Analyzing energy saving retrofit potential of historic homes in hot-humid climates

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ABSTRACT: The implementation of sustainable design practices, building materials and energy efficient products offers benefits to building owners and occupants. An energy efficient and sustainable building can reduce operation and maintenance costs, conserve energy, and improve occupant health. Maintenance and improvements extend the life of building materials, reducing the need for future replacement, thereby saving the need for fabrication and installation of new materials and needless additions to local landfills. Continued use of existing building stock has two primary benefits: 1) retaining the embodied energy of the existing construction, and 2) promoting healthier and stronger communities due to continuity of cultural identity. Property owners need practical, reliable, and accurate information in an accessible format to understand the benefits of employing sustainable products and practices while renovating or retrofitting their existing and affordable homes. Historic homes in particular present unique challenges for energy efficient retrofits both because of the age of the building and its systems and because of the historic preservation-related limitations typically placed on implementing retrofits.

This paper will report on and identify lessons learned from an interdisciplinary project that aimed to identify possible retrofit packages for historic homes in San Antonio, TX. The project, which involved researchers from architecture, mechanical engineering, and real estate finance, aimed to identify cost effective retrofit packages that owners of historic homes can implement to reduce energy use, while maintaining the cultural identity of the homes. The project included the analysis of four case study historic homes constructed in the early twentieth century. Initial results indicate that cost-effective improvements would include installation of a radiant barrier, attic and crawl space insulation, and overall reductions to air infiltration. In general, retention of historic fabric including siding and windows is recommended given the potential negative effect on homes historic character and extended energy savings payback.

KEYWORDS: Historic Homes; Energy Efficiency; Residential Retrofits

INTRODUCTION

Over the past three decades, numerous studies have established the need for adopting the principles and practices of sustainable development. While there is still some lack of consensus over the definition of sustainable development, there is general agreement over the need to balance its three main components: environmental, economic, and social sustainability. The environmental dimension of sustainability stems from the growing realization of the increasing and potentially irreversible damage facing the environment (e.g. WCED 1987, IPCC 2013, IEA, 2014). Offering its strongest assessment to date, the latest IPCC report (IPCC 2013, 2) states that:

> "Warming of the climate system is unequivocal, and since the 1950s many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased".

With regard to the question of human influence on climate change, the IPCC goes on to state that:

> "Human influence on the climate system is clear. This is evident from the increasing greenhouse gas concentrations in the atmosphere, positive radiative forcing, observed warming, and understanding of the climate system".

Energy related issues have been identified as central issues in the sustainability debate. Reddy et al. (1997) contends that energy is not a sectoral issue but one that it is related to numerous dimensions of development, while Johansson & Goldemberg (2004) describe conventional sources of and approaches to providing and using energy as unsustainable and link them to significant environmental, social, and health problems. This increases the significance of studies that aim to identify different strategies to achieve a more sustainable energy system including more efficient use of energy at the point of end use. The built environment plays a major role in the U.S. energy system in particular through energy use in the residential and commercial sectors. The latest data by the Energy Information Agency (EIA 2014) show that in 2013, the building sector accounted for 40.3% of the total energy use in the US with 21.8% of that use happening in the residential sector. This further illustrates the significance of activities aiming at increasing the energy efficiency of buildings in general, and of residential buildings in particular.

Increasing the energy efficiency of the residential sector involves addressing both new and existing housing stocks. Increasing the efficiency of existing residential buildings is particularly important considering that they are typically much less efficient than new ones. Several studies have focused on identifying appropriate retrofit strategies for existing housing in different climate regions (e.g. Florian et al. 2011, Parker 2001, Burgett et al. 2013). However, not much research has been conducted on the retrofit potential of historic homes despite the historical, cultural and social significance they represent to the communities and cities in which they are located. According to HUD (2008), approximately one third of all residential housing units (about 40 million) were built before 1960. That makes them more than 50 years old and likely to have some historical or cultural value. Unknown quantities of housing units are already listed in protected historic districts, with more being designated each year. San Antonio, for example, has created 28 historic districts beginning with King William in 1968. The fact that products and design details generated for new construction are not always a good fit to older homes, and can actually cause irreparable harm if misapplied further increases the need to investigate this issue using a structured and scientifically-valid approach. Additionally, beyond the scientific concerns of building technology, there are competing values that come into play within designated historic districts. Accurate information from objective experts in a format that can be directly applied to real situations is not available and is needed. The potential savings to be realized from retrofit work on existing, older homes is considerable. At the same time, these historic homes need thoughtful attention to the details and features that cause society to give them protected listings due to their cultural heritage value. Overall, the architectural design and construction field lacks case study analysis of real situations that can benefit older homes. The implementation of sustainable design practices, building materials and energy efficient products offers benefits to the building's owner and occupants. An energy efficient and sustainable building can reduce operation and maintenance costs, conserve energy, and improve indoor air quality and occupant health. Maintenance and improvements extend the life of building materials, reducing the need for future replacement, thereby saving the need for fabrication and installation of new materials and needless additions to local landfills. Continued use of existing building stock has two primary benefits: 1) retaining the embodied energy of the existing construction, and 2) promoting healthier and stronger communities due to continuity of cultural identity.

1.0 PROJECT DESCRIPTION

The project described in this paper was initially envisioned as a response to the lack of research focusing on identifying appropriate retrofit opportunities for historical housing in the US particularly in hot and humid climates. To address this need, the project utilized a case study approach in which four pre-World War II homes located in San Antonio, TX were studied to investigate their energy efficiency retrofit potential. This project represents one of the first attempts to investigate this issue in the southwest region of the country. The project aimed to identify practical and economical retrofit measures and design solutions that are based on measurable data, and that can assist contractors and homeowners of historic homes in improving the energy efficiency of their homes in a manner that does not affect the historical and cultural value those homes represent. Findings from this study will allow those homeowners and contractors to make better-informed decisions when considering maintenance, changes or improvements on a historic house. Similar to many other sustainability-related projects, this one addressed a complex set of issues on the environmental, social, cultural, and economic fronts. This made it difficult if not impossible to investigate the problem through a single disciplinary lens. To respond to this complexity, the project adopted an interdisciplinary approach in which a team of researchers from different disciplines and with complementary sets of expertise were involved. The team was led by an expert in historic preservation, and included researchers with primary expertise in the areas of building performance simulation and evaluation, building systems, and real estate finance. This approach made it possible to fully address the complexity of the issues involved and to reach conclusions that are based on sound research while at the same time having practical value to the project's target population. The activities described in this paper represent the first phase of a longer-term effort to investigate the issue of energy efficiency retrofits of historic home, in which specific energy efficiency-related retrofit measures will be installed in historic homes, and their impact on the buildings' energy use will be monitored and verified. The second phase of the work is currently underway in which a similar case study approach is being utilized to investigate the impact of installing radiant barriers in the attics of historic homes from the same time period.

2.0 METHODOLOGY

As mentioned above, the work described in this paper represents the first phase of a larger and longer-term project. The aim of this phase was to identify and prioritize retrofit measures than can both increase the energy efficiency of historic homes as well as preserve their cultural and historical characteristics. Following a case study approach, this first phase involved a detailed study of four historic homes from the pre-World War II period. All four homes were located in the Lavaca neighbourhood of downtown San Antonio. Lavaca was designated as a historic district by the City of San Antonio in 2001. The methodology used in this study consisted of five phases, which will be described in more detail in the following sections.

2.1. Review of relevant literature

The review of literature focused on both identifying prior studies with similar or related focus, as well as researching energy efficiency retrofits in general from the point of view of their suitability for historic homes. With regard to previous studies, the review indicated a general shortage of studies focusing on existing homes and in particular historic ones, especially those that aim to establish a sound research base for their findings. A small number of studies were identified that investigated the retrofit potential of historic homes in cold climates (e.g. Cavalo 2005, Culver and Randall 2010, and Verbeeck and Hens 2005). While useful in terms of methodology, conclusions reached in these studies have limited applicability to homes in hot and humid climates given the large differences between the demands and potentials offered by both climate regions. In hot and humid climates, the Florida Solar Energy Center (Parker et al. 2001) conducted a study, which used a case study approach to investigate the retrofit potential of installing radiant barriers in existing homes in central Florida. Pacific Northwest National Laboratory, PNNL (Chandra et al. 2012) conducted a similar study that covered 51 homes in marine, cold and hot-humid climates including six homes in Atlanta and three in San Antonio. Burgett et al. (2013) used a simulation-based approach to identify retrofit packages for existing homes in hot and humid climates in general. Several other studies focused on monitoring existing homes in hot and humid climates to better understand their load profiles including Parker (2003) which monitored 204 homes in central Florida, and Florian et al. (2011) which included a similar study by CPS Energy, the local municipal utility in San Antonio, monitoring 8 homes in San Antonio. None of these studies, however, addressed the unique conditions presented by historic homes, thus establishing the need for the project described in this paper. These previous studies also helped in identifying retrofit measures generally recommended for existing residential buildings. A more detailed review was then conducted for these measures to identify their potential suitability for historic homes and potential impact on the homes' historical character. This review also covered the costs of installing each of these retrofits in historic homes in San Antonio, which was later used in identifying the potential economic payback each of those retrofit measures can achieve.

2.2. Conditions assessment of case study homes

Four historic homes located in the Lavaca Historic District in San Antonio were selected for the study through a recruitment process in which owners of historic homes with the desired characteristics were encouraged to participate. A detailed conditions assessment was then conducted for each of these four homes. The assessment included the following activities:

1) A visual inspection of the homes, which aimed to insure that they represented the typical characteristics of historic homes from the targeted period in San Antonio primarily in terms of size, construction, and lack of major prior retrofits. The details of those house characteristics are included in Table 1. The inspection also aimed to identify major energy efficiency problems or deficiencies in those home including potential issues in the building envelops (see Fig. 1a, b) and/or in major energy-consuming systems such as HVAC, domestic hot water, or major appliances. Additionally, the inspection utilized infra-red photography to identify area with major infiltration issues in the building envelop (see example in Fig. 1,c)

Table 1: Characteristics of case study homes.

	Home 1	Home 2	Home 3	Home 4
Construction date	1904	Circa 1883	1919	1910
Size (CFA)	1,465 ft^2	1,567 ft^2	1713 ft^2	2099 ft^2
Number of stories	1	1	1.5	1
Number of users	1	4	2	4
Construction	Wood frame on wood piers, raised floor, sheet metal roof.	Wood frame on concrete piers, raised floor, sheet metal roof.	Wood frame on wood piers, raised floor, sheet metal roof.	Wood frame on concrete piers, raised floor, asphalt shingles.
Insulation status	No floor, some parts of walls and roof.	Wall and roof insulation added.	No walls or floor, insulated roof.	No wall or floor, some roof.
Glazing	Single glazing, wood frame, poor condition.	Single glazing, wood frame, poor condition.	Single glazing, wood frame, poor condition.	Single glazing, restored and new.
Cooling system	Central air, 12SEER	Central air, 14SEER	Central air, 10SEER	Central air, 16SEER
Heating system	Electric resistance	Gas furnace, 80 AFUE	Gas furnace, 80 AFUE	Electric resistance
Electric lighting	Incandescent	All CFL	75% CFL	Incandescent
Prior retrofits	Modern kitchen	HVAC; some insulation around openings; roof;	Insulation and radiant barrier in attic.	Window replacement and restoration.

a) poor attic condition in home 3, b) uninsulated attic in home 2, c) infiltration losses in home 2

Figure 1: Sample images from the visual and infra-red inspection of the case study homes.

2) A detailed conditions assessment conducted by a certified home energy rater including a blower door test, a duct leakage test, and identification of the HERS rating for the home. Results of this assessment for each home are included in Table 2, and sample images for the testing are included in Fig. 2. Assessment results shown in Table 2 illustrate the generally poor level of energy efficiency in all four homes, which was expected given their age and condition. However, they also illustrate that the homes showed considerable differences in their performance as indicated be their HERS rating, which ranged from 131 in home 4 to 296 in home 1, representing a difference of more than 225% in energy performance. This is a typical situation with existing homes and in particular historic ones.

Table 2: Results of case study homes conditions assessment.

	Home 1	Home 2	Home 3	Home 4
HERS Index	296	143	204	131
Blower door results	8,876 CFM50	10,495 CFM50	7,508 CFM50	7,845 CFM50
Duct leakage to outside	Front system: 185 CFM25 (15.4%) Back system: 210 CFM25 (17.5%)	193 CFM25 (9.7%)	600 CFM25 (app. 50%)	System 1: 193 CFM25 (12%) System 2: 159 CFM25 (10%)

Figure 2: Door blower testing performed for case study homes.

3) A detailed homeowner survey was also conducted for each of the homes, which collected information on the major energy using systems in the homes, their efficiency, and year of installation. The survey also collected information on energy use patterns and user behaviour, which varied considerably between the four homes. This information was later used to develop and calibrate the energy models used in this study. The survey was adapted from a homeowner survey developed by PNNL for their study discussed above (Chandra et al. 2012). Two years of electricity and gas usage, were also collected for each home.

2.3. Real-time monitoring of energy use

Energy monitoring systems, eMonitors, were installed in each of the four case study homes. The systems provided real-time monitoring of the homes' electricity usage at one-minute intervals. The installed systems monitored both the homes' overall electricity use as well as some end uses depending on the configuration of each home's main electric panel. Data from the monitoring was available to the research team through a web interface, which provided some aggregated metrics as well as the ability to download the raw monitoring data. In most cases, the sub metering allowed for the identification and separation of the energy use of the HVAC system and some major appliances. However, in several homes, the main electric panel did not provide sufficient flexibility to allow for the more fine-grained monitoring of different electricity end uses that the eMonitor system is capable of. This was mainly due to the lack of sufficient sub-circuits or the inadequate distribution of the sub circuits over the different end uses. The eMonitor systems remained installed in the case study homes for at least one year. However, in some cases minor losses of data of a few hours to a couple of days were experienced due to power outages or, in one case, to the accidental disconnection of the system by the owner. In another case, several weeks of data were lost due to hardware failure of the eMonitor system. With all that in mind, the eMonitor systems still provided the research team with valuable information about the energy use patterns within the homes. This information helped in the calibration of the models as will be discussed in the following section. The information also provides the potential for additional studies investigating the differences in usage patterns between the homes and their impact on energy use.

2.4. Performance simulating and model calibration

A whole-building energy use simulation model was developed for each of the four case study homes using the software IES-VE 2012 (IES 2013). The model development was based on the conditions assessments discussed in section 2.2 including the visual survey, measurements of house dimensions, homeowner surveys, and the energy audits conducted by the home energy rater. Information from the homeowner surveys were particularly important in developing appropriate occupancy and systems schedules for the different homes, which was an area in which the survey showed considerable differences between the home owners/users. Other simulation parameters not included in the sources above were based on the Building America program research benchmark definition (Hendron 2008). The model was calibrated primarily using information from the utility bills collected from the homeowners, which provided two years of electricity and gas usage information for each home. Utility bill information as adjusted to correspond to calendar months to overcome the inconsistency of the billing periods' lengths and dates. Additional calibration was also conducted based on information gained from the real-time monitoring system especially with regard to occupancy profiles and usage patterns of different systems in the homes. The results of the calibration are included in Table 3 below. As shown in the table, utility data for all homes showed an increase in usage in 2012 compared to 2011, which could be explained in the most part by differences in climatic conditions. The results of the calibration shown in the table indicate that the energy use of the calibrated model was between +9.3% to -8.2% with the exception of Home 2. For home 2, the utility usage was considerably high in 2012, which is likely due to changes in user behaviour.

Table 3: Results of performance model calibration.

	Model EUI *(kBtu/sqft/yr)*	2011 Utility data EUI *(kBtu/ft^2/yr)*	Model vs. actual	2012 Utility data EUI *(kBtu/ft^2/yr)*	Model vs. actual
Home 1	43.5	41.0	+6.1%	47.4	-8.2%
Home 2	50.9	46.7	+9.1%	66.7	-23.6%
Home 3	69.5	63.6	+9.3%	73.5	-5.3%
Home 4	30.9	29.4	+4.8%	32.6	-5.3%

2.5. Simulation of retrofit measures

Following the model calibration process, a parametric analysis was conducted in which a series of possible retrofits, previously identified from the literature, were simulated using IES-VE, and the impact of each of the proposed retrofits on the annual energy use of the homes was determined. The main types of retrofits investigated through simulation included: 1) reducing infiltration energy losses through weather stripping of historic windows and doors, sealing of HVAC ducts, and sealing of gaps and cracks in the building envelop; 2) adding envelop insulation / increasing the R-value for the walls, attic, and/or crawl space; and 3) replacing single glazed windows with double-glazed ones. Other model characteristics including user behaviour patterns were maintained the same as in the base models. Retrofits were only simulated in the homes in which they could be applied. For example, adding attic insulation was only simulated in the two homes that did not contain such insulation to begin with. For certain retrofits, such as reducing infiltration losses, several levels of reduction in infiltration were investigated responding to different possible retrofit measures.

Other retrofits were also investigated including lighting system retrofits, adding radiant barriers to attics, and adding whole house fans. For the retrofits investigated through simulation, an estimate of the annual savings achieved from implementing these retrofits was calculated based on achieved reductions in energy use (electric and gas) and local cost of energy. An average savings was then calculated for the four homes and used to calculate a simple payback for implementing the retrofit measure based on the local cost of installation. Evaluations of retrofit measures that were not simulated were based on estimates of savings included in prior studies. The results of the analysis were used to identify the optimum retrofit measures for historic homes as will be discussed in the following section.

3.0 IDENTIFICATION OF OPTIMUM RETROFIT MEASURES

The final stage of the work involved the identification of appropriate retrofit measures for the target population of the study, historic homes in San Antonio. Retrofit measures selected were those that offered the most potential from the points of view of energy savings and economic payback, as indicated by the simulation results and previous studies, while at the same time not having a negative impact on the historic character of the homes or the culture significances they represent within their communities. The recommended retrofit measures were divided into three categories: 1) primary retrofits, including retrofits that have a high impact on the home's energy use, a relatively short payback time, and minimal impact on the historic nature of the homes, 2) secondary retrofits, including retrofits that have a high impact on the home's energy use but were not easily implemented given the typical construction of the historic homes and the desire to preserve their character, and 3) retrofits that had a high impact on the home's energy usage but offered relatively long payback periods. Certain retrofit measures were not recommended mostly due to their potential negative impact on the historic character of the homes. The recommendations resulting from the work were included in a project report (Dupont et al. 2013) as well as in a series of posters (see Fig. 3) aimed in particular at homeowners of historic homes in the area. The following sections provide a brief summary of the recommended measures:

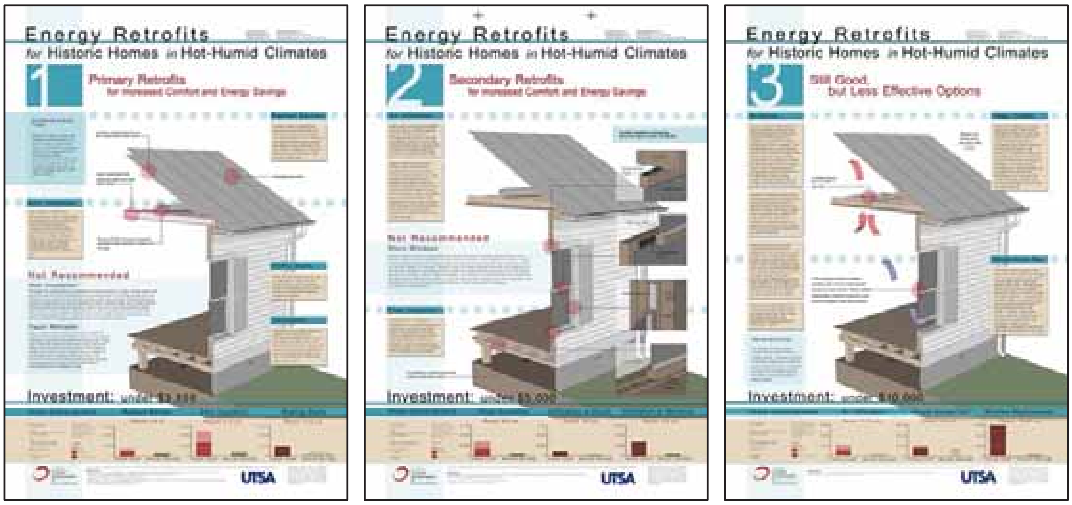

Figure 3: Posters illustrating recommended retrofit measures.

3.1. Primary retrofit measures

Primary retrofit measures identified within this study include: 1) attic insulation, which resulted in an average energy savings of 18.7% and a simple payback of 9-12 years, assuming an initial cost of approximately \$2,500; 2) sealing HVAC ducts, which had an initial cost of \$1,000 and resulted in a simple payback of 3-10 years; 3) radiant barriers, which were not simulated but were still recommended based on results of previous studies; and 4) attic ventilation, which was again recommended based on generally accepted guidance for residential home performance.

3.2. Secondary retrofit measures

The first retrofit measure identified within this category was reducing air infiltration through weather stripping the homes' historic windows and doors. Energy savings from reducing infiltration ranged between 15% to 40% reduction in overall energy use depending on the condition of the home and the level of infiltration reduction achieved. Weather stripping doors and windows resulted in a simple payback of 3-8 years. Adding thermal insulation to the crawlspace was also recommended as a secondary measure and resulted in an average reduction of approximately 15% in overall energy use, with a simple payback of 6-8 years. Several options were examined for crawl space insulation from the point of view of ease of installation and future maintenance potential, and rigid board insulation was recommended as the best option for historic homes.

3.3. Less effective and non-recommended retrofits

The study also identified a group of retrofit measures which can result in relatively high levels of energy savings but would result in very long payback periods, are difficult to implement given the historic nature of the homes, or both. Examples of those include replacing the historic windows with more efficient double-glazed ones, which resulted in a payback of 15-20 years; further reductions in infiltration through sealing of gaps and cracks in the raised flooring, walls, or ceilings, which are generally more difficult to achieve in historic homes; and the installation of whole house fans to be used in the spring and fall seasons instead of the HVAC system. Several measures were also not recommended because of their potential negative effect on the homes historic character and/or being difficult to implement. Examples of those include adding wall insulation or a vapour retarder, and installing storm windows.

3.4. Real estate prices analysis

While a simple payback analysis shows the order one should pursue energy efficient upgrades, the payback period may exceed the horizon over which the homeowner plans to remain in that house. A follow on question is whether a subsequent purchaser will pay a premium for energy efficient upgrades. As part of this study, an economic study was conducted to assess the degree that green retrofits affect the sales transactions prices. We analysed all of the sales of houses 50 years and older (6592 transactions) that sold through the Multiple Listing Service (MLS) in San Antonio, between October 2009 and December 2012. In addition to the standard variables of house size, style, garage spaces, number of bedrooms and bathrooms, etc. this MLS contains data fields to indicate whether the house has Green Certifications (such as LEED or Energy Star, which are becoming more common in new houses), Green Features (such as drought tolerant plants or low flow plumbing fixtures), and Energy efficiency Features (such as radiant barriers, additional insulation, and high efficiency HVAC systems). Table 4 shows the breakdown of our sales by age grouping, including how many transactions were available for each age group, and how common it was to observe a Green Certification (quite uncommon), Green Feature, or Energy Efficient Feature. Energy Efficiency Upgrades are the most commonly observed form of a green upgrade. We also combined these features into a single measure that at least one of these indicators was present (SomeGreen). In our sales transaction data we see that about 16% of sales show a green upgrade. Using Ordinary Least Squares we regressed the log of sales price on the variables that are known to affect sales prices (such as size, bathrooms, garage space, style, neighbourhood amenities, etc.) and our green indicators. Table 5 presents the key finding. Of interest to this study, is the coefficient for SomeGreen, which is statistically reliable 0.094. Because we use the log of house price, this result shows that for in our sales transactions data base, houses more than 50 years old that have at least one green upgrade, sell for a statistically significant 9.4% more than otherwise identical houses that have no green upgrades.

Table 4: Housing sample description for economic analysis.

Age Group	Age *N*	Average Age	# With Green Certification	# with Green Features	# with EE Features	SomeGreen
1	3272	55.6	3	84	498	522
2	1563	64.4	3	42	245	256
3	666	75.0	2	23	99	105
4	730	85.0	2	23	118	120
5	361	99.4	3	21	58	64

Table 5: Regression analysis results and parameter estimates.

Variable	DF	Parameter Estimates	Standard Error	t Value	Pr > l t l
SomeGreen	1	0.09354	0.02968	3.15	0.0016
age	1	0.00078215	0.00051221	1.53	0.1268
SqFt	1	0.52847	0.01332	39.66	< 0.0001

SUMMARY AND CONCLUSIONS

Findings from this project are helpful in three ways: 1) they aid historic homeowners in making smart investments in energy improvements; 2) they identify and recommend improvements that retain the integrity and identity of the architecture of the homes; and 3) they pioneer methods of reducing energy consumption in historic homes in hot and humid climates, all of which should be of great interest and value to the various stakeholders. In general, the results of the project indicate that retention of historic fabric is found to be compatible with attainment of energy savings, increased comfort, and increased home values. The general methodology used in this project, which utilized a case study approach combined with building performance simulation, is consistent with similar studies to assess the impact of retrofits of existing buildings and identify optimum retrofits. The small sample size and the large differences in performance between the selected homes made it difficult to reach more specific results with regard to the economic payback of installing different retrofit measures. This was addressed through providing a range of economic performance for each retrofit. However, such variations in performance are typical for residential buildings in general and historic ones in particular, and therefore the results can be considered as representative of this challenging sector of the market especially for homes located in areas similar to San Antonio. The depth of information collected within this study, including the detailed homeowner surveys and the real-time monitoring, add to the validity of the results and somewhat mitigate any limitations that may result from the small sample size. The real time energy monitoring component of the methodology allowed for a finer-grain calibration of the model, although this was sometimes affected by the technical difficulties encountered in collecting data from the monitoring systems as discussed above. Having such a component, however, will be key in the following phases of the work as discussed below. The inclusion of economic payback analysis also added considerably to the value of the study to its primary target population of contractors and historic homeowners in San Antonio, although the results may vary for other parts of the country in which installation costs can be different.

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