February 2017

Radiant Barrier Retrofits to Improve Energy Efficiency of Older Homes in Hot-Humid Climate Zones

PREPARED BY:
The University of Texas at San Antonio's Center for Cultural Sustainability—part of the College of Architecture, Construction and Planning

PRINCIPAL INVESTIGATOR:
Professor William A. Dupont

Co-Principal Investigators:
Dr. Hazem Rashed-Ali | Dr. Randall D. Manteufel | Dr. Suat Gunhan

PROJECT SPONSOR:
The National Center for Preservation Technology and Training
National Park Service, U.S. Department of the Interior

GRANT NUMBER:
P14AP00143

UTSA
Center for Cultural Sustainability

Table of Contents

Executive Summary

Research purpose

The grant from NPS NCPTT funded a study regarding the energy efficiency and cost-effectiveness of radiant barrier retrofits of historic homes in hot-humid climates.

Project description

This project addresses a national need in preservation technology to educate the public on best practices for energy improvement retrofits to older homes. The research measured the actual energy use impact of one significant retrofit—installation of the radiant barrier—in six case study homes, one story high, historic, and small. The average home size is 1,381 square feet; the median is almost identical at 1,404 square feet. The research project concerns building performance before and after the energy retrofit. The particular retrofit evaluated, a radiant barrier, is relatively inexpensive and straightforward to install within existing homes, thus suggesting high potential value as a retrofit.

Findings and recommendations for next steps

Data collected from the six homes in the study revealed that the radiant barrier was generally effective at reducing the total energy use of the case study homes, normalized for weather, by an **average difference** of -7.2 percent improvement. The range across the six case studies was rather wide, from a maximum improvement of -25.5% to an actual increase in cost of 4.2%. The **median difference**, also weather normalized, was -5.9%.

The installation cost of the radiant barrier into each home averaged $1,544; the median cost was significantly lower at $1,228 because there was one outlier in the costs dataset. Based on the median data, and adjusting for the variations in weather over the years of comparison, the simple payback on the installation cost is projected to be 14 years. Compared to the projected payback on other retrofits, this is a good result, but not exceptional. The wide range of results from only six case-study homes must temper consideration of the payback analysis from median data.

The performance variables are many, and the study indicates a wide range of possible results from this one retrofit. Smaller homes appear to be inherently more difficult to show a large percentage of improvement with retrofits because they use less energy overall than bigger homes. Therefore, the smaller the home, the longer the payback one would generally anticipate from a retrofit.

Next steps should include three areas of increased research attention: 1.) more homes for analysis to produce more accurate data; 2.) more analysis of cost data on the radiant barrier installation because the labor rate has a huge impact on financial efficacy of this retrofit; and 3.) exploration of heating profile and performance in climate zone 2A because the data showed natural gas EUI to be 35% higher than electric EUI. This EUI dataset was unexpected and remains unexplained, given that the cooling load is supposed to be the greater concern in climate zone 2A.

ASHRAE Climate Zone 2A extends from central Texas to Florida.

Introduction

What is a radiant barrier and how does it work, in theory?

A radiant barrier is a highly reflective film commonly fitted into roofs or attics that will reduce transmission of radiant heat, reflecting it back toward the source. The radiant barrier's purpose is to reduce the amount of radiant heat transmitted from a warm object or material. In a warm climate zone such as San Antonio (zone 2A), the solar energy heats the roof materials, and the absorbed heat is then re-radiated to the building materials of the home, including HVAC ducts if located in the attic. In cold climates, the effect is beneficial to energy savings in the reverse direction. The radiant energy of the heated home is reflected back at the home in the winter season.

The research studies retrofits in 6 case study homes. These homes are of similar wood-frame construction, detached one-story structures averaging

1,382 square feet built between 1905 and 1936 and located within a historic district.

A radiant barrier is relatively inexpensive and straightforward to install, thus offering high potential value as a retrofit. The HVAC ducts in older homes in warm-humid climates are invariably placed in the attic. The advertised and anticipated value of a radiant barrier application in warm-humid climate zone is to mitigate the temperature rise in the mechanically cooled air as it flows through the ducts within the attic spaces.

Radiant barriers are known to work differently in combination with various levels of attic insulation, and they work differently depending on where the barrier is placed within the building assembly (Medina, 2001). See description below for the assembly tested by this study.

Climate change impacts

Climate change is happening, but precise causes, pace and projected amount of change remain unknown. Every available technique to reduce man-made causes of climate change deserves attention. The National Aeronautics and Space Administration and the National Oceanic and Atmospheric Administration agree that climate change is occurring. The Environmental Protection Agency reports that human activity is contributing to the change (Environmental Protection Agency, "Climate Change Facts," http://www.epa.gov/climate change/basics/facts.html, accessed December 22, 2014). Within the specific study area, climate zone 2, coal is a primary energy source for the electricity for air-conditioning (CPS Energy, "Facts and Stats," http://newsroom.cpsenergy.com/resources/facts-and -stats/, accessed December 22, 2014). Coal combustion produces carbon emissions that are a major contributing factor in climate-change models. Energy retrofits of older buildings can reduce the pace of climate change by reducing the consumption of fossil fuels. Prioritization of retrofits by efficacy can encourage home-owners to pursue the best options with their investment dollars, and engender reductions in fossil fuel consumption.

Innovation

The primary innovation of this project is the focus on financial value to homeowners in climate zone 2A. Furthermore, existing research on energy retrofits has focused on northern climate zones, leaving a dearth of information applicable to historic homes in southern climate zones. More published evaluations are needed by independent entities regarding actual retrofit outcomes relevant to climates where cooling is the dominant concern. This evaluation of the radiant barrier in ASHRAE climate zone 2A (hot and humid) has relevance to climate zones 2B, 3B, and 3A, as well.

Project assumptions and approach

Case study homes were recruited with advertisements in neighborhood newsletters and announcements from the City of San Antonio Office of Historic Preservation (see Appendix A). Once signed on as a study participant, the homeowners hired an independent installer of their choosing to apply a basic radiant barrier (meeting specifications of the research team, see Appendix B) stapled to the underside of the roof rafters. After installation, the performance of each home was monitored for 12 months, or more. The study assumes that accurate financial data on the installation cost and real-world energy savings will be useful to homeowners. The need to conduct the study in this manner was necessitated by the inability of computer modeling programs to simulate effectiveness of the radiant barrier as a retrofit.

Our evaluation measured the actual cost and corresponding energy use reduction of only one significant retrofit—installation of the radiant barrier. The participants in the study were required to do only this one retrofit and no other improvement. One of the six case study homes did make a simultaneous repair to leaky ducts. That home received a duct-blaster test before and after the repairs in order to isolate the improvement to the ducts; see methodology explained below. All homeowners agreed to maintain normal behavior with no change to patterns of energy usage during the 12-month study period.

A radiant barrier is relatively inexpensive and straightforward to install, offering high potential value as a retrofit. The ducts in older homes are invariably placed in the attic, giving added value to the radiant barrier. The evaluation will be made after 12 months of operation with the retrofit installed.

Anticipated outcomes

Based manufacturers' claims and results of one other study done in Florida (Parker, Sherwin, Anello, 2001), the anticipated outcome was a 5 percent to 10 percent reduction in annual energy consumption. Since the study launched with the NCPTT grant in 2013, two other studies have been completed with favorable results— Asadi & Hassan, 2014; and Lee et. al, 2016. See information on prior research in the methodology section below.

Historic landmark designations

A historic residence is one that has been legally designated as historic. The case studies in this research are located in San Antonio, Texas, within a legally designated historic district. The radiant barrier is not visible from the exterior, so it is not a change that needs review by the city's Historic and Design Review Commission, nor is a construction permit necessary for this retrofit. Many retrofits do cause a material impact or visual change that needs to be thoughtfully considered before making the change to a designated historic property. The design issues of energy retrofits to older homes can be complex. (Grimmer, 2011, and Frey, 2013)

The radiant barrier fits within the attic, not visible from the exterior

Methodology

Prior research on radiant barrier performance in hot-humid climates

Lee et. al. (2016) conducted an extensive review on radiant barriers and reflective insulations. The results showed 26 percent to 50 percent reduction of the cooling load for the summer season and 7 percent to 13 percent reduction of the heating load for the winter season. Results varied significantly based on the building type, ceiling insulation, and climate zone. Likewise results varied among laboratory measurements, field measurements, and model simulations. The study reaffirmed the consistent observation that radiant barriers are more effective in humid tropical and humid subtropical climate zones. In the United States, the hot-humid climate zone extends from central Texas to Florida. The range of reported reductions tends to be higher for field measurements compared to computer simulations and laboratory measurements. The winter heating load is typically lower in the types of homes where radiant barriers are tested, with computer simulations and field measurements ranging up to about 16 percent but averaging around 9 percent for the reduction in the winter heating load. Results for winter heating loads are less consistent, and the performance of the attic radiant barrier appears to be best for winter conditions if it is installed horizontally over the ceiling insulation instead of attached to the rafters.

Asadi and Hassan (2014) conducted an 8-month-long experimental study using two homes in Louisiana. The results include hourly temperature measurements of asphalt roofing, attic air, and attic insulation. They conclude the radiant barrier can reduce ceiling heat flux between the attic and conditioned living space by as little as 8 percent in heating season and as much as 25 percent in the cooling season. In the cooling season, the top of attic insulation was measured to be up to 12°F higher in comparable homes without a radiant barrier. The results are less significant for climates with significant cloud cover or roof shading.

Gomez et. al. (2015) analyzed approximately 350,000 detached, single-family homes in San Antonio, Texas, to study their summer and winter energy usage based on 2013 utility consumption data. The majority of homes have an annual energy use ranging from 25 to 50 kBtu/sf. For homes built prior to 1950 and ranging in size from 1,000 to 1,499 sf, the annual energy use is about 67 kBtu/sf with a standard deviation of 28 kBtu/sf. Hence the data shows a wide range of energy use in historic homes. In the summer it is estimated that about 35 percent of the energy use is for cooling purposes and in the winter months about 41 percent is used for heating purposes. Gomez et.al. recommend that homes with energy use exceeding 50 kBtu/sf should be targeted for energy conservation measures.

Requirements and procedures for IRB approval regarding human subject research

The research for this project is within the definition of "human subject research" because it involves use of information that is not publicly available—the homeowners' energy bills. As such, advance review and approval by the university's Internal Review Board (IRB) was required. The review included approval of forms used to recruit participants as well as an agreement signed by each participant that defined their role and obligations as a participant. All participants had the right to drop out of the study at any time without questions or penalty of any sort.

Research protocols

Participant selection

Advertising and recruitment of appropriate case study homes is an essential component to success of the research study. To select appropriate participants, flyers were distributed through public advertisement, local government agencies, NGO's and the neighborhood associations of the relevant historic districts. Interested parties were directed to contact the research team. After phone interviewing, a research team member made a brief field inspection to assess existing energy-efficient characteristics and appropriateness of participation in the study. Detailed phone and email communications transpired with thirty-eight (38) potential participants. Of these 38, the research team concluded that 17 did not meet one or more criteria for the study, another 15 eventually declined or ceased communication.

The homeowners were informed that their participation would require an energy retrofit improvement of unknown value. The participants were informed that the radiant barrier installation was not promised to produce operational cost savings.

The research team encountered complications in recruiting study participants who would install the radiant barrier. Many qualified participants never pursued the installation. This caused delays, and also fewer participants than anticipated. At the outset we expected to have ten homes in the study. Reluctance of participants seemed to be caused by the installation cost. Three reasons for high cost were observed -- 1.) some quotes that were never accepted included radiant barrier products in excess of specifications for the study; 2.) often the installation contractor would propose extra work for additional retrofit improvements that were not requested by the homeowners; and 3.) labor rates were for skilled personal rather than unskilled.

Ultimately, and with concurrence of the project sponsor, the scope of the radiant barrier assessment was reduced from ten to six case study homes. More homes would have been preferable, but good and valid results for analysis were produced from the group of six.

Inclusion/exclusion criteria

Inclusion/exclusion criterion	Requirement
Type of house	Single story, detached
Number of bedrooms	2–3
Size	Approximately 1,500 s.f.
Year built	1900–1950
Location	Historic districts of San Antonio
Occupied	At least previous 2 years
Heating and air-conditioning	Functional central system
Condition	Well maintained
Expansion	No, extensive expansion project in the past
Modification	No, heavy modification in the past
Retrofit for energy savings	No full retrofit (a.k.a. deep-energy) for better energy performance in the past
Other	WiFi service required

Installation

All installations (labor and material) were paid by the study participants and completed by professional installers. There was no incentive or subsidy; homeowners paid the full cost of the radiant barrier installation. There was no industry involvement or financial support. See UTSA permission agreement with study participants in Appendix C.

Participants in this study were required to use an industry standard roof radiant barrier with an emittance of 0.05 or less as tested in accordance with ASTM C-1371 (Standard Method of Determination of Emittance of Materials Near Room Temperature Using Portable Emissometers) or ASTM E-408 (Standard Test Methods for Total Normal Emittance of Surfaces Using Inspection-Meter Techniques), installed according to the manufacturer's instructions.

The radiant barrier material was trimmed to fit and then stapled to the underside of the roof rafters and also to vertical studs at gable ends. Gaps at roof ridge and eaves were left to allow airflow in the cavity between radiant barrier and roof substrate. This configuration is typically called a roof-truss or under side of rafter installation.

All homes in the study have ventilated attics and HVAC equipment located in the attic.

Infiltration and Duct Leakage Tests

To better understand the energy use patterns in the case study homes, a certified energy rater performed both a blower door test and a duct leakage test on each home. The tests were paid with grant funds (so not a cost to homeowner) and conducted prior to the installation of the radiant barrier. Results of the tests included an assessment of the infiltration rates and duct leakage rates of the home, two factors that have considerable impact on the homes use of cooling and heating energy. Details of these results are included in section IV.

Energy Use Data Collection

Two methods for collecting energy use data were used for each of the case study homes. First, utility bill data were collected for the period before and after the installation of the radiant barrier. For the pre-installation period, at least one year of electricity and gas utility bills was collected, and in some cases two years were collected. For the post installation period, minimum one year of utility bill data were collected. All utility bill data were inputted into the EPA Portfolio Manager Online Tool (Energy Star, 2017), which was then used to calculate electricity and gas use by calendar month, as well as a weather normalization factor for both the pre-installation and the post-installation periods. A more detailed discussion of the weather normalization process in Portfolio Manager can be found in Energy Star (2017).

The second method of energy use data collection involved the installation of an energy use tracking system in each case study home. The system used was the SiteSage system (Powerhouse Dynamics, 2017), which is capable of providing real-time monitoring of electricity use at the end-use level. The installation of the SiteSage system took place after the installation of the radiant barriers. For all homes except one, the team was able to collect one full year of overall and end-use electricity use data, which made it possible to isolate the use of electricity for cooling (all homes have gas heating systems). No monitoring of gas usage was conducted.

Energy Use Data Analysis

The analysis of the energy use data involved the comparison of one full year of pre-retrofit energy use data with one full year of post-retrofit energy use data to identify the impact of the radiant barrier installation. With the exception of one home, all case study homes did not have any major retrofits during the comparison period. One home, RTA5, had ceiling insulation added at the same time of the radiant barrier retrofit. Based on this, it was assumed that differences between pre and post energy use will represent the impact of the radiant barrier after accounting for weather differences and non-heating and cooling energy use.

As stated above, to account for weather differences between the pre- and post- periods, all utility bill data were inputted into the Portfolio Manager tool and the tool was used to calculate both calendar month use of electricity and gas as well as a weather normalization factor for each period based on the specific period being analyzed. The weather normalization factor was based on overall energy use and did not distinguish between the hot and cold seasons. The weather normalization factors used are included in Table 5. Both the pre- and post- installation periods varied slightly between the case study homes based on the installation time and the availability of pre-installation utility bill data. But in all cases, one full year of data was analyzed and normalized to account for weather differences.

Additionally, heating and cooling degree day data (CDD and HDD) were obtained for the periods being evaluated. CDD and HDD data were used to compare the changes in weather in both the cooling and heating seasons. This data is included in Figures 1 and 2, and generally indicate that the cooling seasons for the pre- and post-retrofit periods did not change significantly, while the heating seasons did show a considerable difference with the post-installation period being much milder than the pre-installation one. CDD data for the post-installation period was on average 3.4 percent less than the pre-installation period, while HDD data was on average 23.7 percent less than the pre-installation period.

In addition to the comparison of overall energy use, a comparison of cooling energy use was also conducted. For the post-installation period, cooling energy use data was obtained directly from the SiteSage tool, while for the pre-installation period, the cooling energy use was estimated by subtracting the base load (which represented lighting and plug loads for the most part) from the overall electricity use obtained from the electricity bill.

All energy calculations were made based on an Energy Use Intensity (EUI) metric to eliminate the impact of the home size.

Results and Discussion

Assessment of each home

	RTA5	RTA7	RTA8	RTA9	RTA11	RTA13
Year Built	1922	1927	1936	1930	1927	1905
Size, sq. ft.	1795	1004	1386	1422	1456	1228
Appraised Value (Bexar County 2016)	$154,430	$120,000	$240,000	$262,000	$135,110	$193,400
Orientation, facing	NNE	S	S	S	NNE	SSW
Construction	wood frame	wood frame	wood frame	wood frame	wood frame	wood frame
Roof	asphalt	asphalt	asphalt	asphalt	asphalt	metal (~2010)
Siding	stone	wood clapboard	wood-brick	wood clapboard	stucco on lath	wood clapboard
Attic Insulation	1–4 in. loose (2 in.)	4–5 in. paper batting (5 in.)	3–4 in. loose (3 in.)	12–16 in. loose (6 in.)	5 in. paper batting (5 in.)	5–16 in. loose (6 in.)
Shade Trees	none	1 large, SSW side	minimal	1 med., SSE side	minimal	1 med., SSW side
Ceiling fans	5	4	2	6	5	3
HVAC	central	central	central	central	central	central
Heating	gas	gas	gas	gas	gas	gas

Table 1. Summary of historic single family home characteristics

Additional findings of site-visit and assessment forms

As discussed above, only one home, RTA5, had any other retrofits installed during the monitoring period. In this home, ceiling (the attic 'floor') insulation was added at the same time as the radiant barrier retrofit. Based on this, it was assumed that differences between pre- and post- energy use will represent the impact of the radiant barrier after accounting for weather differences and non-heating and cooling energy use. As expected, this home showed the highest reduction in cooling EUI (approximately 20 percent). However, it did not significantly exceed the reductions achieved in other homes. This could be the result of behavioral changes between the pre- and post- installation periods.

Exterior of RTA 5, above

Exterior and attic of RTA 7

Exterior of RTA 8

RTA 9 Exterior

Exterior of RTA 11

Exterior of RTA 13

Analysis of construction labor costs

The installation of the radiant barrier does not require highly sophisticated skills. It is possible to install this material as a DIY (do it yourself) project. However, according to the construction company owner who provided the installation services for one of the houses in this project, RTA 5, installers are required to have technical expertise in tack staplers, box cutters, and must have expertise in geometry to measure and cut lengths of radiant barrier foil. Additionally, their installers must have experience in working in attic locations and have general construction knowledge. They receive approximately four hours of classroom/video training and 16 hours of observation training prior to participation on a work crew. The radiant barrier installation crew consists of three installers and a crew lead.

Installers of the company who handled RTA 5 are paid between $12 and $17 per hour, and crew leads earn between $15 and $22 per hour. When a house has a low-pitch roof, difficult access to attic and/or limited access throughout the attic, additional labor is required which increases the installation costs. The company owner said they currently have seven regular employees and three contract employees. The company utilizes certified energy consultants, certified as HERS (home energy rating system) raters or Building Analysts (The Building Performance Institute) to complete energy evaluations to calculate anticipated energy savings for energy efficient upgrades.

Payback Period

This research study includes six case study homes. The median material and installation cost per square foot of roof deck was $0.70/sf. The results of the study indicate that the homeowners saw a median difference of -5.9 annual improvement, weather normalized, and an average difference of -7.2, also weather normalized. The radiant barrier installation is expected to provide uniform savings throughout the coming years. The simple payback period can be calculated as follows (Riggs and West 1986):

Payback period = First cost (initial investment) / Net annual savings.

Calculation of a simple payback period requires weather normalization for the heating degree days (HDD), due to the large difference observed across the two years of data collection. The team first calculated an average rate per kBtu electricity and another per kBtu gas in each home, then calculated a median rate for each for the 6 homes. These rates were $0.03/kBtu for electricity and $0.01/kBtu for gas. The weighted average of the two rates based on the total electricity and gas usage for all homers provides an average rate per kBtu for all homes that combines both gas and electricity. This rate was $0.02/kBtu. Multiplying this rate, $0.02/kBtu, by the weather-normalized reduction in energy use provides a weather-normalized reduction in utility cost. The median reduction for all homes was $89.06. The range of the reduction is very large though, from $16 to $274. Using the same per kBtu rate for the cooling loads (without normalization), we see a median reduction of $38.21.

If the median installation cost is $1,238, and the median, weather-normalized, energy bill reduction is $89.06 per year, then the median payback period is 13.9 years.

Using the same median installation cost, and looking only at cooling loads with a $38.21 median annual reduction, the payback period is 32.4 years.

Analysis of data

Blower door and duct blaster tests

The results of the blower door and duct leakage tests are included below in Table 3. As shown in the table, all homes showed very high rates of envelop infiltration, consistent with their age. However, there were no major differences between the homes in this regard. ACH50 results for all homes ranged between 19.2 and 23.4, with most homes having approximately 20 ACH50. Duct leakage results, on the other hand, did show some notable differences with RTA8, RTA11, and RTA13 having considerably higher duct leakages than the other three case study homes. RTA 9 posted a good number for duct leakage outside envelope. As will be seen later, RTA 11 and 13 showed the highest reductions in overall energy use both with and without normalizing for weather, and RTA 9 saw little improvement.

Table 3: Results of Blower Door and Duct Leakage Tests

Home #	Envelop Leakage (CFM@50P)	Envelop Leakage *(ACH50)	Duct Leakage outside envelope (CFM@25P)	Leakage to outside / 100ft2 ** (CFM)
RTA 5	5,527	20.5	242	13.5
RTA 7	3,361	20.7	143	13.2
RTA 8	4,224	20.3	315	22.7
RTA 9	4,436	20.5	108	7.6
RTA 11	5,121	23.4	461	31.6
RTA 13	3,537	19.2	285	22.8

* Envelop Leakage should be 5 ACH50 or less in IECC 2015

** Duct Leakage outside envelope should be 12 CFM or less in IECC 2009 and 4 cfm or less in IECC 2015

Local, ambient degree-day comparison over past 3 years

The number of Cooling Degree Day (CDD) and Heating Degree Day (HDD) have been evaluated using 5 years of temperature observations recorded at Kelly Air Force Base, San Antonio, TX. The CDD and HDD are computed as the difference in the daily average temperature and a base temperature of 65°F.

The figure below compares the CDD data. The 5-year average annual CDD is 3130°F-day. In comparison, the cumulative 2015 CDD was 3077°F-day, which is 1.7 percent lower than the average of the previous 5 years. For 2016 the cumulative CDD was 3139°F-day, which is 0.3 percent lower. Hence the 2015 and 2016 cooling seasons were nearly the same as the preceding 5-year average cooling seasons, as shown in Figure 1. There are slight differences between the years, as it can be seen that 2015 has a mild start to the cooling season and a more severe finish, yet the cumulative is the same as previous years.

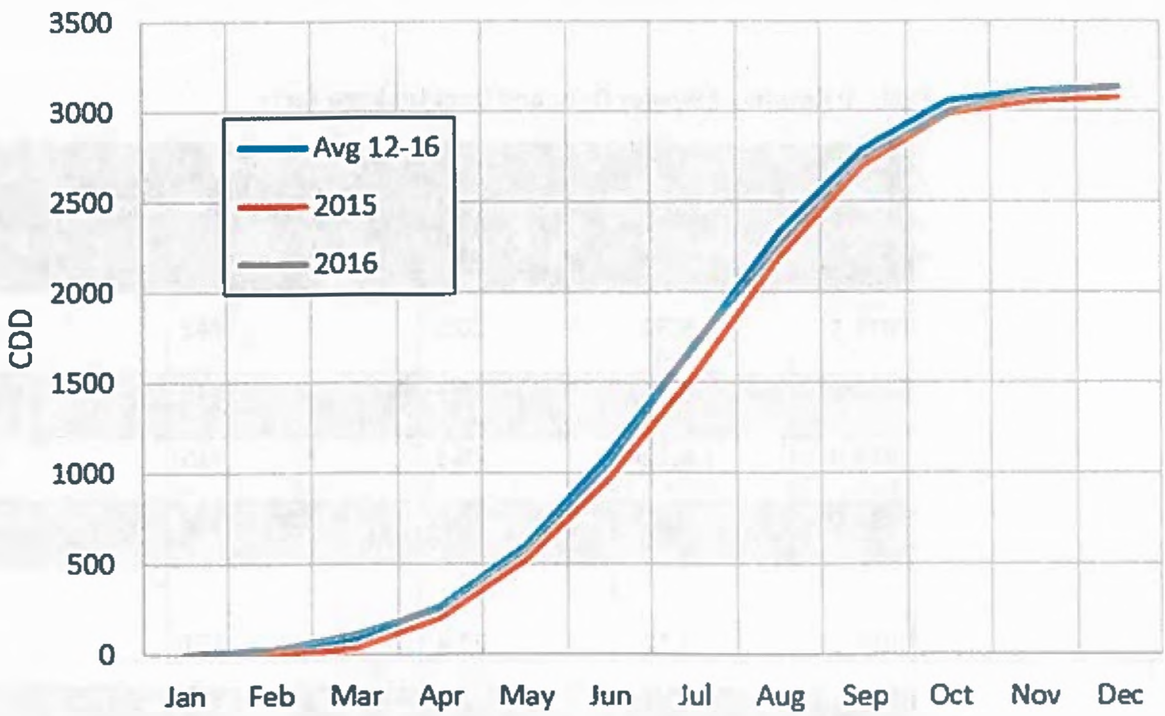

Figure 1

Comparison of monthly cumulative Cooling Degree Days (CDD) showing 2015 and 2016 had essentially equivalent cooling seasons.

The figure below (figure 2) compares the HDD data. The heating season runs from fall to spring, so the annual cumulative season starts in July and ends in June. So the first season starts in July 2011 and ends in June 2012. The 5-year average annual HDD is 1427°F-day for the heating season. In comparison, the 2014–2015 heating season had a cumulative HDD of 1692°F-day, which is 19 percent higher than the average. For 2015–2016 the HDD was 1213°F-day, which is 15 percent lower. The 2014–2015 winter was colder than normal, and the 2015–2016 winter was warmer than average.

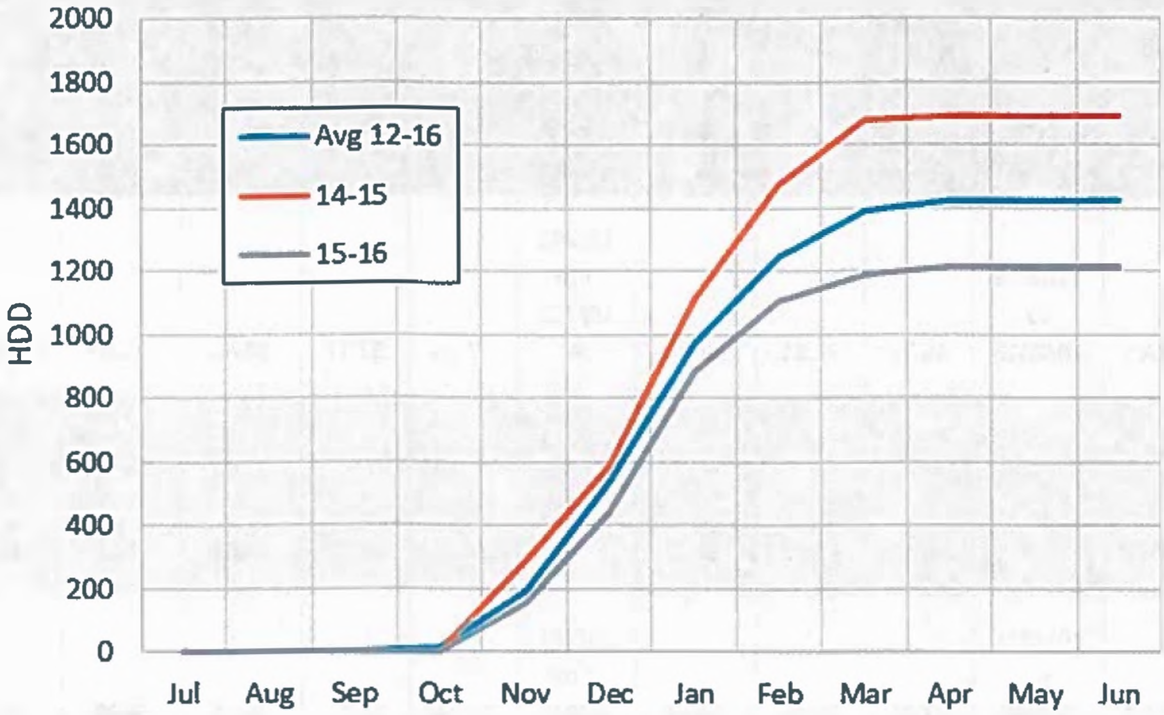

Figure 2

Comparison of monthly cumulative Heating Degree Days (HDD) showing 2014–2015 heating seasons was 19 percent higher than average and the 2015–2016 heating season was 15 percent lower.

Comparison of Energy Use Data

As discussed above, the energy use before and after the installation of the radiant barrier was compared in several ways, all of which are included below. First, Table 4 shows the overall electricity and gas utility energy use of the homes, without normalizing for weather. Table 5 shows the same overall utility energy use after normalizing for weather using the normalization factors obtained from Portfolio Manager. Finally, Table 6 shows the cooling electricity energy use, without normalizing for weather, unnecessary because the difference between the years of analysis was so slight. All results are reported on an EUI basis.

Home #	Post Retrofit Period	Post Electri-city EUI*	Post Gas EUI	Post Overall EUI	Pre Retrofit Period	Pre Electri-city EUI	Pre Gas EUI	Pre Overall EUI	Overall Diffrnce (EUI)	Overall Diffrnce (%)
RTA 5	11/2015 to 10/2016	16.32	22.61	38.93	11/2013 to 10/2014	17.23	33.17	50.40	-11.47	-22.8%
RTA 7	01/2016 to 12/2016	22.62	15.68	38.3	12/2014 to 11/2015	22.26	20.30	42.56	-4.26	-10.0%
RTA 8	10/2015 to 9/2016	27.96	20.46	48.42	10/2014 to 9/2015	25.34	31.17	56.51	-8.09	-14.3%
RTA 9	1/2016 to 12/2016	11.93	14.90	26.83	1/2014 to 12/2014	12.81	18.14	30.95	-4.12	-13.3%
RTA 11	1/2016 to 12/2016	17.39	16.75	34.14	1/2014 to 12/2014	19.85	25.35	45.19	-11.05	-24.5%
RTA 13	12/2015 to 11/2016	16.33	16.00	32.33	10/2014 to 9/2015	18.38	28.87	47.25	-14.92	-31.6%

Table 4: Comparison of Pre-and Post-Installation Utility Energy Use

Home #	Weather Normalization* Factor Post-Retrofit	Weather Normalization* Factor Pre-Retrofit	Overall Energy Use-post	Overall Energy Use-Pre	Savings	% Savings
RTA 5	105.19%	90.87%	40.95	45.79	-4.84	-10.6%
RTA 7	113.84%	98.36%	43.60	41.86	1.74	4.2%
RTA 8	107.80%	96.1%	39.00	39.50	-0.5	-1.3%
RTA 9	111.94%	97.08%	30.00	30.00	0.00	0.0%
RTA 11	112.90%	97.12%	38.54	43.89	-5.35	-12.2%
RTA 13	108.05%	96.62%	34.93	45.66	-10.72	-23.5%

Table 5
Comparison of Pre and Post Installation Overall Utility Energy Use – Weather Normalized.
*the weather normalization factor varies due to retrofit installation dates; see Table 4.

Home #	Cooling-Post	Cooling-Pre	Difference	% Difference
RTA 5	8.06	10.06	-2.00	-19.9%
RTA 7	5.22	6.39	-1.18	-18.4%
RTA 8	9.30	10.30	1.00	-9.7
RTA 9	4.95	5.67	-0.72	-12.6%
RTA 11	8.40	9.84	-1.44	-14.6%
RTA 13	7.31	9.12	-1.81	-19.8%

Table 6
Comparison of Cooling Energy Use—Not weather normalized
(no need to weather normalize because there was no significant change in CDD; see Figure 1)

Discussion of results

Efficacy of retrofit

The data shows generally positive results, but the variety of conditions among the six case studies indicates difficulty in accurate prediction of performance gains to be expected. Generally, the homes starting from a baseline of relatively poor performance in terms of energy consumption, in other words the homes that consumed more energy and thus had the greatest room for improvement, could realize a bigger positive impact from the retrofit.

There is not doubt that this retrofit will have a positive impact, but data from this study shows the degree of impact is not specifically predictable.

Performance of six homes

Variables impacting outcomes

Material and labor for installation is impacted by the size of the roof, pitch (a.k.a. slope) of roof, configuration of roof, and access into attic. Labor cost has a far greater impact than the cost of materials. The material cost for five of the homes in this study (material cost for RTA 5 was not disclosed) was low, ranging from $204 - $319. Thus, the labor cost (looking at RTA-7, 8, 9, 11, 13 only) ranged from $900 to $1,225 per home. Higher installation cost means longer payback period.

RTA 8 showed the least improvement in the summer cooling season. Data from the e-Monitor showed a clear increase in base (non-cooling) loads in 2016 compared to 2015. Base load in 2015 was about 600 kWh/month while in 2016 (per the monitoring system) it was about 760 kWh/month. Accounting for this, RTA 8 still showed a decrease in cooling loads of -9.7% but it is still the lowest percentage of reduction in all 6 homes.

The six homes in the study displayed a wide array of energy consumption rates. The biggest home, RTA 9, used the least amount of energy pre-retrofit, indicating this home was fundamentally a better baseline performer. Duct blaster tests for RTA 9 were much better than other homes. Given the good performance, one would expect a minor impact from the radiant barrier, which is exactly what happened. RTA-9 did not show improvement with addition of the radiant barrier.

Summer shade trees will block the solar energy from striking the roof, so shaded roofs will radiate less energy into the attic. However, two of the homes in the study with medium to large shade trees on the southern side, RTA 7 ands 13, nonetheless showed strong improvement in the summer cooling season. Surely, the shade trees were providing relief, but not enough to obviate the positive effect of the radiant barrier.

RTA 13 showed exceptional improvement from the retrofit. This small home has a steep roof and thus a high ratio of roof area to floor area. The radiant barrier may have produced a larger impact because the baseline home (pre-retrofit) had more radiant heat energy than the other case study homes.

Also regarding RTA 13, it was the only case study home with a metal roof. Radiant barrier installers typically avoid homes with metal roofs on the premise that they have a higher index of solar reflectivity, and thus are not radiating as much heat into the attic as other roof surface types. However, RTA 13 proved to be the best performer post-retrofit. Perhaps because the roof was installed in 2010, and had accumulated 6 years of pollen/dirt/dust film, the solar energy was able to heat the roof substrate even better than an asphalt roof?

Conclusion

Implications and potential of the radiant barrier retrofit

The long-term implications of our findings should be greater use of the radiant barrier as a retrofit in older (pre-1950) homes. Every older home is unique, and any improvements must be preceded by inspection and thoughtful analysis. The radiant barrier retrofit may not be a uniformly cost-effective choice for all homeowners (unless cheaper or DIY labor is utilized), but it appears to be a uniformly positive retrofit.

The immediate potential of the radiant barrier retrofit to older homes in climate zone 2A is overall good, but the amount of positive impact is not predictable. An unexpected and unexplained factor appeared in the data: the case study homes used more energy heating than cooling. Gomez et. al. (2015) had a similar finding in analysis of older homes in San Antonio. This means homes in San Antonio are able to realize improvement from the radiant barrier in both heating and cooling seasons. The amount of improvement observed in energy heating does not align with results anticipated by the research team.

Relative comparison to other, potentially more impactful retrofits

The radiant barrier is one of many types of retrofits a homeowner may choose to pursue. Research and analysis shows a wide array of retrofits with higher cost-benefit potential (see Dupont, et. al., 2016). A central purpose of this study was to determine if the radiant barrier deserves greater attention from homeowners as well as utility companies who seek to lower energy consumption overall. Is the radiant barrier a 'low-hanging fruit' for energy savings, capable of effective results for a reasonable installation cost? The answer is affirmative, but not enthusiastically affirmative. Any optimism must be tempered with reservations due to the many unknown variables of pre-existing conditions in older homes that impact performance.

Recommendations for further study and analysis

Additional research is necessary and justified because the radiant barrier remains very worthy of consideration as a cost-effective retrofit. First and foremost, a much larger study is warranted. Data from more homes will allow analysis with far greater accuracy, and result in more precise and useful findings. A larger sample size will not be inexpensive to acquire. Participation in a controlled, 2-year study by hundreds of homeowners will need to be subsidized or underwritten. Homeowners will signup enthusiastically to receive a free retrofit, or one with a very minimal cost.

The labor cost has a huge impact on cost-benefit analysis for this retrofit. More data is needed on the installation costs of the radiant barrier installation. A future study can be done independent of other research. Data can collected from prior installations, along with information on roof type and size. Field assessment of actual, case study installations will be necessary to fully analyze results and produce useful recommendations.

Finally, the unexpected and unexplained energy use pattern discovered in this study needs further attention. Data showed natural gas EUI to be 35% higher than electric EUI. Future research is needed to explore the energy heating profile and performance in climate zone 2A, and determine why this is occurring, because the cooling load is supposed to be the greater concern in climate zone 2A.

Acknowledgements

This report was made possible by a grant from the National Center for Preservation Technology and Training, National Park Service, U.S. Department of the Interior, under Task Agreement Number P14AP00143. Principal Investigator was William A. Dupont. Research Team of Co-Principal Investigators: Drs. Hazem Rashed-Ali, Randall D. Manteufel, and Suat Gunhan. Graduate assistants Mary Minor and Cristina Gonzalez Pope contributed. Layout/production by Tracie Quinn.

References

Asadi, S., and Marwa M. Hassan M.M. (2014). *Evaluation of the thermal performance of a roof-mounted radiant barrier in residential buildings: Experimental study*. Journal of Building Physics 38:66-80.

Cazayoux, E.J. (2003). *A manual for the environmental & climatic and responsive restoration & renovation of older houses in Louisiana.* Baton Rouge, LA: Louisiana Department of Natural Resources, Technology Assessment Division, Energy Section.

Dupont, W. A., Rashed-Ali, H. M., Manteufel, R. D., Thomson, T. A., & Sanciuc, L. (2016). Energy Retrofit of Older Homes in Hot and Humid Climates. *APT Bulletin: The Journal of Preservation Technology. Mount Ida Press, 47*(1).

EPA (2017). Energy Star Portfolio Manager. Accessed at: www.energystar.gov/buildings/facility-owners-and-managers/existing-buildings/use-portfolio-manager, February 1, 2017.

Frey, P., Dunn, L., Cochran, R., Spataro, K., McLennan, J.F., DiNola, R., . . ., Humbert, S. (2012). *The Greenest Building: Quantifying the environmental value of building reuse*. Washington, DC: National Trust for Historic Preservation, Preservation Green Lab.

Gomez, Juan D., Afamia Elnakat, Martha Wright, and Jourdaine Keener (2015). Analysis of the energy index as a benchmarking indicator of potential energy savings in the San Antonio, Texas single-family residential sector. *Energy Efficiency* 2015, 8:577-593.

Grimmer, A.E., Hensley, J.E., Petrella, L., Tepper, A.T. (2011). *The secretary of the interior's standards for rehabilitation & illustrated guidelines on sustainability for rehabilitating historic buildings*. Washington, DC: U.S. Department of the Interior, National Park Service, Technical Preservation Services.

Lee, S.W., Chin H.L., Elias I.B.S. (2016). Reflective thermal insulation systems in building: A review on radiant barrier and reflective insulation. Renewable and Sustainable Energy Reviews, 65: 643-661.

McIlvaine, J., Sutherland, K., and Martin, E. (2013). *Energy retrofit field study and best practices in a hot-humid climate*. Prepared for: The National Renewable Energy Laboratory, on behalf of the U.S. Department of

Energy's Building America Program, Office of Energy Efficiency and Renewable Energy. Cocoa, FL: BA-PIRC/Florida Solar Energy Center.

Medina, M.A. (2001). *On the performance of radiant barriers in combination with different attic insulation levels.* Energy and Buildings 33,5. New York: Elsevier.

U.S. Energy Information Administration, U.S. Department of Energy. *Annual energy review 2010.* (2011). Retrieved from http://www.eia.gov/totalenergy/data/annual/pdf/aer.pdf , February 23, 2012.

Powerhouse Dynamics, 2017. SiteSage: manage assets, operations and energy, Accessed at: www.powerhousedynamics.com, February 1, 2017.

Parker, D.S., J. R. Sherwin and M. T. Anello, (January 2001). "FPC Residential Monitoring Project: New Technology Development - Radiant Barrier Pilot Project," Contract Report FSEC-CR-1231-01, Florida Solar Energy Center, Cocoa, Florida.
http://www.fsec.ucf.edu/en/publications/html/FSEC-CR-1231-01/

Riggs, J. L., & West, T. M., 1986. Essentials of engineering economics. McGraw-Hill College.

Appendix A

Participants Needed for Research on Energy Efficiency of Older Homes

Study Title: Radiant Barrier Retrofits to Improve Energy Efficiency of Older Homes in Hot-Humid Climate Zones

Researchers at The University of Texas at San Antonio want to find ways to improve the energy efficiency of older homes while sustaining the cultural heritage of the home and surrounding neighborhood. Participation is voluntary.

Would the study be a good fit for me?

This study might be a good fit for you if:

- You own a detached, one-story home (2 – 3 bedrooms; approximately 1,500 – 2,200 square feet).
- The home was built between 1900 and 1950 and is located in one of San Antonio's historic districts.
- Your home is occupied (going back at least two years), heated and has some form of air conditioning.
- Your home has been continuously maintained and is in reasonably good condition.
- Your home has not been extensively expanded or heavily modified.
- Your home has not yet been fully retrofitted for better energy performance.
- You have a router with WiFi that can be used to transmit very small quantities of data to the research team from an electric energy use monitor.

What would happen if I took part in the study?

If you decide to take part in the research study, you would:

- Allow limited field inspection and testing of the home, as follows:
  - Attic access for measurement and documentation of existing construction.
  - A test of your home's air-tightness, called a blower-door test, as well as HVAC duct leakage test, both to be performed by a qualified contractor at university's expense.
- Allow an energy monitoring device (e-monitor) to be installed at the home's exterior electric panel box by a licensed electrician, at university's expense.

- Provide researchers with copies of CPS energy bills going back at least 12 months prior to retrofit (two years of historical data preferred, if available), and going forward at least 12 months after the retrofit is completed.
- Hire a qualified contractor to install (at the homeowner's expense) the radiant barrier improvement specified by the research team.
- Provide records of the radiant barrier installation cost to the research team.

There may be possible benefits if you take part in the study.

- You will acquire a potential valuable energy retrofit improvement to your home.
- Though anticipated, the radiant barrier installation is not warranted or promised to produce operational costs savings to the home occupants.

To take part in this research study or for more information, please send an email to william.dupont@utsa.edu.

The principal researcher for this study is William A. Dupont, San Antonio Conservation Society Endowed Professor, and Director, Center for Cultural Sustainability

Appendix B

Radiant Barrier Product Specifications
Center for Cultural Sustainability — November 19, 2014

Researchers at the Center for Cultural Sustainability (CCS), UTSA College of Architecture, Construction and Planning, are conducting a study on the performance of radiant barriers as a retrofit to older homes.

This document provides the product specifications for installation of a radiant barrier into a home that is a participant in the research study.

Notes to Installers:

- The radiant barrier can be installed by either the homeowner or a contractor.
- Please comply with these specifications, or else the home cannot continue in the study.
- Contact the CCS prior to installation to confirm that your work will comply. Faculty researchers will be available to answer questions.
- Your installation will be inspected at the conclusion of the work to assure that it complies with the specifications provided below.

CCS contact information: william.dupont@utsa.edu

General Spec Sheet for Radiant Barrier Installation

Tools

- Scissors or Utility Knife
- Measuring Tape
- Stapler and Staples
- Safety Goggles
- Light(s)

Industry Standards

A **radiant barrier** is a highly reflective material that reflects radiant heat rather than absorbing it. They are usually installed in attics primarily to reduce summer heat gain and reduce cooling costs.

-www.energy.gov/energysaver/articles/radiant-barriers

Required product: a roof radiant barrier with an emittance of 0.05 or less as tested in accordance with ASTM C-1371 (Standard Method of Determination of Emittance of Materials Near Room Temperature Using Portable Emissiometers) or ASTM E-408 (Standard Test Methods for Total Normal Emittance of Surfaces Using Inspection-Meter Techniques).

The radiant barrier shall be installed according to the manufacturer's instructions.

pg. 1

Radiant Barrier Product Specifications
Center for Cultural Sustainability — November 19, 2014

Acceptable Products (not listed in any order of preference, all are equally acceptable)

- **Silver Shield Radiant Barrier or Radiant Shield**
  - FI-Foil Company
  - http://www.fifoil.com/products/radiant-barriers/silver-shield
  - Auburndale, Florida
- **Reflectix Radiant Barrier RB4812550**
  - Reflectix, Inc.
  - http://www.reflectixinc.com/basepage.asp?PageName=Radiant+Barrier&PageIndex=624
  - Markleville, IN, USA
- **Super R Platinum Radiant Barrier Reflection**
  - Innovative Insulation, Inc
  - http://www.radiantbarrier.com/diamond-insulation.htm
  - Arlington, TX
- **3023 Silvertanium Reflective Insulation Roll**
  - Reach Barrier LLC
  - http://www.reachbarrier.com/products/3023
  - Richardson, TX
- **Enerflex Radiant Barrier**
  - Universal Forest Products, Inc.
  - http://www.enerflexfoil.com/products.aspx
- **Ultra NT SCIF Barrier**
  - TVM Building Products, Inc.
  - http://www.ultrantscifbarrier.com/images/[illegible]-1258.pdf
  - Kissimmee, FL

Recommendations and Safety Guidelines Prior to Installation

Follow manufacturer's instructions including all safety precautions and recommendations.

Do not step or store materials between joists. Use plywood to distribute weight across joists.

Use eye protection when operating a staple gun.

Be aware of where electrical wiring is located. Stapling into a wire can cause severe shock or death. NEVER staple into electrical wiring.

Do not work in areas where temperatures are too hot.

Installation, general:

The foil surface of your barrier should be installed facing a minimum of ¾" air space.

Be sure not to block ventilation paths when you install radiant barrier.

Check the area you are insulating and make any needed repairs. Any worn electrical wiring should be replaced before you begin installing.

Make sure work areas are well ventilated and well lighted.

Pg. 2

Radiant Barrier Product Specifications

Center for Cultural Sustainability — November 19, 2014

Under Side of Rafter Installation Method:

Unroll the radiant barrier as you work and cut it into suitable lengths. It may be easier to unroll and cut sections of barriers on the ground into specific lengths before taking it up to the attic.

The barrier can be purchased to fit normal rafter spacing at widths of 16" and 24" for easier installation.

Install around existing attic ventilation. It is important to maintain attic ventilation. Leave a 1" gap around all vents.

Install product perpendicular to the rafters with a 2" overlap on the seams. No taping required.

Staple to the rafters at 2" to 3" intervals.

Leave a 2" to 3" gap on each side of the roof peak and a gap at the lower edge of the roofline

Staple to the face of the studs on gables. Do not cover or block vents.

Pg. 3

Appendix C

Permission to Take Part in a Human Research Study

Title of research study: Radiant Barrier Retrofits to Improve Energy Efficiency Of Older Homes in Hot-Humid Climate Zones ***(14-239)***

Investigator: William A Dupont

Purpose of the research study and reason for your participation:

This project addresses a national need in preservation technology to educate the public on best practices for energy improvement retrofits to older homes. The research will measure the actual cost and corresponding energy use reduction of one significant retrofit – installation of the radiant barrier – in ten case study homes. The research concerns building performance before and after the energy retrofit. The particular retrofit to be evaluated, a radiant barrier, is relatively inexpensive and straightforward to install within existing homes, offering high potential value as a retrofit.

Your participation is necessary because the researchers need measurements of energy use from representative examples of older homes in hot-humid climate zones. Once selected for participation, each homeowner will be responsible for installation of the radiant barrier retrofit, including the cost. We invite you to take part in a research study because your home matches the criteria for the focus of our research, as follows:

- Detached, one-story home (2 – 3 bedrooms; approximately 1,500 – 2,200 square feet).
- Construction date between 1900 and 1950.
- Located in one of San Antonio's 28 historic districts.
- Occupied for at least two previous years; heated and has some form of air conditioning.
- Home has been continuously maintained and is in reasonably good condition.
- Home has not been extensively expanded or heavily modified.
- Home has not yet been fully retrofitted for better energy performance.
- Existing attic insulation attaining R-30 (50% of study group), or no attic insulation (50% of study group).
- Available Wi-Fi signal for internet access. This will be used for transmission of energy usage data from a monitoring device to the research team.

Conditions surrounding your participation:

- Someone will explain this research study to you.
- Whether or not you take part is up to you.
- You can choose not to take part.
- You can agree to take part and later change your mind.
- Your decision will not be held against you.
- You can ask all the questions you want before you decide.

14-239
Approved: 08-08-14

IRB Approval Date

Document Revision Date: August 11, 2014

Permission to Take Part in a Human Research Study

Contact information:

If you have questions, concerns, complaints, or think the research has harmed you, you may talk to the research team at:

William Dupont, 210-458-3092 or william.dupont@utsa.edu

This research is being overseen by an Institutional Review Board ("IRB"). You may also talk to them at (210) 458-6473 or IRB@utsa.edu if you have questions regarding your rights as a research participant or other questions, concerns, or complaints.

Participation in the research study:

After phone interview screening, a research team member will make a brief field inspection of your home to assess existing energy-efficient characteristics and appropriateness of participation in the study. Attic access will be necessary at the time of this preliminary field inspection.

If your home meets the selection criteria and you agree to take part in this study, you will then be asked to:

- Allow limited field inspection and testing of your home, as follows:
    - Allow researchers access for field inspection and testing. Researchers will enter your attic to obtain physical measurements and technical information on construction materials and assemblies.
    - Allow researchers to administer a test of your home's air-tightness, called a blower-door test, as well as HVAC duct leakage test, both to be performed by a qualified contractor at university's expense.
    - This field inspection and testing will require 1/2 day of time, to be conducted August/ September/ October 2014.
- Allow an energy monitoring device (e-monitor, purchased and installed at expense of the university) to be installed at your home's exterior electric panel box by a licensed electrician. The monitor will transmit data over the internet to the research team, and requires a Wi-Fi signal available at the home. Installation is expected to be October/ November/ December 2014.
- Provide researchers with copies of CPS energy bills going back at least 12 months prior to retrofit (two years of historical data preferred, if available), and going forward at least 12 months after the retrofit is completed.
- Hire a qualified contractor to install (at your expense) the radiant barrier improvement specified by the research team. A research team member will attends a "kick-off" meeting with the contractor to review the scope of work and explain the need to execute the retrofit precisely. A research team member will make a field inspection after installation for quality conformance. Installation needs to be complete by the end of March 2015.
- Provide records of the radiant barrier installation cost to the research team.
- There will be 12 months of data monitoring after installation of the radiant barrier. The data will be analyzed to determine the energy use reductions and corresponding operational cost savings.
- The house needs to continue a normal pattern of residential use for at least 12 months following the installation of the radiant barrier. The Wi-Fi needs to be available for data transmission from the e-monitor. Notify the research team of significant changes in use, such as an atypical period of vacancy.

Permission to Take Part in a Human Research Study

- Allow researchers to remove the energy monitoring devices from your home at the project's conclusion, expected to be September 2016.
- You may be asked to extend your participation in the research study by leaving the energy use monitoring device installed and transmitting data from your home to the research team members.

Additional information:

This research is being funded by U.S. Department of the Interior, National Park Service, National Center for Preservation Technology and Training.

Participants will incur the cost of radiant barrier installation in their home.

Risks and Discomforts:

We do not anticipate any risks to you participating in this study, however, a possible inconvenience may be the time required for the field survey and blower-door test, as well as installation and removal of the energy monitoring devices.

There is a risk that the radiant barrier installation will not result in any operational cost reductions to the home occupants.

Benefits for Participation:

Though anticipated, the radiant barrier installation is not warranted or promised to produce operational costs savings to the home occupants. There is no prior research to accurately predict positive results that may result from this particular energy retrofit.

Participant Privacy and Research Record Confidentiality:

The data resulting from your participation may be used in publications and presentations. The research team intends to disseminate findings to academic, professional and general public audiences. Non-identifiable photographs of your home may be included within publications and presentations. Your identity, name and home address will not be disclosed.

The private, identifiable information, including the identity of study participants and home occupants, as well as the specific addresses of the case study homes, is not relevant to the project's research objectives. Numerical identifiers for each home will be utilized to protect identity. The research and analysis will be conducted using the numerical identifiers.

Permission to Take Part in a Human Research Study

Signature Block for Capable Adult

Your signature documents your permission for the named participant to take part in this research.

14-239
Approved: 08-08-14
IRB Approval Date

Name of participant homeowner

Signature of legally authorized representative — Date: 9 Nov. 2015

Signature of person obtaining consent — Date: 9 Nov 2015