of the foam insulation as well as in a bay without the radiant barrier. The test bays were isolated from the remainder of the roof to prevent cross-communication of air from the rest of the roof into the test bays.



Four temperature and relative humidity sensors were installed on top of the foam insulation below the roof decking in each of the bays. The data logger recorded temperature and relative humidity data at 15 minute intervals.

Figure 3. Thermocouples installed in each test bay on top of the closed cell foam, beneath the roof deck.

3. Results & Discussion

Comparison of the data for each bay gives an insight into the potential additional heat rejection and the potential improvement in insulation performance using this strategy. Results of the monitoring from July through October are displayed in Table 1 and Table 2. The temperatures for each bay listed in the tables are based on the average of the four temperature sensors for each 15 minute interval.

Table 1. Maximum Temperatures Recorded – Ambient, Standard Bay, Bay w/ Radiant Barrier

	Maximum Temperatures Recorded (°F)		
	T_{out}	$T_{Standard}$	$T_{Radiant}$
July	116.68	141.8	129.0
August	112.09	136.2	123.9
September	110.04	129.3	116.3
October	102.03	116.0	103.7
November	91.41	96.7	87.6

Table 2. Minimum Temperatures Recorded – Ambient, Standard Bay, Bay w/ Radiant Barrier

	Minimum Temperatures Recorded (°F)		
	T_{out}	$T_{Standard}$	$T_{Radiant}$
July	83.96	73.56	74.86
August	66.41	51.36	53.52
September	63.63	48.67	50.75
October	46.74	32.58	34.76
November	41.26	27.45	30.28

Figure 4 and Figure 5 display the average temperatures for each bay over a one week period in July and one week in November. While the temperatures gradually decrease each month as the exterior temperatures drop, the basic profile of the data remains the same. The following observations apply to all months monitored:

- The air space on top of the insulation and under the roof sheathing in the bay without the radiant barrier is consistently hotter at peak times of the day.
- Peak temperatures in the standard bay occur a couple of hours before the peaks in the bay with the radiant barrier.
- The bay without the radiant barrier cools off quicker and also consistently shows lower minimum cavity temperatures.
- Although it comes within a couple of degrees, the bay with the radiant barrier never gets as cool as the standard bay.

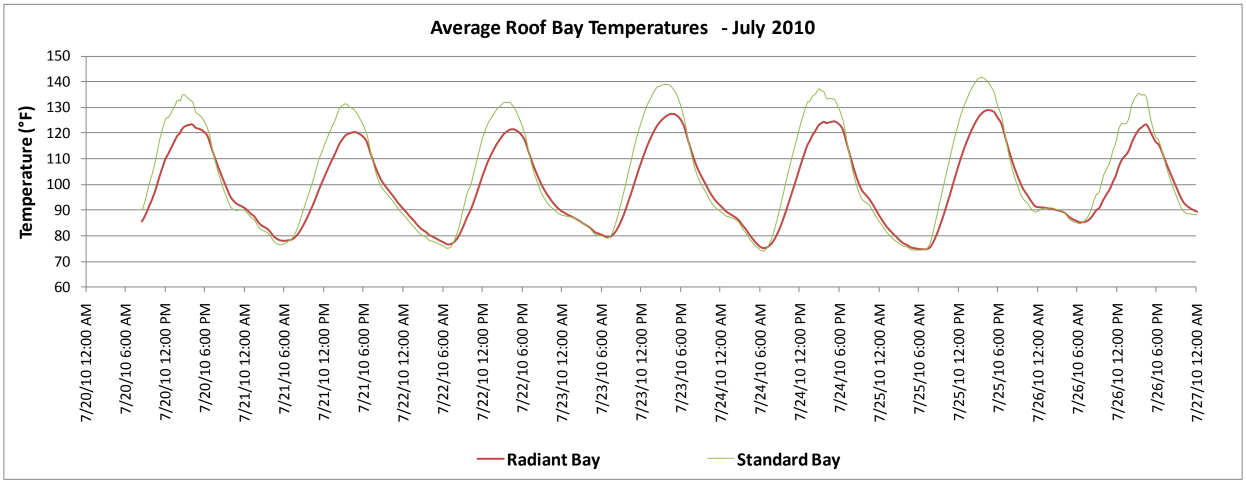


Figure 4. Average temperatures in each bay for one week in July 2010.

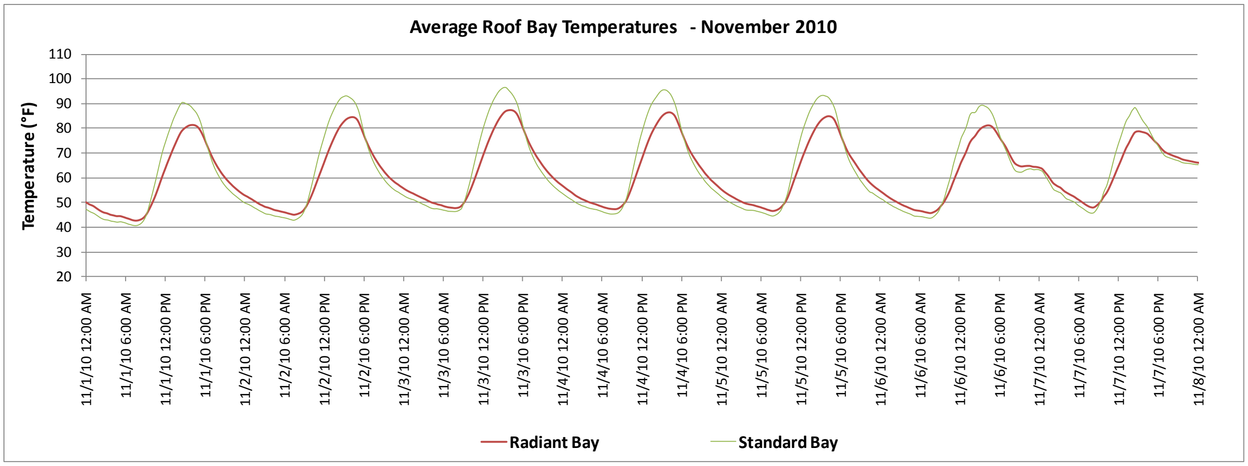


Figure 5. Average temperatures in each bay for one week in November 2010.

Figure 6 and Figure 7 display the calculated heat gain and heat loss for each bay based on the insulation R-value, the recorded temperature in the bay and an assumed interior temperature. The interior temperatures are assumed to be 78°F during the cooling season and 70°F during the heating season.

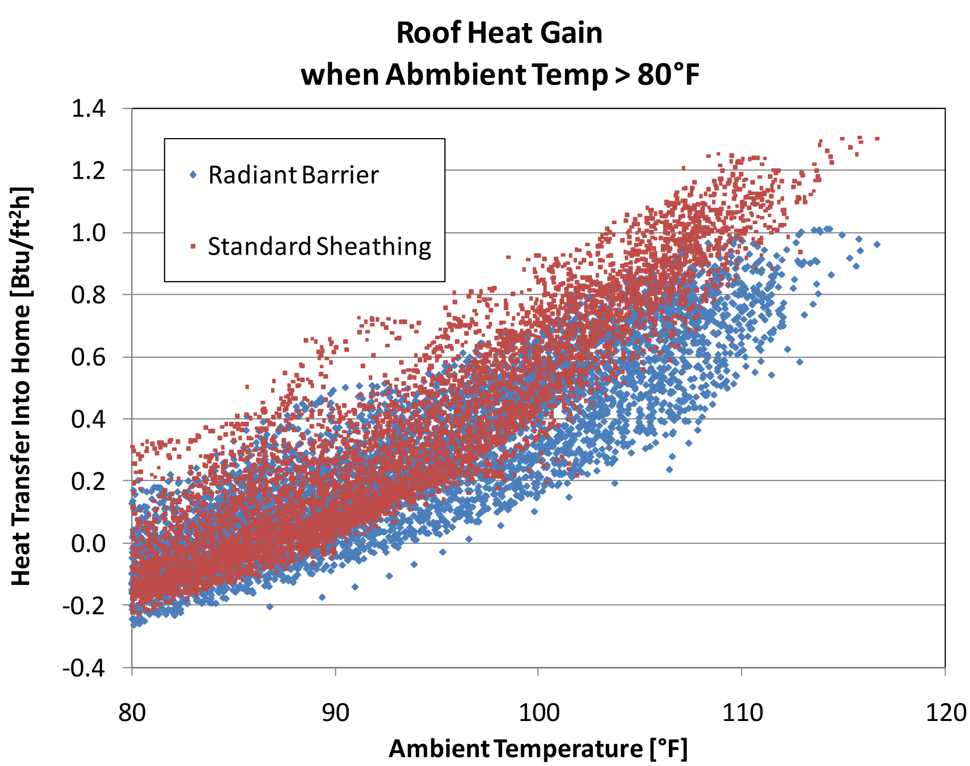


Figure 6. Heat gain into home through each bay monitored (Btu/ft^2 h).

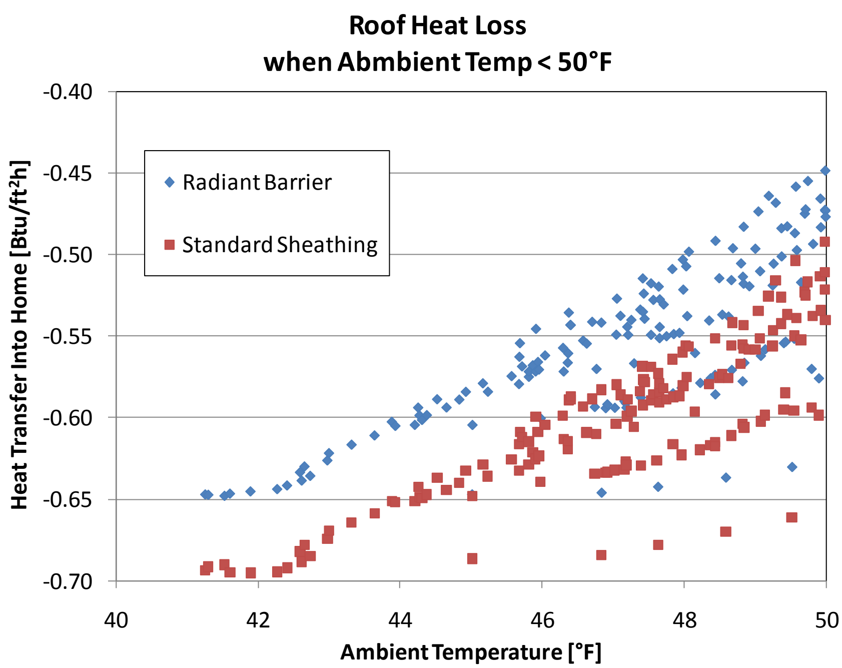


Figure 7. Heat loss from each bay monitored (Btu/ft^2 h).

Although there is far less data for the heating season vs. the cooling season, these graphs show that application of the radiant barrier results in a decrease in both the cooling and heating loads in this climate. The bin temperature analysis summarized in Table 3 and Table 4 confirms these reductions in energy use due to the presence of the radiant barrier.

Table 3. Heating Season Bin Temperature Analysis for Recorded Outdoor Ambient Temperatures

Bin Range	Hours Measured	Average Heat Loss from Roof [Btu/ft^{2}h]	
		Radiant Barrier	Standard Sheathing
40-45°F	6.5	0.62	0.67
45-50°F	31	0.54	0.59

Table 4. Cooling Season Bin Temperature Analysis for Recorded Outdoor Ambient Temperatures

Bin Range	Hours Measured	Average Heat Gain from Roof [Btu/ft^{2}h]	
		Radiant Barrier	Standard Sheathing
80-85°F	297	-0.04	-0.03
85-90°F	314	0.08	0.11
90-95°F	276	0.19	0.25
95-100°F	248	0.35	0.47
100-105°F	217	0.52	0.70
105-110°F	167	0.68	0.94
>110°F	35	0.80	1.11

As mentioned earlier, the performance of spray foam insulation is affected by the temperature to which it is exposed, but when analyzed the increase in performance for the insulation in the radiant bay as compared to the standard bay was less than 1%. Based on this study, the real benefit of the radiant barrier comes from a reduction of temperature differential across the building cavity during both summer and winter conditions – ultimately resulting in smaller cooling and heating loads. This simple analysis assumes that when the outdoor temperature decreases below 80 °F there is no cooling, and when it increases above 50°F there is no heating.

On average, there is approximately a 27% reduction in the annual heat gain through the roof during the summer and an 8% reduction in the heat loss through the roof during the winter. Obviously, total savings depends on the efficiency of the home for which this technology would be applied. For instance, the savings during the cooling season due to installing a radiant barrier on the entire roof of this home as retrofitted would be 27% of 127 kWh/yr or $7/yr, whereas if the radiant barrier were applied to the home prior to retrofits, the predicted savings would be 27% of 640 kWh/yr or $34/yr. At a cost of $0.15/ft^2 for the material, it would have cost less than $300 to cover the entire roof. This yields a pay back of 43 years for the retrofitted home and 9 years for the home before retrofits based on the savings from cooling alone.

Finally, another benefit of using the radiant barrier is shifting of the peak cooling load. Based on the data collected it is anticipated that the peak load will be shifted by approximately 2 hours from about 3 pm to 5 pm. This technology could possibly be used as a demand side management tool by utilities to shift peak loads and avoid the need for increasing capacity at what are currently peak times.

4. Conclusions

The use of a radiant barrier in conjunction with a cool, metal roof may prove to be a cost-effective retrofit in Nevada depending on the overall efficiency of the home. The benefit is mainly a result of decreased roof cavity temperatures in the cooling season and an increased temperature in the heating season. Other benefits of this technology may include peak load shifting and increases in lifetime of materials due to exposure of less extreme temperatures.