Alternative Assembly Materials for Residential Cool Roofs

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Abstract

This study explores the energy saving potential of roofing assemblies made from alternative materials and tests their ability to cool residential attics. In this engineering study, asphalt-shingle and metal roof-assembles were re-engineered; the researchers were integrating alternative materials in the roof design to reduce thermal conductivity. These designs were initially tested for efficiency on small models versus traditionally-shingled roof assembly scaled models. Testing data on small-scale models show the temperature reduction, expressed as a percent, using the following alternative materials: Recycled Cans (Green Assembly) at 12% reduction, Heavy-Duty Foil 4%, Enerflex 4%, and Rmax R-3.2 at 21%. These four assemblies were then tested on large-scale models and the testing results surprisingly showed Enerflex having the highest temperature reduction at 6%. A modified metal roof assembly was considered in the study and it had only a 1% temperature reduction against traditionally-shingled roof assemblies, and almost 3% reduction against traditional metal roof-assemblies. The efficient alternatives should be especially useful to roofing contractors, thermal engineers and residential architects.

Keywords

Cool roof, modified roof assembly, scrap aluminum, aluminum foil

Introduction

Residential home attic temperatures can rise higher than 30 ^{o}F from ambient air temperatures. Roofs become heat exchangers collecting solar energy from the sun and transferring that energy to the attic. Attics with poor ventilation quickly rise in temperature and then slowly dissipate the heat. Higher attic temperatures lead to higher cooling costs and lower roof service life (see guidelines by Urban and Roth[1]). Roofing assemblies and materials can be modified to lower attic temperatures. Figure 1 illustrates traditional roofing assemblies which are made of metal or shingle roof with a water barrier between the plywood and the roofing exterior. Black asphalt shingle is the most common type of roofing material used for residential roofing (the asphalt shingles popularity in the residential market is mainly due to aesthetics and not functionality).

Roofs that are designed for functionality and stay cooler than traditional roofs are known as “Cool Roofs”. In order to be classified as a “Cool Roof” the roof must meet specification set by non-profit organization named Cool Roof Rating Council[2]. The specifications refer to a roofing material’s reflectance and emittance. Reflectance is the amount of solar energy reflected back into the atmosphere by a roofing material. Emittance is the energy absorbed by the roofing material being emitted back. Reflectance and emittance is measured from a value of 0 to 1. Higher reflectance or emittance values correspond to cooler roofs. The reflectance value for a cool roof is greater than 0.25 and the emittance is greater than 0.75 (Kirn[3]). Shingle roofs usually have low reflectance and high emittance values. Metal roofs are the opposite of shingle roof and have high reflectance and low emittance values. Neither the traditional shingle nor metal roof assemblies meet the requirement for a "cool roof" status. Some metal roofs meet the reflectance value for cool roof but not the emittance value.

The benefits of cool roofs include reduced loads on air conditioning systems, longer roof service life and reduction of the "Urban Heat Island Effect" (UHI). Heat from hot attics leak into climate controlled rooms. The addition heat requires air condition units to use more electricity in order to remove the addition heat. Higher emittance and reflectance properties of cool roofs allow them to have lower surface temperatures which reduce material breakdown due to high temperatures. The combined lower surface temperatures of multiple roofs in a community lower ambient air temperatures which reduces the "Urban Heat Island Effect" (UHIE). C. Y. Jim[4] suggested that with intensification of global warming superimposed on UHIE, cities are literally heating up, pleading for sustainable and cost-effective climate-adaptation solutions. K.S. Ong[5] tested several laboratory sized units of passive roof designs, side-by-side, under outdoor conditions to obtain temperature data of the roof, attic and ceiling in order to compare their performances and effect on temperature reduction. Placing insulation under roof was preferred against placing insulation above ceiling level.

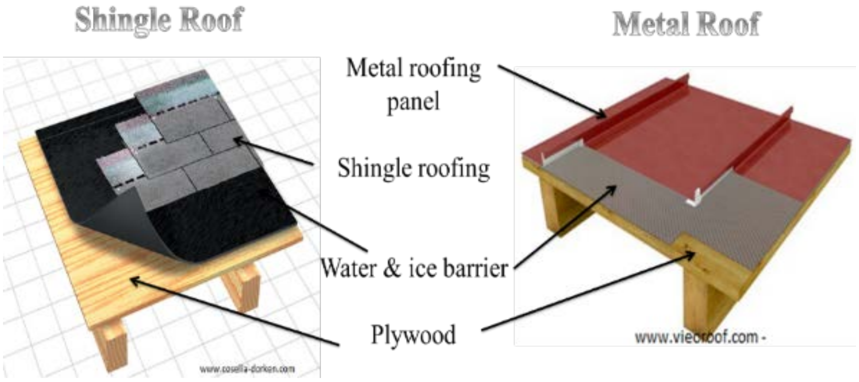

Figure 1: Traditional roof assembly

Currently in the market there are commercial available products that reduce roof and attic temperatures. The products are called "Thermal barriers" because of they create barriers between the roof and the atmosphere. The thermal barriers can be broken down into three categories. The first category is the radiant barrier which increases the reflectance value of a roof. The second category is the insulation barrier. The insulation barriers insulate the attic from heat being emitted by a hot roof. The third category is a combination of radiant and insulated barriers.

Literature Review

A team of researchers in California looked into insulation requirements needed to equal "cool roof" criteria after the state passed energy efficiency standards for residential and commercial buildings (see Bianchi, et.al.[6] study in the reference section). This standard prescribed nonresidential buildings to be cool roofs or meet cool roof standards. The research team looked at the possible substitution of insulation from solar energy versus the reflecting of solar energy. In this research they found that cool roofs reduce the demand on air condition units in the summer time but they increase the load on heating units. The team measured the reduced cooling load (Btu/ft^2) during the summer and the increased heating load (Btu/ft^2) in the winter. Cool roofs reflect and emit the solar energy not only during the summer time but also the winter time. The benefit of having addition solar energy added to a home during winter is lost. Equivalent insulation is measured in R-value. R-value is the thermal resistance of a certain material. Higher the thermal resistance is equivalent with a higher the R-value. With 0.2 solar reflectance, 0.9 thermal emittance and R-52 insulation the roof assembly was able to reduce heating loads by 68% and cooling loads as much as 48%. Insulation can reduce the loss and gain of heat through the roof but surface temperature of the roofing materials remain high. High surface temperatures will reduce the service life of the roof and the urban heat island effect.

The Cool Roof Rating Council[2] is a non-profit organization that provides information promoting the use of cool roofs. Information provided by the council goes from brief definitions of reflectance and emittance of cool roofs to detailed testing needed to determine the reflectance and emittance of roof by ASTM. Examples of testing: ASTM E1918 -Standard Test Method for Measuring Solar Reflectance of Horizontal and Low-Sloped Surfaces in the Field; ASTM C1371 -Standard Test Method for Determination of Emittance of Materials Near Room Temperature Using Portable Emissometers. Figure 2 is the brief illustration of reflectance and emittance provided by the CRRC to educate the public (Cool Roof Rating Council[2]).

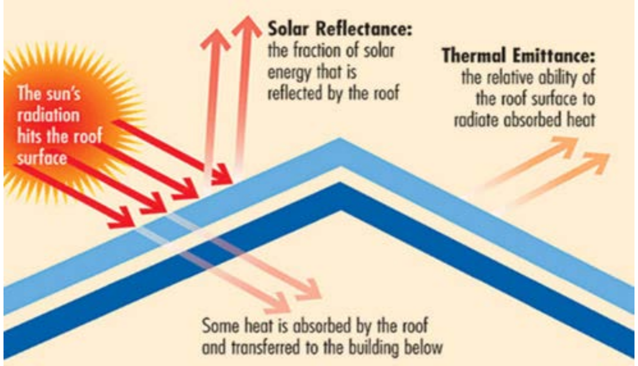

Figure 2: CRRC reflectance and emittance

Scope of Study and Deliverables

Cool roof assemblies will be developed using alternative materials. Alternative materials are considered in this study as materials not being sold as commercial thermal barriers for roofs. Three alternative materials were tested, they include: Recycled aluminum cans, Heavy duty aluminum foil, and Styrofoam insulation. The alternative materials were added to a traditional shingle roof assembly. The addition of alternative materials created a “modification” to the original assembly and the new assembly is called the “Modified roof assembly” as shown in Figure 3.

The recycled aluminum cans and aluminum foil are being used because radiant barriers are made of aluminum alloy. Hypothetically the aluminum in the alternative materials will reflect the infrared energy emitted by the sun back out into the atmosphere. The recycled cans assembly was called in this study the “Green Assembly” because it is environmentally friendly by using scrap metal pieces. The Styrofoam insulation is being tested because its great insulating properties. Black asphalt shingles and untreated metal roofs have high surface temperatures when exposed to direct solar energy. The Styrofoam’s intent is to thermally insulate the plywood from the hot roofing.

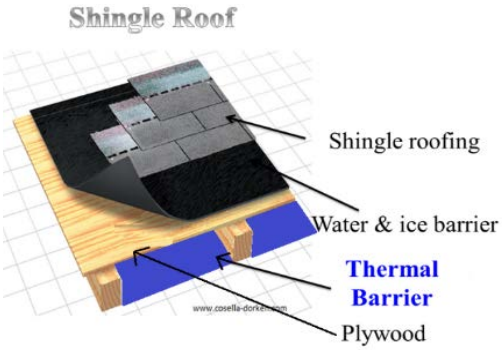

Figure 3: Modified roof assembly

In addition, a traditional metal roofing panel was hammered to create indentations to its flat surface (considered an actual 3D Metal Assembly). The indentations were created with intention to reduce the area of the metal panel in contact with plywood thus reducing the thermal conductivity of the panel. The indentations will also create space for ventilation between the plywood and the metal panel. Greater air ventilation will consequently increase the metal panel’s thermal emittance.

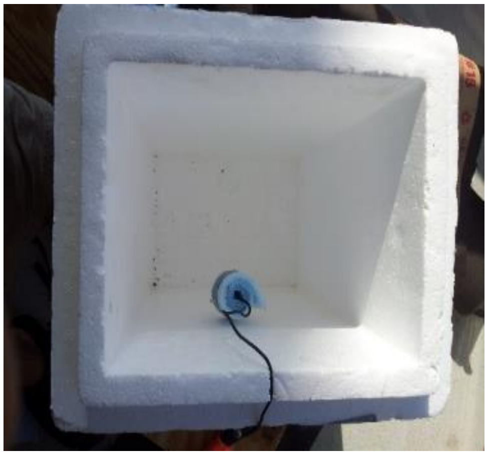

Figure 4: Foam cooler model

Figure 5: Scale model roofs

Thermal barrier assemblies are first tested on foam coolers shown in Figure 4. The insulated cooler retains heat better than model roofs. The greater energy retention will reduce the total time needed to test each assembly to one hour. Therefore, foam cooler testing allows for ineffective materials to be ruled out with waste of additional time and materials that would otherwise be spent on testing on larger models. The foam cooler assemblies' dimensions are 1ft. by 1ft. It was placed on the opening of the coolers to seal the space inside. If the modified roof assemblies test as well as the commercially available products then the assemblies are tested on a scale model roof shown in Figure 5. Both the foam and scale models will have a "Control" type assembly, the traditional assembly. The "Control" traditional assembly is used to compare the results of the modified roof assemblies and the commercial products existing on the current market. All assemblies were tested in the lab with infrared heat lamps substituting for the sun.

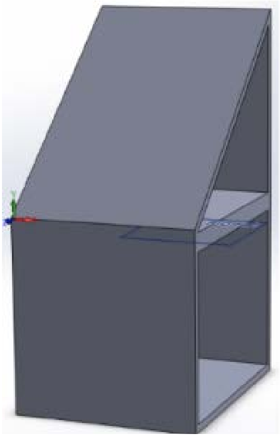

Figure 6: Solidworks model

The model roof assemblies were tested for five hours to imitate exposer to the sun. Foam model assemblies were test of one hour with data point take every 20 minutes. To increase productivity during testing a remote monitoring system was developed. The remote monitoring system (RMS) is needed to log temperatures of the tests.

Methodology of the Study

The RMS (Remote Monitoring System), acting as a data logger, was created to automate the task of logging each data point (Figure 7). For years automating the monitoring and logging of experiments has been widely used in science. There are many systems in the markets that can complete this task, such as the systems offered by National Instruments[7]. These systems can complete the task of data logging in a simple and compact manner; however they are not always cost effective. Another monitoring system for the continuous measurement of electrical energy parameters such as voltage, current, power and temperature was developed by Barakat, et. al.[8] This specific system is designed to monitor the data remotely over internet. The RMS developed for this study has similar capabilities that commercial systems have with a significantly lower cost.

The basis for the RMS consists of four parts, the sensors and their read out screens, the video capture device, the computer processing device, and the software running on the computer processing device. For video capture, a generic low resolution universal serial bus (USB) camera was deployed. The number of cameras used was in direct proportion to the sensor read outs used.

These cameras were position in front of the sensor read outs. The images that the cameras generated were fed via USB into the computer processing unit consisting of a Raspberry Pi. Raspberry Pi's are a small single board computers developed by the Raspberry Pi Foundation. These computers are running Linux, a free open source operating system used in many fields of science and engineering (see Ferrill[9]).

Using Linux as the operating system gives the RMS the advantage of running a large number of software tools, from image processing to advanced communication software, due to its large market share (Operating system market share[10]). The software component of the RMS allowed for a simple and expandable data logging system. The user simple specified the number of cameras to be used, what each camera views, the interval to gather the data, and how long to run the data logging. Once this had been specified the user can begin the experiment and allow the system to run on its own for any time required. This system does not store the data directly into a readable number format such as a spreadsheet; the user must read the images and place the data manually. When the experiment is completed the user can simply copy the log file on to a flash drive to be analyzed at a later time and another location. The RMS is a system that has similar capabilities to the expensive commercial data logging systems, but at a much lower cost, creating a new opportunity for more cost effective research.

In the future, the RMS is to be expanded in capabilities and size. The first thing to be added is perhaps an experiment completion alert and remote data transfer. When the experiment is done, the computer can perform an automatic transfer of files into an email or server to be sent to the user, eliminating the need to directly remove the files from the computer. Secondly, is an addition of built in data analysis software. At the current time the user must handle the data transfer manually. With the addition of an optical character recognition software (OCR) such as Tesseract (Smith[11]), this process becomes automated, simplifying the use of this system.

The current RMS using the minicomputer needs three individual cameras placed in front of the temperature sensors to record temperatures. Extending the temperature sensor's range, so all the temperature readings can be taken with a single camera reduces the need for the minicomputer to analyze the data from multiple pictures. The increased sensor range will also be beneficial once testing begins with scale roofs which are considerably bigger than the foam cooler model. So far the range of only one temperature sensor has been extended. The extended sensor is accurate under low temperatures but begins making errors at high temperatures. The error could be the attributed to the increased impedance due to the extension and the quality of the wires used to increase the range. The problem may also be caused by heat loss due to poor insulation of the extended wires. Another temperature sensor will be extended using a wire with as the same gage as the original and a better insulation.

Figure 7: Remote Monitoring System (RMS)

Figure 8: Foam Cooler and Infrared Lamps

Description of Employed Materials

Foam coolers dimensions employed in the experimentation were 8.07 in x 6.1in x 12 in and had a volume of 0.342 ft^3. A total of three coolers are being used with one being used for control. All cooler have a digital thermometer suspended 28 inches from coolers. To ensure uniformity all models are left open to the testing environment until they reach room temperature. Three 250 watt infrared lamps are suspended 28 inches from the surface of assemblies being tested (Figure 8).

Scale model roof is built with 15/32" thick plywood sheet and 2 x 4 studs. The model is suspended on furniture dollies for mobility. The base of the model roof is 36 inches by 44.5 inches. The model has a height of 6 ft. and sloping roof of 78.6 %. The final design calls for creating separate attic and living space inside the model. The separation of living space is done using drywall and R-30 fiberglass insulation. A computer model of scale roof has been completed in Solidworks software (Figure 6).

Roof assemblies are composed of 15/32" thick plywood, No.15 asphalt roof felt, Oak AR Onyx Black and Thermal Barriers. Union Corrugating 96-in x 24-in 29-Gauge Plain Ribbed Steel Roof Panel was used for the traditional metal roofing. Thermal barriers that was used include 4 x 8 ft. Rmax 3.2 radiant board insulation, recycled aluminum cans, 5.5 in x 50 ft. Styrofoam Sill Seal, 1.5 ft. x 500 ft. 16 micron thick aluminum foil, 15 in x 25 ft. Reflectix radiant barrier and 4ft x 12 ft. Enerflex radian barrier. The shingles, roofing felt and thermal barriers are secured to plywood using roofing nails and brad staples.

The RMS is composed of three web cams connected to a minicomputer (Raspberry Pi). As mentioned above, the Raspberry Pi runs of a Linux based operating system. The minicomputer is connected to an LCD monitor, keyboard and an optical mouse. The LCD monitor requires a conversion cable to convert from HDMI port to a VGA port. The use of soldering iron, solder and electrical wires were required to extend the range of thermometers.

Data Collection

The efficiency of the modified and commercial assemblies will be measured in percent difference between temperatures from the “Control” assembly and the “Test” assembly. Since all tests were done with the “Control” assembly day to day variables such as room temperature and humidity can be negated out by taking the percentage difference of assemblies tested in the same conditions. The percentage difference was calculated by subtracting the temperature of the “Test” assembly from the “Control” assembly then dividing the difference by the temperature of the “Control” assembly. To rule out the temperature variance due to a color difference, both the metal and asphalt shingle assemblies were spray painted black.

Two versions of the “Green” assembly were tested. The first Green assembly covered the entire surface of the assembly with flat pieces of aluminum (Figure 9). After testing, the first Green assembly had a temperature reduction of 12.94%. After the promising results of the first assembly, a second Green assembly was created using shredded and crushed pieces of aluminum glued on to a roofing felt (Figure 10). This second assembly more realistically represented the shredded scrap aluminum found at recycling plants. The second assembly, due to the uneven scrap aluminum pieces was partially not covered by the aluminum cans. The temperature reduction of the second assembly was 12.31%. There was very little difference between the efficiency of the glued scrap aluminum to the flat uniform aluminum assembly (Table 1). To have a comparison basis for all collected data, humidity (%) was recorded throughout all laboratory experiments.

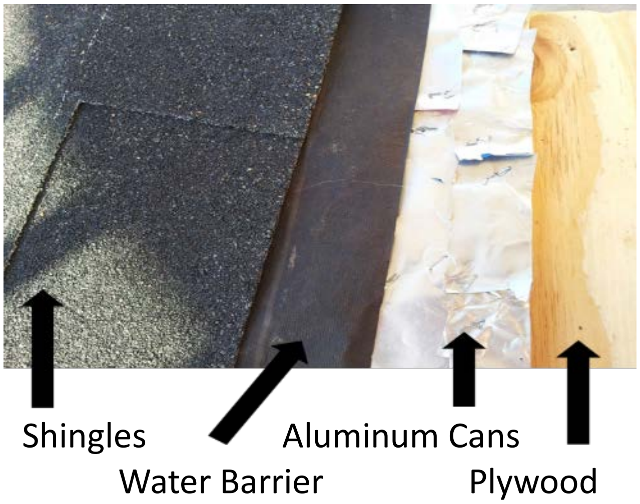

Figure 9: Green Assembly 1

The assembly test done using Styrofoam Sill was named the “Sill Assembly” (Figure 11). The sill assembly ended up with a temperature reduction of 1.5%. Initially the temperature reductions were high at 7% but over time the insulating capacity of the Styrofoam deteriorated and the temperature reductions fell to 1.5% (Table 2). The aluminum foil assembly had a temperature reduction of 5.72%. This assembly actually got hotter with temperature gain of almost 4% in the first 20 minute interval before temperatures started to reduce (Table 2).

Figure 10: Green Assembly 2

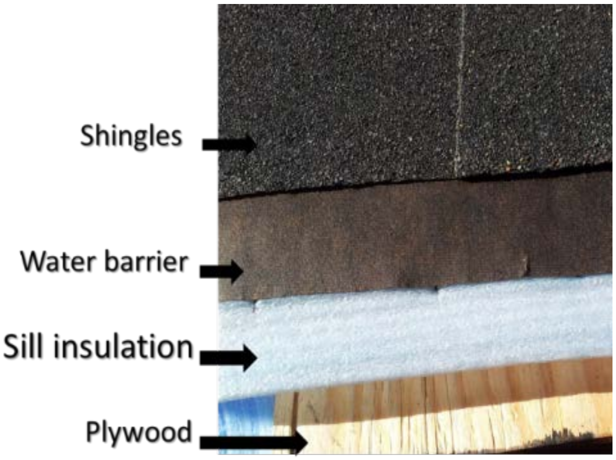

Figure 11: Sill Assembly

Table 1: Green Assemblies 1 & 2 data

Initial Roof Assembly Tests : Green Assemblies						
Time	Control	Green Assembly 1		Control	Green Assembly 2	
(Min.)	(°F)	(°F)	Difference %	(°F)	(°F)	Difference %
0	69.80	69.80	0.00	69.80	69.80	0.00
20	83.30	80.60	-3.24	77.18	76.60	-0.75
40	97.80	86.54	-11.51	96.62	88.70	-8.20
60	105.40	91.76	-12.94	106.70	93.56	-12.31
			Humidity 70%			Humidity 74%

Table 2: Initial Test Data

Initial Roof Assembly Tests : Modified Assemblies									
Time (Mins)	Green Assembly 2 (°F)			Foil (F°)			Sill Foam (°F)		
	Control (°F)	(°F)	Difference %	Control (°F)	(°F)	Difference %	Control (°F)	(°F)	Difference %
0	69.8	69.80	**0.00**	69.80	68	**0.00**	69.80	69.80	0
20	77.18	76.60	**-0.75**	83.30	78.26	**3.83**	83.30	77.40	-7.08
40	96.62	88.70	**-8.20**	97.80	93.2	**-0.77**	97.80	94.10	-3.78
60	106.7	93.56	**-12.31**	105.40	97.88	**-5.72**	105.40	103.82	-1.5
	Room 69.8 °F		Humidity 74%	Room 68 °F		Humidity 43%	Room 69.6 °F		Humidity 70%

There were three assemblies tested using commercial products. One assembly tested was a radiant barrier called Enerflex. The Enerflex barrier had a temperature reduction of 4.16%. The second commercial assembly was a combination barrier called Reflectix. The Reflectix had a temperature reduction of 7.88%. The last commercial barrier was also a combination barrier called Rmax R-3.2 board. The Rmax had the highest temperature reduction of 21.42%. Rmax also had the most insulation out of all assemblies tested (Table 3). All initial data gathered was placed into the graph of Figure 12.

Table 3: Initial Commercial Data

Initial Roof Assembly Tests : Commercial Assemblies									
Time (Mins)	Rmax R-3.2 (°F)			Enerflex (F°)			Reflectix (F°)		
	Control (°F)	(°F)	Difference %	Control (°F)	(°F)	Difference %	Control (°F)	(°F)	Difference %
0	69.80	69.80	**0.00**	68	68	**0**	68	68	**0**
20	77.18	72.50	**-6.06**	75.38	74.66	**-0.96**	85.64	84.2	**-1.68**
40	96.62	78.26	**-19.00**	93.92	88.7	**-5.56**	96.8	90.68	**-6.32**
60	106.70	83.84	**-21.42**	103.82	99.5	**-4.16**	102.74	94.64	**-7.88**
	Room 69.8 °F		Humidity 74%	Room 68 °F		Humidity 43%	Room 68 °F		Humidity 43%

Four of the initial assemblies were chosen to be tested in larger model. The two modified roof assemblies chosen were the Green Assembly 2 and the Foil Assembly. The two commercial assemblies were the Rmax R-3.2 and the Enerflex. The Enerflex was chosen as an average representation for all the other variations of reflective barriers in the market. Rests of the assemblies were chosen to be tested because of their high efficiencies. Table 4 shows the results of the test done in the larger scale models. Test on the 3D Metal assembly was done directly onto the scale model (Table 5). The results were not that promising with only 1% temperate reduction

Table 4: Final Data

Initial Roof Assembly Tests : Asphalt Shingles												
Time (Mins)	Foil (°F)			Rmax R-3.2 (°F)			Enerflex (°F)			Green Assembly (°F)		
	Control (°F)	Test (°F)	Difference %	Control (°F)	Test (°F)	Difference %	Control (°F)	Test (°F)	Difference %	Control (°F)	Test (°F)	Difference %
0	75.02	74.12	-1.20	75.38	74.84	-0.72	73.94	73.58	-0.49	73.94	73.58	-0.49
15	75.74	75.02	-0.95	76.46	75.38	-1.41	76.10	74.84	-1.66	75.38	74.30	-1.43
30	78.80	76.10	-3.43	78.62	77.00	-2.06	78.62	75.92	-3.43	77.90	75.92	-2.54
45	80.78	77.36	-4.23	80.42	78.62	-2.24	80.60	76.82	-4.69	80.06	77.54	-3.15
60	82.40	78.44	-4.81	81.86	79.70	-2.64	82.22	77.54	-5.69	81.50	78.80	-3.31
75	83.30	79.16	-4.97	82.76	80.78	-2.39	82.94	78.26	-5.64	82.58	79.70	-3.49
90	84.02	79.70	-5.14	83.30	81.32	-2.38	83.66	78.62	-6.02	83.30	80.42	-3.46
	Humidity 56%			Humidity 56%			Humidity 60%			Humidity 65%		

against a traditional asphalt shingle roof assembly. In the test of traditional metal and asphalt shingle, the metal assembly was actually hotter than the asphalt shingle after 90 minutes of testing.

Table 5: Metal Roof Assemblies Data

Initial Roof Assembly Tests : Metal Roof Assemblies									
Time (Mins)	Traditional Metal (°F)			3D Metal (°F)			Traditional Metal vs. 3D Metal (°F)		
	Traditional Shingle (°F)	Traditional Metal (°F)	Difference %	Traditional Shingle (°F)	Traditional Metal (°F)	Difference %	Traditional Metal (°F)	3D Metal (°F)	Difference %
0	73.58	73.58	**0.00**	73.94	73.76	**-0.24**	73.76	73.76	**0.000**
15	75.38	76.46	**1.43**	76.10	76.46	**0.47**	76.28	75.56	**-0.944**
30	78.44	79.88	**1.84**	78.98	78.98	**0.00**	79.70	77.90	**-2.258**
45	80.42	81.86	**1.79**	80.96	80.60	**-0.44**	81.50	79.34	**-2.650**
60	82.04	82.94	**1.10**	82.22	81.68	**-0.66**	82.94	80.78	**-2.604**
75	82.94	83.84	**1.09**	83.30	82.58	**-0.86**	83.84	81.32	**-3.006**
90	83.66	84.38	**0.86**	84.02	83.12	**-1.07**	84.38	82.04	**-2.773**
105							84.74	82.40	**-2.761**
120							84.92	82.58	**-2.756**
	Humidity	60%		Humidity	59%		Humidity	56%	

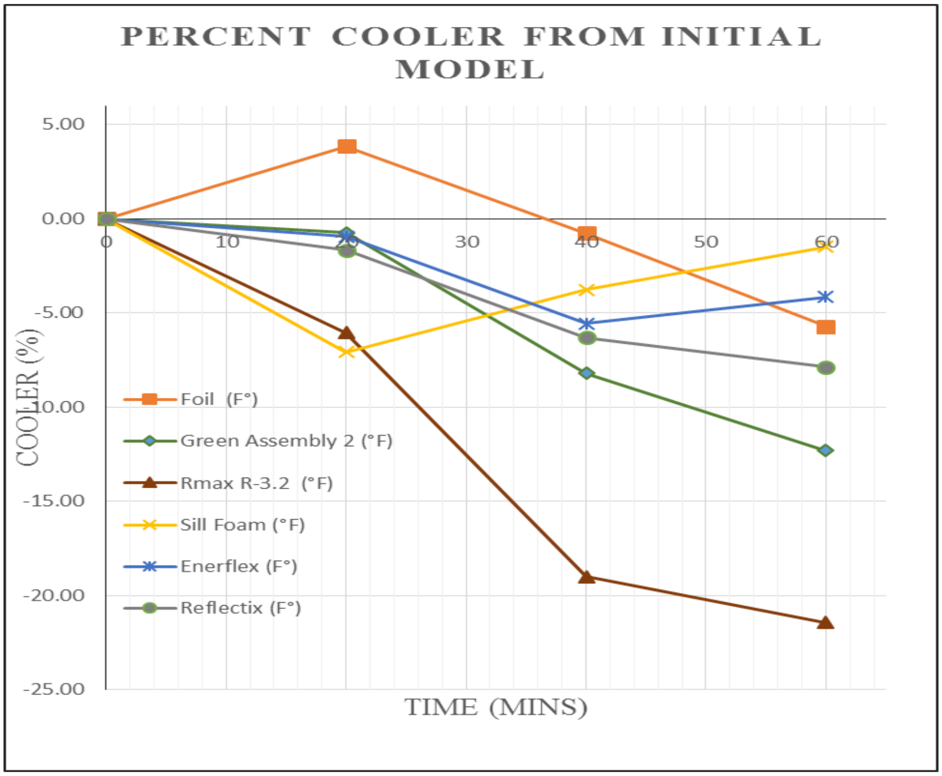

Figure 12: Initial Data

Cost per Square-foot Analysis

The Green Assembly 1 cannot be considered in cost benefit analysis because it is not feasible to install the product due to potential manufacturing issues. Green assembly 2 is the best option to compare cost and efficiency against other assemblies. The green assembly cost was calculated to be \$0.145 ft^2. The calculations include the glue and paper used to attach the scrap onto the respective assembly. The price calculations were based on the weight of the aluminum and glue used per square foot. The scrap aluminum price is the purchase price of recycled aluminum and the glue is priced by the gallon. The most expensive assembly was the Reflectix at \$0.51/ft^2. The least expensive was the foil at \$0.04/ft^2. The price per square foot of rest of the barriers and material are shown in Table 6.

Table 6: Cost/SF data

Material costs	
Material	Cost ($\$/ft^2$)
Green Assembly 2	\$ 0.145
Sill Insulation	\$ 0.340
Aluminum Foil	\$ 0.040
Rmax R-3.2	\$ 0.310
Reflectix	\$ 0.510
Enerflex	\$ 0.480

Conclusions and Recommendation for Future Work

Initially Green assemblies were the most efficient assemblies out of the alternative materials considered in this study. The surprisingly low results in the scale model roofs may be attributed to the manufacturing process. The Green Assembly produced for the scale model had fewer pieces of aluminum per square foot than the ones used for testing in smaller models. The pieces of aluminum required to make the Green Assembly for the smaller initial models was less and were therefore cut smaller and glued on with greater density per square foot. The scale roof model require greater quantities of scrap metal and therefore cut bigger pieces and glued on with less density than the smaller models. The reduced density of scrap aluminum also reduces the material in the assemblies that would deflect the solar radiation. Greater efficiency may be achieved in the Green Assembly if it is created again with smaller pieces of aluminum and glued on with greater density.

The aluminum foil assembly was the least expensive assembly out of all material tested. The foil assembly's temperature reduction of 5.14% is not the highest but still higher than commercially available Rmax R-3.2 value. The low cost and commercial product efficiency are the reasons foil assembly should be considered as great alternative to commercial products. Foil may not be sold as commercial barrier but a civilian person can apply a foil barrier around their attic by themselves in order to get energy savings.

The Enerflex had highest efficiency value of 6.02% reduction of temperature and should be used at least as reference of commercial products in future testing. Sill and Rmax R-3.2 both used insulation barriers as their main method of shielding attics. The Styrofoam Sill and Rmax

R-3.2 did have some reduction and lower cost than other commercial product but the efficiency of 1 to 2% is not enough to be considered as thermal barriers. The Sill and Rmax R-3.2 assemblies were also losing their efficiency over time (Figures 12 and 13). The radiant barriers in the commercial market are the most efficient out of all the assemblies tested.

The 3D metal assembly had some improvements over the original assembly. The efficiency is not as great as the thermal and alternative assemblies but still greater than the traditional metal roof assembly. The indentations made for the 3D assembly were not that great and the average indention is less than a ½ inch deep. Greater efficiency can be achieved if the indentions were increased. The bigger indentations would increase the ventilation spaces and the thermal emittance of the metal roofing panels. Due to the change in values when switching from small models to large models, all promising assemblies should be installed in actual roofs for real world testing. These tests on actual roofs should be conducted only after replicating the current results on the scale models.

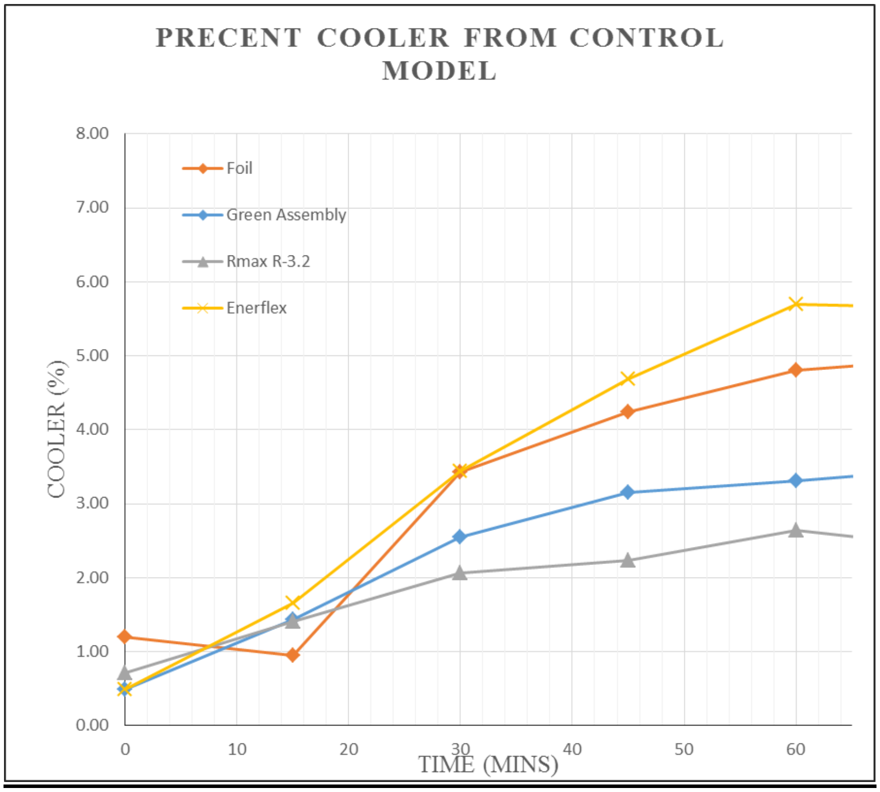

Figure 13: Scale roof assemblies' results

This way the process is better understood and potential for decreased temperatures are achieved at a higher percentage rate as proved on the comparison with small and large scale tests involved in this study. The methodology can be certainly applied on specific educational projects for civil engineering materials classes or for construction materials and system classes under construction management curriculum. The study concluded with important results that reveal great potential for energy savings on non-traditional assemblies capable of maintaining cooler residential roofs and attic spaces during hot and relatively humid summer days in south eastern United States.

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References

1 Urban, B., & Roth, K. Guidelines for selecting cool roofs (DE-AC05-00OR22725). U.S. Department of Energy Building Technologies Program and Oak Ridge National Laboratory. 2010. Retrieved from Fraunhofer Center for Sustainable Energy Systems website: https://www1.eere.energy.gov/femp/pdfs/coolroofguide.pdf

2 COOL ROOF RATING COUNCIL. Cool roofing information for home and building owners. 2013. Retrieved from http://coolroofs.org/resources/home-building-owners

3 Kirn, B., Gravline, S., Turnbull, P., & Roodvoets, D. Everything you need to know about cool roofing. COOL ROOF RATING COUNCIL, The American Institute of Architects, Continuing Education systems. 2006. Retrieved from http://coolroofs.org/documents/IREPanel_EverythingYouNeedtoKnowAboutCoolRoofingforweb.pdf

4 Jim, C.Y. "Assessing climate-adaptation effect of extensive tropical green roofs in cities". Landscape & Urban Planning, Vol. 138, 2015, pp. 54-70.

5 Ong, K. S. "Temperature reduction in attic and ceiling via insulation of several passive roof designs". Energy Conversion and Management, 2011, 52(6):2405-2411

6 Bianchi, M., Desjarlais, A. O., Miller, W. A., & Patris, T. W. "Cool roofs and thermal insulation: Energy savings and peak demand reduction" (Master's thesis). Available from ASHRAE. 2007. Article retrieved from http://web.ornl.gov/sci/buildings/2012/2007%20B10%20papers/225_Bianchi.pdf

7 National Instruments. What is a data logger?, 2012, Retrieved from http://www.ni.com/white-paper/2946/en/

8 Barakat, E., Sinno, N., Keyrouz, C. "A Remote Monitoring System for Voltage, Current, Power and Temperature Measurements". 8th International Conference on Material Sciences, CSM8-ISM5, Physics Procedia, Vol. 55, 2014, pp. 421-428

9 Ferrill, P. Explore linux as a scientific computing platform: crunch numbers with sage and python. Informally published manuscript, IBM, 2012. Retrieved from http://www.ibm.com/developerworks/opensource/library/l-science-compute/l-science-compute-pdf.pdf

10 Operating system market share. Market Share Statistics for Internet Technologies. 2009. Retrieved from http://marketshare.hitslink.com/operating-system-market-share.aspx?qprid=8

11 Smith, R. "An overview of the tesseract OCR engine". Manuscript submitted for publication, Google Inc., Available from IEEE (0-7695-2822-8/07). 2009. Retrieved from http://tesseract-ocr.googlecode.com/svn/trunk/doc/tesseracticdar2007.pdf

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