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The Sustainability Institute

Historic Charleston Foundation

Energy Efficiency in Historic Residences: A Case Study

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Introduction

Historic preservation and green building share the fundamental goal of preserving natural resources and promoting sustainable, vibrant communities. Traditionally, preservation has been discussed in terms of its cultural value to society, but increasingly preservation is being promoted for its environmental values as well. Existing buildings, historic or otherwise, have an inherent embodied energy value. The energy and natural resources consumed during the construction process of existing buildings has already been expended and realized, and this significant investment of resources should be valued. Demolition and new construction waste additional natural resources and expend tremendous amounts of additional energy. From a resource management perspective, renovating and rehabilitating historic structures exemplifies green building at its core—adaptive reuse and the efficient use of energy.

Despite this fact, historic buildings have gained a stigma for being unsustainable, primarily due to higher operational costs. Newer, "green" buildings are often hailed as clean and efficient based solely on lower energy operational costs. In many cases the green building movement is product-driven, encouraging consumers to replace products in their homes, or build new buildings, in an effort to become more energy efficient. This process is often expensive and invasive, without a commensurate increase in efficiency. Energy efficiency retrofits should always be performance-based to ensure that the renovations are targeted and strategic. Renovating with a focus on preservation principles provides owners of historic homes the ability to reap the benefits of the embodied value of their historic building while at the same time lowering its operational costs. Historic structures are inherently sustainable and will continue to be if their sound construction and superior materials are preserved properly. This important fact is supported by the research in this case study.

This study is the result of a partnership between the Sustainability Institute and Historic Charleston Foundation. The partnership focuses on bringing broader public awareness to the inherent efficiency in historic buildings and outlines the most cost-effective ways to make an historic building more energy efficient. To substantiate these assertions, we analyzed five historic structures in Charleston, South Carolina to assess their energy efficiency capabilities in the context of a warm, humid climate. Through modeling, performance testing, and careful analysis of the buildings within their climate context, this study proves that historic structures are capable of much higher levels of efficiency than generally thought. Using the *Secretary of Interior's Standards for Rehabilitation* as a guideline, this study seeks to prove that increased energy efficiency and reduced environmental impact are possible while maintaining and preserving the historic fabric of existing buildings. Through this analysis, this case study emphasizes the vital role historic preservation plays in sustainability both in the Lowcountry of South Carolina and around the world.

How are historic buildings energy efficient?

Historic buildings are often located in dense, mixed-use communities where walking and biking to neighborhood resources provide a reasonable alternative to driving. From a sustainability perspective, avoiding long drives to neighborhood amenities makes living in historic communities a more efficient use of natural resources. Adaptive reuse of historic buildings preserves the neighborhood fabric and drastically reduces the environmental impact of our daily activities.

Aside from location, one of the principal highlights of historic buildings that contribute to their sustainability profile is their embodied energy. *Embodied energy* is the sum total of energy necessary for an entire product lifecycle. This lifecycle includes raw material extraction, transport, manufacture, assembly, installation, disassembly, deconstruction and/or decomposition. In a recent article from *Preservation* magazine, Wayne Curtis rationalizes adaptive reuse and renovation rather than "building from scratch". He writes:

> "When people talk about energy use and buildings, they invariably mean operating energy: how much energy a building—whether new or old—will use from today forward for heating, cooling, and illumination. Starting at this point of analysis—the present—new will often trump old. But the analysis takes into account neither the energy that's *already bound up* in preexisting buildings nor the energy used to construct a new green building instead of reusing an old one."[1]

Curtis goes on to quote Mike Jackson, chief architect with the Illinois Historic Preservation Agency: "Old buildings are a fossil fuel repository, places where we've saved energy." By accounting for the energy stored in our historic buildings, we can take advantage of the "non-recoverable energy embodied in an existing building and extending the use of it." Therefore, adaptive reuse is generally the most efficient use of resources

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[1] Wayne Curtis. *"A Cautionary Tale: amid our green building boom, why neglecting the old in favor of the new might cost us dearly"*, (New York, *Preservation* magazine, 2008)

because it takes advantage of the significant embodied energy encapsulated in an existing building. [2]

By design, most historic homes were originally energy efficient. Historic homes were often built before the advent of air conditioning and they utilized the earth's natural energies, such as sunlight and wind, to provide for heating and cooling. In Charleston, these passive features were designed to catch coastal breezes, bring in natural light, provide shade, and capture rainwater for household use. Several of the buildings in this study are Charleston single houses, a vernacular building typology in the city. The Charleston single house utilizes many features that were created to adapt to the climate. These buildings were typically two or three stories over an open basement or crawl space, which provided height to catch the ocean breezes, even if they were not immediately next to the water.[3] The piazzas, or covered porches, were usually located along the south or west elevations, which shaded the building from intense sun and helped to funnel the prevailing breezes to all levels of the building.[4] These passive features are another sustainable aspect of historic properties.

Today, many sustainably focused companies utilize these same design techniques to achieve increased efficiency in new buildings, but with a noticeably more contemporary building shell. Examples of using historic building techniques in modern construction include daylighting strategies that offer natural lighting without heat gain,

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[2] Ibid.

[3] Gerald F. Foster. *"American Buildings: A Field guide to the Architecture of the Home",* (New York: Houghton Mifflin Harcourt, 2004): *154.*

[4] Ibid.

siting the building footprint to take advantage of passive solar energy, and using rainwater collection systems to capture water for landscape irrigation or toilet wastewater. These centuries-old techniques can effectively be applied to new construction to increase efficiency beyond high efficiency heating and cooling systems. In historic buildings, rediscovering these passive systems can constitute a strong foundation from which to build increased efficiency.

The addition of heating and cooling (HVAC) mechanical systems to historic buildings can create the largest obstacle to realizing efficiency gains. Ill-designed and poorly installed HVAC systems not only increase the energy consumption of a building but can also cause irreparable harm to the building. Originally, historic buildings were designed to take advantage of natural breezes in the Lowcountry. Additionally, these buildings rarely included insulation, making heat gain a constant issue when employing modern heating and cooling strategies. The standard approach to addressing infiltration and heat gain during rehabilitation has been to drastically increase the capacity of the HVAC system to overcome the indoor conditions of the homes. This process requires an extraordinary amount of energy and can be a catalyst for numerous problems that may impact the historic integrity of the structure. Sensitive retrofitting that protects the material integrity of the structure and increases the energy efficiency of the building is certainly possible. The impact and methodology of these retrofits are the focus of this report.

National and international efforts towards energy efficiency

The National Trust for Historic Preservation (the Trust) is a national, non-profit organization that seeks to "save historic places and revitalize America's communities."[5] Perhaps the most notable of their recent initiatives is their involvement in the ever-expanding "green" movement, partly exhibited by the dedication of the January/February 2008, March/April 2009, and March/April 2010 editions of *Preservation* magazine to "Green Issues." These issues are a part of their growing sustainability initiative, which focuses on promoting public policy (at the local, state, and federal levels) that supports the nexus of sustainability and preservation, facilitating new research in this rapidly expanding field, and providing outreach to local governments, practitioners, and property owners. The Trust has also established a Green Lab in Seattle, Washington in an effort to educate the public on retrofitting historic structures for increased efficiency. The primary goals of the Green Lab are to "develop and implement policies that support green retrofits and adaptive reuse, as well as reinvestment in existing communities." They intend to achieve this by setting up retrofitting projects both in Seattle and across the country in order to lead by example on this important issue. The current pilot cities are Seattle, Washington, San Francisco, California, and Dubuque, Iowa. The Trust's Green Lab is just the first of many research facilities that will continue to expand on the understudied subject of the energy performance of historic buildings.

The notion of promoting the inherent sustainability of historic buildings is not a new concept. During the late 1970s oil crisis, the preservation community was stalwartly

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[5] The National Trust for Historic Preservation, "About Us" www.preservationnation.org/about-us.

focused on the issue of energy efficiency and historic buildings. The National Trust produced a popular poster with an historic building in the shape of an oil can which read: "It takes energy to construct a new building. It saves energy to preserve an old one." The Trust has promoted the sustainability of historic buildings through the years, but the recent renewed international focus on sustainability has re-energized the preservation community's focus on energy efficiency in historic buildings.

Many U.S. cities are beginning to understand the impact that the residential sector has on the overall U.S. consumption of energy. As a result, cities like San Francisco, Berkeley, and Austin have created ordinances that require certified energy audits when properties are sold. These cities are implementing these policies in an effort to offset peak energy load and prevent the necessity of new power generation facilities. Many have embraced the idea of conservation as the quickest and most efficient method for securing energy independence.

Internationally, the European Union (EU) has increased its focus on energy efficiency across the continent. Many countries within the EU are requiring energy performance certificates to be produced whenever a building is constructed, sold or rented in order to keep an up-to-date measure of the efficiency of the structure.[6] Irish law, for example, requires all buildings for sale or lease, to have an energy efficiency certificate. Understanding the impact of such regulations on historic buildings, The English Heritage, a government-funded historic preservation group, has also produced a

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[6] Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings: http://europa.eu/scadplus/leg/en/lvb/l27042.htm.

guide to help building owners increase energy efficiency in historic structures without compromising the integrity of the building. This guide is tailored specifically to climate conditions and building materials found in historic structures in England so that retrofitting helps to improve energy efficiency, while protecting historic integrity of the buildings.

Similarly, this case study seeks to analyze energy consumption in historic structures in Charleston and to begin the development of guidelines that can increase the efficiency of such properties. The Trust's efforts are timely with respect to the efforts of the Charleston Green Committee (the "CGC") to create the Plan for Climate Protection and Sustainability for the City of Charleston.[7]. Comprised of 24 business, academic, nonprofit and government leaders, the CGC recognizes that buildings are the primary contributor to Charleston's greenhouse gas emissions for which it is working to establish and implement energy efficiency standards including retrofitting guidelines within a historic context. With over 3,000 historic structures on the peninsula and a sophisticated base of knowledge in historic preservation and restoration, Charleston serves as an ideal laboratory for developing energy efficient retrofitting techniques that also preserve the historic integrity of our building stock. In furthering its mission, the Trust may have an unprecedented opportunity to selectively collaborate with CGC to protect and enhance the historic and environmental qualities distinct to Charleston.

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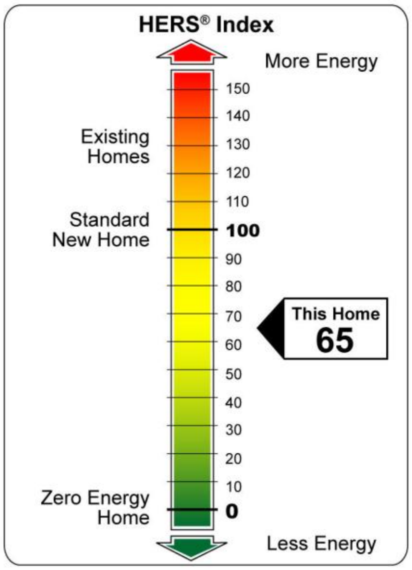
[7] Charleston Green Committee, http://www.charlestongreencommittee.com/index.html

RESNET and HERS



National efficiency efforts began to take root in the United States in the early 1990's. In 1995 a collaborative of state energy officials and mortgage lenders formed the Residential Energy Services Network (RESNET). RESNET's goal was to make energy efficient homes available to more people. To achieve this goal, RESNET developed a national standard for rating a home's energy efficiency, the Home Energy Rating System Index (HERS Index). The index is a relative energy use scale similar to a miles-per-gallon rating on a car, but measures a home's energy use instead of fuel. A rating of zero indicates that the home uses no net-purchased energy. The standard 'new American' home built to the adopted International Energy Conservation Codes (IECC) is assumed to have a HERS rating of 100. An Energy Star Home, which is a green built home designed to use notably less energy and water, achieves an index of 85, which is 15% more efficient than a home built to code. A lower HERS rating means the house is performing more efficiently.

Research Goals

The goal of this research is to establish guidelines for improving the energy efficiency of Charleston's historic residential buildings without negatively impacting their historic integrity. Baseline energy models using the Home Energy Rating System developed by RESNET were used to establish improvement analyses for each of the buildings in the study. Improvement analyses identified the most cost-effective, practical, and historically sensitive retrofits that will improve energy use. This case study offers specific recommendations to improve the energy efficiency of each building within the study; however, it also analyzes broader trends to identify strategic improvements that apply to all historic buildings in Charleston.

Methodology

The historic structures in this study were analyzed using the Home Energy Rating System (HERS) protocol and The Sustainability Institute's analysis and reporting procedure. This procedure consists of four stages: site visit, baseline energy modeling, improvement analysis, and reporting.

Site Visit

The site visit includes measurement of the building envelope components, gathering information on the efficiencies of mechanical equipment, blower door testing, and duct blaster testing. During the site visit, researchers measure the exterior of the building, often called the building "envelope". The total square footage, volume, and glazing area of the building are calculated.[8] The frequency of glass openings and their degree of shading throughout the day impacts the energy efficiency of the building as a result of passive heating or cooling. For this reason, the site visit also includes the notation of operable shutters, trees, and even nearby buildings to determine the natural air changes per hour in the analysis of the testing data. Other notes taken while on site

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[8] The glazing area is the amount of glass, whether in windows or doors, that is present on the exterior walls of the building.

visits include the method of construction, the conditions and types of attic and crawl spaces, and the specific sizes and types of mechanical systems currently in place.

Blower Door Testing

All site visits included blower door testing using a Minneapolis Blower door assembly. A blower door is a calibrated fan assembly that measures the amount of leakage through the exterior floors walls and ceilings of a building. The fan depressurizes the house by pulling the interior air out of the house. Every cubic-foot-per-minute (CFM) of air leaving the building must be replaced by an equal amount of outside air. Based on this principle, the blower door assembly can estimate the amount of air leakage through the building shell.

This assembly can also be used to locate the source of leakage. As the fan activates, the change in pressure exacerbates the leakage coming through gaps and cracks in the building's shell. Simply holding a hand in front of a likely leakage location can indicate the source of the leakage. In many instances, homeowners participate along with researchers by locating and marking leakage points for later identification and repair.

Duct Blaster Testing

Site visits also included duct blaster testing using a Minneapolis duct blaster assembly. Like the blower door, the duct blaster uses a calibrated fan assembly to measure leakage in the ductwork. Ductwork is the network of pipes that distributes conditioned air from the central HVAC system to the rooms of the house. Any leakage in the ductwork reduces the HVAC system's ability to provide conditioned air to the house. During the site visit, the fan assembly is attached to the return register of the HVAC system and all of the supply registers are closed off using a non-marring tape. The fan pressurizes the ductwork and a pressure gauge measures the total amount of leakage in the duct systems. Leakage typically occurs at connection points and the leaky areas often easily identified with a cursory inspection.

Baseline Energy Modeling

Baseline modeling involves entering all of the collected data from the site visit into a computer modeling program that estimates and predicts energy use. This process is used to calculate the HERS index, energy consumption, and operational costs associated with the existing building. The computer modeling program used by Sustainability Institute researchers is called the REM/Rate™ Energy Modeling Software. REM/Rate™ is a sophisticated residential energy analysis, code compliance, and rating software developed specifically for the needs of the Home Energy Rating System. The software calculates heating, cooling, hot water, lighting, and appliance energy loads, consumption and costs for both new and existing single and multi-family homes[9]. The climate data entered into the system is available for cities and towns throughout North America, making it customizable and more accurate as a result.

Using REM/Rate™, researchers were able to create a highly accurate baseline energy model that depicts the existing (baseline) energy use for the building. In an effort to maintain accuracy the computer energy model is quality controlled by a third-party

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[9] Architectural Energy Corporation, www.archenergy.com

qualified RESNET Quality Assurance (QA) provider. The QA provider verifies protocol was followed and verifies the accuracy of the baseline energy model. Once approved by the QA provider, the rater can begin the improvement analysis.

Improvement Analysis

Once a RESNET QA provider has verified the quality of the baseline model, researchers use the REM/Rate™ modeling program to simulate changes to the building and estimate the impact on energy consumption. The modeling program also allows for cost benefit analyses of suggested changes. Changes to the leakage rates, insulation levels, windows, and mechanical equipment are analyzed to determine which improvement component is most effective. By altering many different aspects of the building within the computer program, researchers can model anything, from changing insulation levels to replacing windows, without actually changing the structure itself. This virtual testing assures that only the most effective changes that will not substantially damage the historic fabric of the building will be made.

Reporting

The final step in the energy audit process is the production of an improvement analysis report to summarize the results. Every homeowner who commissions a HERS rating receives a personalized report indicating which retrofits are justifiable based on a cost benefit analysis. Homeowners can use the financial information from the report to prioritize improvements and as a guide for making repairs. The financial information in the report will also help to determine if a homeowner qualifies for an Energy Improvement Mortgage (EIM).

EIMs are a mortgage tool developed in the mid 1990's and are currently in use by all major lending institutions. Energy efficient mortgages allow homeowners to count energy savings as extra income. If the energy savings of the suggested improvements outweigh the improvement cost, the homeowner can refinance the improvements into a mortgage and use the energy savings to pay for the improvements. EIM's have not gained popular acceptance among lenders, due primarily to the extra steps required to qualify a customer. However, as HERS ratings become more popular EIM's will be more widely used by lending institutions. For more information about Energy efficient mortgages see the "Energy Ratings and Mortgages" section of the RESNET website: http://www.resnet.us/ratings/overview/default.htm

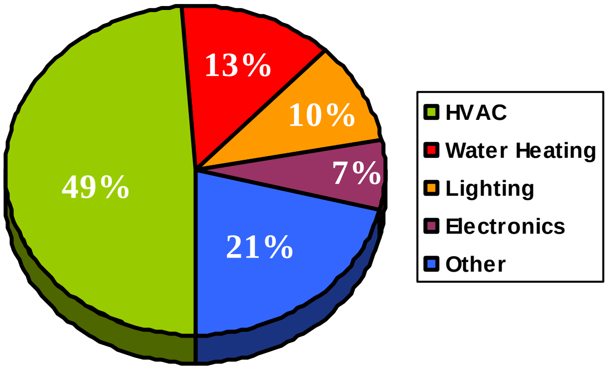
The improvement analysis report not only offers financial information related to suggested repairs but provides specific suggestions to contractors for the most appropriate methods for repairs and rehabilitation. Building professionals, such as contractors and architects, can use the report as a guide during the rehabilitation process. Any simulated modifications to the historic buildings include only those that follow the *Secretary of Interior's Standards for Rehabilitation* and are justifiable to the average property owner. As a result, recommendations are guaranteed to be practical, cost effective, and historically sensitive. Information in the report should be especially helpful to HVAC technicians as the report provides analysis of envelope and duct leakage and the insulation levels (both existing and recommended). This information is needed to properly size and install an effective HVAC system. Furthermore, the report provides industry best management practices to ensure that the repairs are completed in a way that protects the building from damage.

In a climate such as Charleston's, contractors must make sure adequate attention is paid to moisture control, insulation, and air sealing to prevent damage to the building. Understanding the dynamics of heat flow, pressure, and moisture transmission will assure proper installation of materials to prevent damage to the historic building assessed. The improvement analysis report offers building specific details of how repairs should be conducted to avoid potential for problems in the future. The following section will address the science behind how buildings operate so the reader can understand and avoid common pitfalls of building rehabilitation.

Foundations of Building Science: The Energy Profile

Increasing energy efficiency begins with an understanding of residential energy use. The home energy profile illustrated in the figure below shows the typical end uses of energy in a home. The energy profile helps to establish the best areas to target for energy efficient improvements.

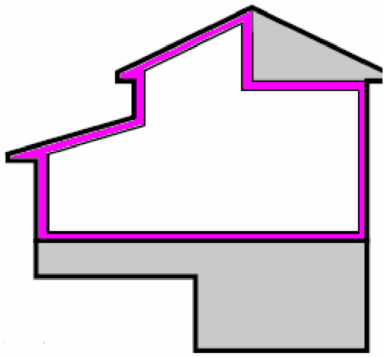
Almost half of residential energy is consumed by heating, cooling and ventilation systems (HVAC). Energy use from water heating, lighting, appliances, and electronics respectively make up the remaining components of the energy profile. Improvements to each of these components should be based on impact, practicality, and



Source: The Energy Information Administration

cost. In a historic home, energy efficiency is achieved through successful management of the energy profile components. Because heating, ventilation, and air conditioning comprise the majority of a home's energy use, it is often the best point of attack when attempting to reduce residential energy consumption.

The House as a System


***The building envelope** is the highlighted area on the edges of the structure (Source: Southface technical bulletin)*

Heating, cooling and ventilation comprises the majority of energy use in a home. This is partly due to the efficiency of the equipment we choose but also because of the efficiency of the building envelope. The phrase "building envelope" is a term describing the walls, floors, and ceilings that separate conditioned and unconditioned spaces. Homes with a well-sealed and well-insulated envelope are easier to heat and cool. As a result, energy consumption and energy bills are lower. The building envelope is responsible for keeping conditioned air inside the house and outside air from penetrating indoors. Focusing on building envelope improvements is often the most effective and least expensive method for increasing energy efficiency.

An effective building envelope consists of four main components:

- **Air Barrier**- An air barrier stops convective heat flow by inhibiting air from infiltrating the building.
- **Thermal Barrier**- A thermal barrier stops conductive heat flow by providing insulation from heat flow.
- **Radiant Barrier**- A radiant barrier inhibits the absorption of heat energy by reflecting the energy away.
- **Moisture barrier**- A moisture barrier inhibits moisture transfer.

The Air Barrier

A successful air barrier seals the house tightly and inhibits air leakage. Examples of air barriers include any building material that prevents the flow of air (plaster, caulk, weather-stripping, etc). In a hot-humid climate like Charleston, S.C., air leakage is one of the most important factors impacting energy efficiency. Infiltrating air reduces efficiency by allowing heat and humidity to filter into the building envelope. The introduction of warm, moist air causes a home's HVAC system to work harder to condition and dehumidify the air to reasonable levels. Sealing and creating a tight building envelope reduces heat gain and moisture infiltration and can drastically increase efficiency. Retaining the integrity of the building envelope, specifically the air barrier, is the combined responsibility of many tradesmen, from framing contractors to plumbers. Each member of the building team is partly responsible for maintaining low leakage rates. With no central responsibility for maintaining air tightness, air leakage often goes unchecked and unabated.

The blower door test measures how effectively the building envelope provides a barrier to air infiltration. The blower door measures infiltration in air changes per hour (ACH). This can be thought of as the percentage of the indoor air that escapes per hour. The standard American home may have 65%-100% ACH under natural conditions, meaning that 65% to 100% of the conditioned air in the house is lost through the building envelope every hour. A house with a well-sealed air barrier may have less than 35% leakage.

Historic homes often have leakage rates well above 100%. This high level of leakage creates a building envelope that allows massive amounts of heat flow and moisture intrusion through the process of convection. This leakage can compound energy and moisture problems because larger HVAC systems are required to overcome the high level of heat and humidity transfer in historic buildings. Depending on how well an HVAC system is installed, it can effectively condition the indoor environment of the house, but at great cost both in energy consumption and utility bills.

A more effective approach consists of making repairs to the air barrier first, then installing an HVAC system. Reducing heat and moisture transfer first by repairing the building envelope increases comfort and reduces the heating and cooling load, thereby saving energy and reducing utility bills. In addition, future HVAC systems will not have to be as large to overcome heat gain in the building.

Green building standards like Energy Star, EarthCraft House, and LEED for Homes have embraced the idea that a solid and well-sealed air barrier is the first step towards energy efficiency. As a result, all of the green building standards mandate a maximum allowable leakage rate allowed to certify a home as energy efficient and "green". To achieve certification under a green building standard, contractors must limit the home's air leakage to an absolute minimum. In existing homes, an effective air barrier may offer the cheapest and easiest means to reduce the strain on the HVAC system and consequently reduce energy consumption. Simply by locating and sealing holes in the building envelope with caulk, spray foam or other air sealing measures the home becomes easier to condition and energy costs decline.

The Thermal Barrier

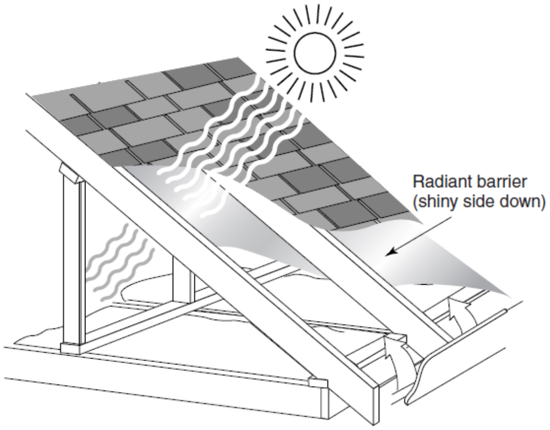
The thermal barrier controls conductive heat flow, which is heat transferred through solids. An effective building envelope will resist the flow of conductive heat using insulation. The "R" in "R-Value" describes the level of resistance insulation provides from heat flow. The higher the R-value, the greater the resistance to heat flow. In Charleston's climate, the recommended level of wall insulation is R-13. However, areas with extreme temperature differentials like attics and crawl spaces require higher insulation levels to properly maintain comfort. To provide an effective thermal barrier, the current energy code suggests R-30 insulation in the ceiling and R-19 in floor systems and knee walls.

Insulation is often confused as an air barrier. However, it is important to realize that insulation alone will not stop airflow. With only insulation in place, convective heat and moisture can flow unabated through the building envelope through air currents. The most effective thermal barrier should be installed without gaps or compressions and in direct contact with an air barrier discussed in the previous section.

In any home, but particularly a historic home, attics and crawl spaces are the best places to start when considering retrofitting options. These assemblies harbor the most extreme temperature differentials and therefore require elevated insulation levels. These spaces are often readily accessible through access hatches and can be upgraded easily. Wall systems, in contrast, require extreme modification to retrofit insulation. In many cases, installing insulation in wall systems is a costly, invasive, and destructive process. Historic interior fabric such as plaster and woodwork are often lost to this type of renovation. Therefore, improvements to the thermal barrier should focus on attic and crawl spaces first, because this does not impact the historic fabric of the building.

Radiant Barriers

Radiant barriers reflect heat energy. In construction applications, these barriers are often installed as films in an effort to reflect the sun's radiant heat away from the building and prevent heat gain. Most radiant barriers are thin sheets of reinforced aluminum. In attics, radiant barriers can be installed on the underside of the roof to limit the absorption of heat energy. Under normal situations, the sun's energy strikes the surface of the roof. The roof warms and radiates the heat downward into the attic, increasing heat gain. A radiant barrier installed on the underside of the roof will prevent the heat gain in the attic by reflecting the energy back up through the roof. Radiant barriers have potential to reduce attic temperatures and increase the effectiveness of attic insulation. For more information about radiant barriers see the "Radiant Barriers" fact sheet from the Southface Energy Institute:



Radiant barrier installed to rafters
(Courtesy of Southface)

http://www.earthcrafthouse.com/documents/factsheets/14radiantbarriers.pdf

Moisture Barriers

Moisture control is often one of the most important and misunderstood duties of the building envelope. It is also one of the most difficult components to manage within the building envelope. The building envelope keeps us safe from inclement weather and water intrusion and avoids problems associated with rot and mold. The building envelope is comprised of several barriers to control moisture effectively.

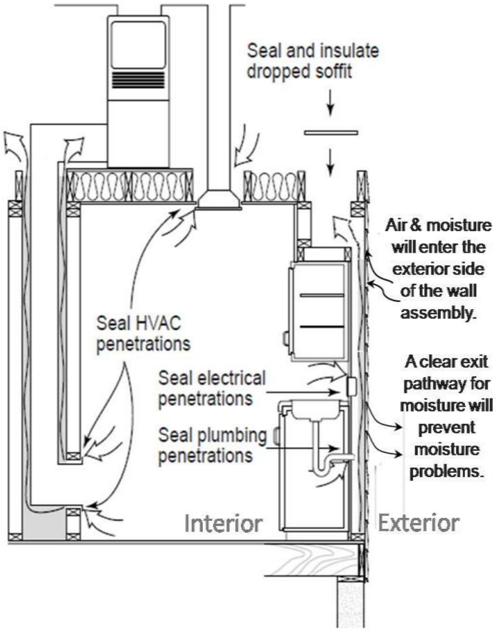
A *weather barrier* controls bulk moisture, such as rain or snow, and shelters the occupants of the house from the elements. Weather barriers can take the form of siding or roofing shingles. An *air barrier* prohibits the infiltration of moisture transferred by convection. This barrier prevents moisture intrusion in the form of humidity by limiting air infiltration. The air barrier is represented by air sealing components like caulking or weather-stripping or building components like plywood or drywall.

Condensation is another problematic issue for historic buildings. Collectively, weather and air barriers can help prevent moisture problems due to condensation. In many historic Lowcountry homes, condensation occurs on the interior surfaces such as, windows, HVAC registers, floors and even entire walls. If left unchecked, the excess moisture can cause mold, rot, and structural issues unless efforts are made to prevent condensation. To prevent moisture problems related to condensation, it is important to understand the physics of moisture dynamics.

Simply speaking, warmer air can hold more moisture than colder air. The condensation process occurs when central HVAC systems cool ambient air and interior surfaces of the home. As the air is cooled, it loses its ability to hold water and condensation forms on the interior surfaces of the home. One may experience this same process drinking a glass of iced tea on a warm summer day. Warm, moist air encounters a cold surface of the glass and condensation forms on the glass. In a construction application, the condensation is deposited on the interior surfaces of the home such as HVAC registers and windows.

For condensation to occur, warm, moist air must encounter a cold “condensing” surface. As it is nearly impossible to remove cold surfaces from the home, the standard approach to preventing condensation in homes has been to remove the warm moist air from the home, thereby preventing condensation. For most houses, the central HVAC system can accomplish this task. However, many historic houses are so egregiously leaky that the HVAC system may not have the capacity to remove all of the humidity from the air. The standard procedure to fix this problem has been to install whole-house dehumidification systems. This additional mechanical equipment may effectively remove moisture, but it will also drastically increase energy consumption and utility cost.

A better approach for preventing this problem lies not in removing moisture from the house, but in *preventing* moist air from entering the building. Preventing air infiltration, with the installation of an effective air barrier, reduces the amount of humidity in the indoor air environment. As a result, condensation is less likely to occur and moisture issues are drastically reduced.



Air movement through a typical historic wall assembly (adapted from Southface Factsheet)

The concept of air sealing a historic home causes concern for many builders and preservation-minded individuals due to the belief that air sealing a house may trap moisture inside wall, floor, and ceiling assemblies. In the past, builders have gone to the extreme and have attempted to seal historic buildings using techniques like caulking all of the seams in exterior siding, removing attic ventilation, and even going so far as to wrap the entire house in a plastic vapor barrier. These techniques can potentially trap moisture within wall assemblies and cause mold, rot and deterioration of the home's historic fabric. Though well meaning, the ill fated attempt at air sealing could very easily cause damage to the building.

The figure to the left depicts the movement of air through a typical wall assembly. Air and moisture can easily infiltrate into wall cavities through gaps between siding, around windows, doors and the many other exterior bypasses of the building. Without a clear pathway out of the wall cavity, the infiltrating humidity can become trapped and cause a moisture problem. To avoid trapping moisture and causing damage, air sealing should occur on the *interior* of the house.

The goal of air sealing should be to prevent air and accompanying humidity from entering the conditioned spaces of the house. Common interior pathways for this infiltration are plumbing, electrical, and HVAC penetrations like shown in the picture at the left. As buildings settle and age, gaps and cracks also form in ceilings, walls and floors. In laymen's terms, if there is a hole, fill it, patch it, fix it, or otherwise have it repaired in an effort to stop air from entering the building through that space. Sealing these penetrations prevents the infiltration of unconditioned air and the loss of conditioned air. As a result, the building is easier to heat and cool and energy consumption is reduced.

Capillary action presents an additional means for moisture to transfer into building components. Flowing from wet areas to dry, moisture can transfer, or wick, from the ground into porous building materials like brick or wood. Capillary action can cause brick foundations and wood framing to absorb and retain moisture within the walls floors and ceilings of a building.

A *capillary break*, like a termite shield or sill sealer, will prevent moisture transfer from the ground to building materials. Weather, air, and capillary barriers are important in all climates to prohibit moisture intrusion in buildings.

The Vapor Barrier

Moisture, in its vapor state (gaseous) comes typically in the form of humidity. An area with high humidity is said to have a high concentration of water vapor molecules. Moisture will naturally travel from high concentrations to low through a process called diffusion. In the built environment, the diffusion process occurs regularly when a moisture differential exists across the building envelope. During summer months, conditioned building interiors are typically less humid than the ambient air. This causes the outside air to have a higher concentration of moisture. Because of this differential, moisture will naturally diffuse into the building. During the winter heated air can produce the opposite effect—the conditioned air is warm and moist and the moisture will diffuse to the exterior of the house.

A vapor barrier impedes the flow of vapor molecules and slows the diffusion process. Installed correctly, the vapor barrier should be facing the high-pressure area (towards the heat and humidity). If Charleston's climate were warm and moist 100% of the time, a vapor barrier would be effective if installed facing the exterior of the house only. However, Charleston winters, though mild, provide instances where the inside of the home is warmer and moister than the outside. These environmental variables can cause moisture to be trapped on the inside of wall systems. If left unchecked, the excess moisture can cause mold, rot, and structural issues.

Therefore, it is best to not install a vapor barrier in historic houses in Charleston. Though moisture will find its way into wall systems, without a vapor barrier it will have a clear exit pathway so that the wall system is less likely to be compromised by mold, rot, or other moisture issues.

Beyond the Building Envelope: Heating, Ventilation, & Air Conditioning (HVAC)

The modern household uses mechanical equipment to condition the indoor environment to comfortable levels. The application of heating, cooling, and ventilation at various locations maintains the comfort of building occupants by controlling air temperature, humidity, air flow, and the temperature of the surrounding surfaces of the house interior. As described in the previous section, it is most important to provide for a sound building envelope. After this is established, mechanical equipment should be sized and installed correctly.

Sizing

Correctly sizing mechanical equipment begins with an HVAC load calculation. The load calculation determines the capacity, or size, of a heating and cooling system required to overcome the indoor environmental variables. The Air Conditioning Contractors Association (ACCA) has established standards to determine how many tons of heating and cooling are needed based on building variables such as square footage, building orientation, infiltration rates, insulation levels, climate, internal loads, and ventilation requirements.[10] Over-sizing HVAC systems can complicate moisture issues by limiting a system's capacity to remove moisture from the indoor air environment. An oversized system is prone to short cycling- a process by which the system activates, quickly cools a space, and deactivates in a short period of time. Short cycling can cause moisture issues because dehumidification may not be possible within so short of a time frame. This process may cause comfort issues, higher utility cost, and may shorten the useful life of equipment.

The historic elements of a home can be compromised by inappropriately sizing an HVAC system by exacerbating the condensation process described above. At a minimum, HVAC contractors should use the *Manual J* load calculation (established by the ACCA) to size the mechanical equipment based on an established protocol. Sizing systems based on "experience" or rules-of-thumb should be avoided. [11]

Ductwork

Ductwork is the series of pipes that carry conditioned air from the HVAC system to the rooms of the building. Correctly sizing ductwork will allow the proper volume of air to reach the intended spaces. Contractors should install ductwork to be as short and straight as possible. Kinks, bends, and long runs in the ducts will inhibit the flow of air

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[10] These variables, among others, are calculated in the ACCA's "Manual J" load calculation procedures.
[11] "Right-Size Heating and Cooling Equipment Technology Fact Sheet", Southface Energy Institute, www. earthcrafthouse.com/documents/factsheets/RS-Right-size_HVAC 02-1490.pdf

and will cause pressure imbalances in the house. This can lead to comfort issues, burgeoning energy consumption, and potential indoor air quality issues.

The duct system must also be free of leaks. Leaky ductwork is one of the largest drains on energy in residential construction. Up to 20% leakage is typical in an HVAC installation. With that high degree of leakage, an HVAC system's efficiency can be cut by 50%! Having no duct leakage would be ideal; however, this is impossible unless the HVAC system is installed completely within the conditioned spaces of the house. When HVAC systems are installed in attics or crawl spaces, a reasonable goal for any system should be 4%-6% leakage based on square footage served by the system.

Summary

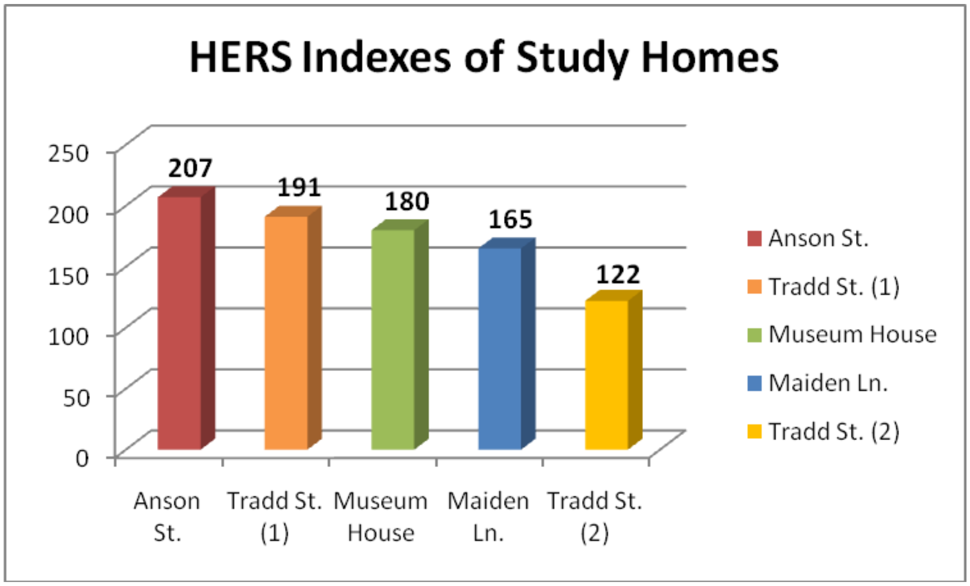
Collectively, envelope improvements and proper installation of HVAC systems can drastically reduce energy consumption in a historic home. Based on impact and practicality, these improvements are often the least costly and offer a beneficial return on investment. Contractors can easily manage air leakage, insulation levels, and duct leakage within the confines of the *Secretary of the Interior's Standards for Rehabilitation*. With proper installation, tremendous reductions in energy use can be realized while renovating in a historically sensitive manner.

Case Study Results and Conclusions

Researchers tested and analyzed five historic structures in the Charleston area in an effort to better understand trends in the energy use and performance of residential buildings in Charleston. The ages of the buildings range from the mid-18th century to the early 20th century, with an average construction date of 1831. The size of the buildings varies as well, but they are generally around 3,500 square feet. Four out of five of the homes were located in downtown Charleston. Houses one and two are located on Tradd Street (Tradd St. 1 & Tradd St. 2); houses three and four are located on Anson Street and Maiden Lane respectively. The fifth house in the study is located outside of the downtown area and is currently being used as a museum house for guided tours. Most buildings in the study set are brick masonry construction; however, Tradd St (1) is a wood-frame building. The testing results of these structures and their implications are discussed below.

HERS Index Ratings of Case Study Buildings

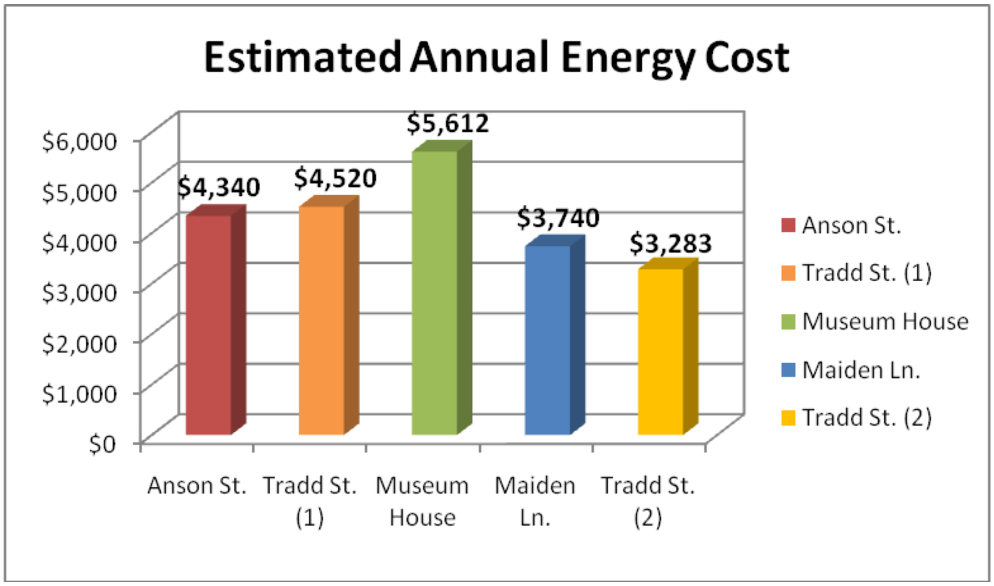
The Home Energy Rating System (HERS) index for each structure in the study is shown in the following graph. This HERS index is a measure of overall efficiency based on the protocol set by the Residential Energy Services Network. Higher index ratings indicate reduced efficiency. The average new American residence has a HERS rating of 100, while the average existing building rates around 130. The average HERS index of this study set is 149, indicating that, on average; the historic homes in this study are 49% less efficient than the typical new American residence.



The Anson Street home has the highest index rating, primarily due to extreme duct leakage. Researchers found a detached HVAC duct during the site visit, which was causing massive amounts of duct leakage and drastically reduced efficiency. Tradd Street (2), in contrast, yielded an index of 122, indicating that the home is 8% more efficient than the average existing American home. The lower HERS index of the residence at Tradd St. (2) indicates that achieving efficiency levels on par with the average existing home is indeed possible.

Estimated Annual Energy Costs for Case Study Buildings

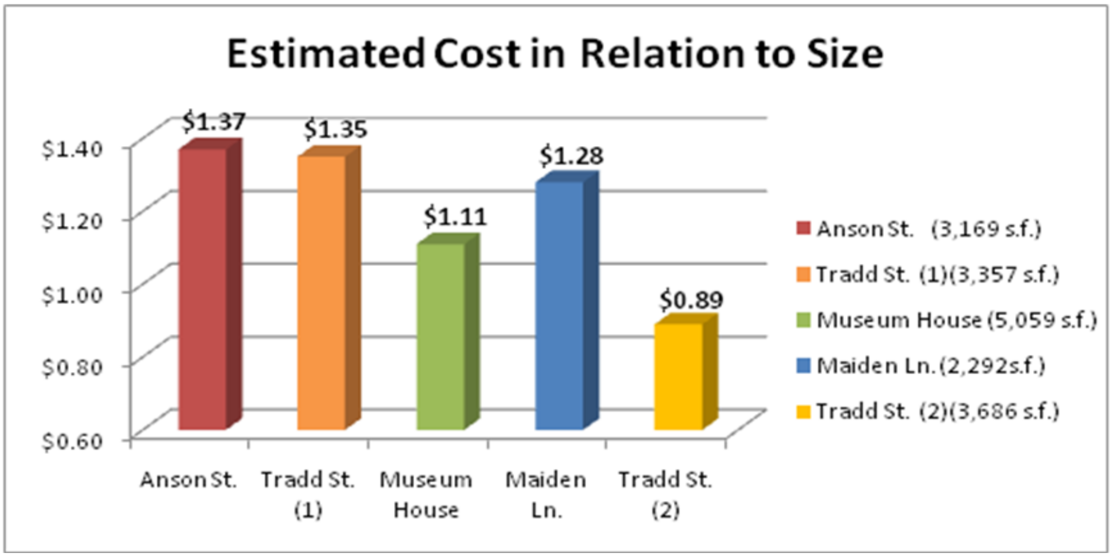
The graph below shows the estimated annual energy costs for each building as determined by the REM/Rate energy model. The model estimates energy use based on assumptions made about occupancy levels and typical human behavior.



Tradd Street (2) experienced the lowest energy costs in the modeling process primarily due to low levels of envelope leakage and proper insulation levels. The Museum House energy model produced the highest estimated energy costs. This high cost is likely due to the size of the building as compared to the others in the study—the Museum house is more than 5,000 square feet of conditioned floor area making it more than 1,775 square feet larger than the average square footage of the other buildings in the study.

Cost in Relation to Size for Case Study Buildings

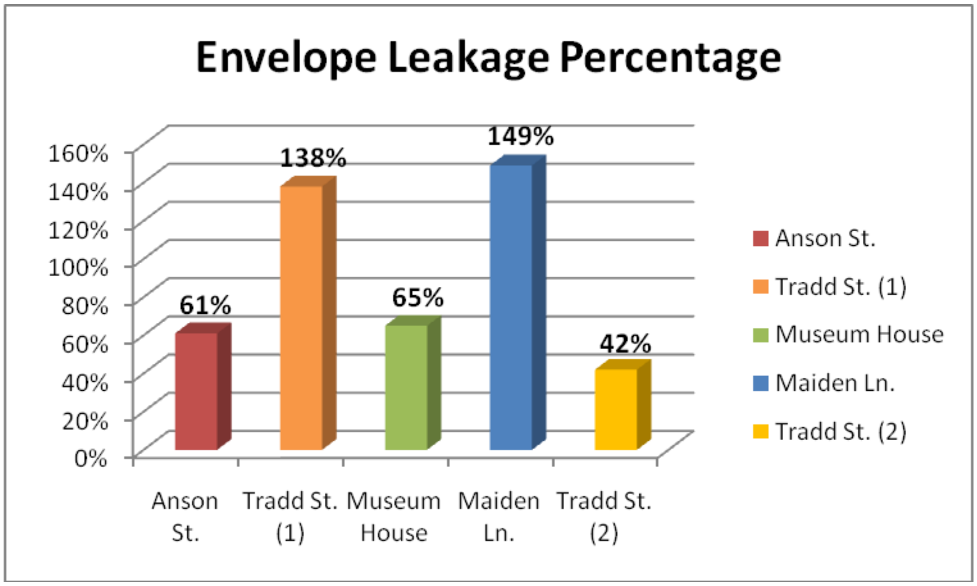
The figures below show the square footage and energy cost per square foot for each of the buildings in the study. Because the houses varied in size, normalizing based on square footage allows for a better comparison of the energy cost across the case study.



As is shown above, the cost varied quite significantly, ranging from $0.89 per square foot at Tradd St. (2) to $1.37 per square foot at the Anson St. House. Tradd St. (2) still ranks as the most efficient of all of the homes in the study. Again, this is likely due to the well-sealed and well-insulated building envelope. Using this reporting method, the Museum House's cost per square foot indicates one of the lower rankings. The Anson St residence, in contrast has the highest cost per square foot, likely due to the aforementioned extreme duct leakage.

Envelope Leakage Levels in Case Study Buildings

The envelope leakage figures indicated below are based on the blower door testing conducted on each of the buildings. This pressurization test indicates the specific leakage ratio for each tested structure in percentage of air volume exchanged under natural conditions. Homeowners should seek to achieve a 35% level of envelope leakage which is recommended by many green building standards.

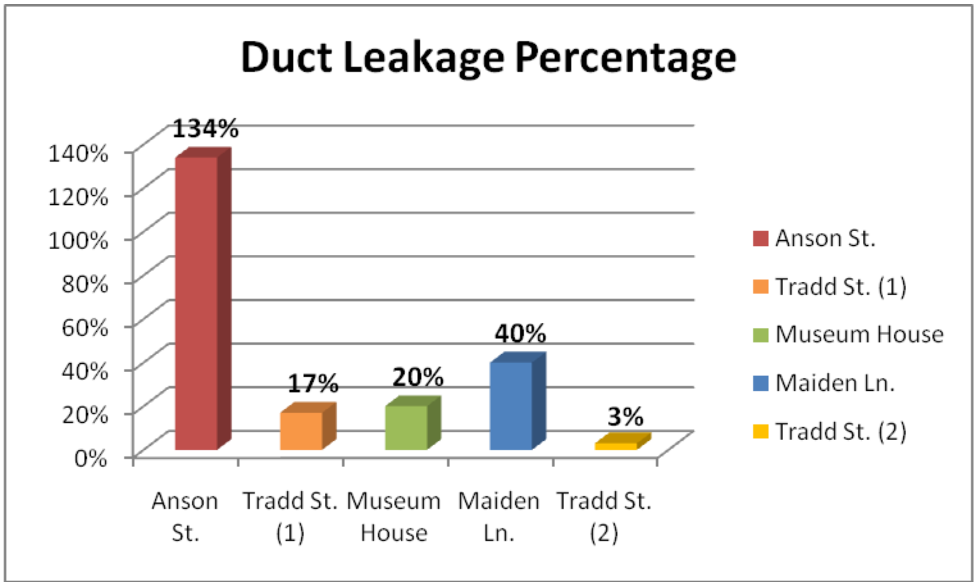


The Maiden Lane residence experienced the highest level of envelope leakage at 149%. This level of leakage suggests that 149% of the indoor air is lost through holes in the building envelope every hour. The level of envelope leakage experienced in the Maiden Lane and Tradd St. (1) residences is greatly responsible for the increased energy consumption in these buildings. In contrast, the Tradd Street (2) residence has an extremely low level of envelope leakage (42%), even when compared with a new American home. Low levels of envelope leakage contributed to the low heating and cooling costs for this building by reducing the load on the HVAC system.

There were no notable moisture problems in the Tradd St (2) residence. The envelope leakage data suggests that low levels of leakage are achievable in a historic building without causing moisture issues or compromising the historic integrity of the building. Further research is necessary to definitively evaluate causes of moisture problems in historic houses though this research suggests energy efficiency gains can be effectively made by properly air sealing the building envelopes of historic houses.

Duct Leakage in Case Study Buildings

The duct leakage figures indicated below are based on the duct blaster testing conducted during site visits. A duct blaster pressurization test indicates the level of leakage in the duct systems. The level is expressed as a percentage of air lost to the outside of the building shell based on the square footage served by the system. Leakage levels between 4%-6% are acceptable for ductwork installed outside of the conditioned spaces of the house. Air leakage through the HVAC ducts is a major problem in many residential structures, modern or historic. The graph below depicts the levels of leakage experienced by the homes in this study.

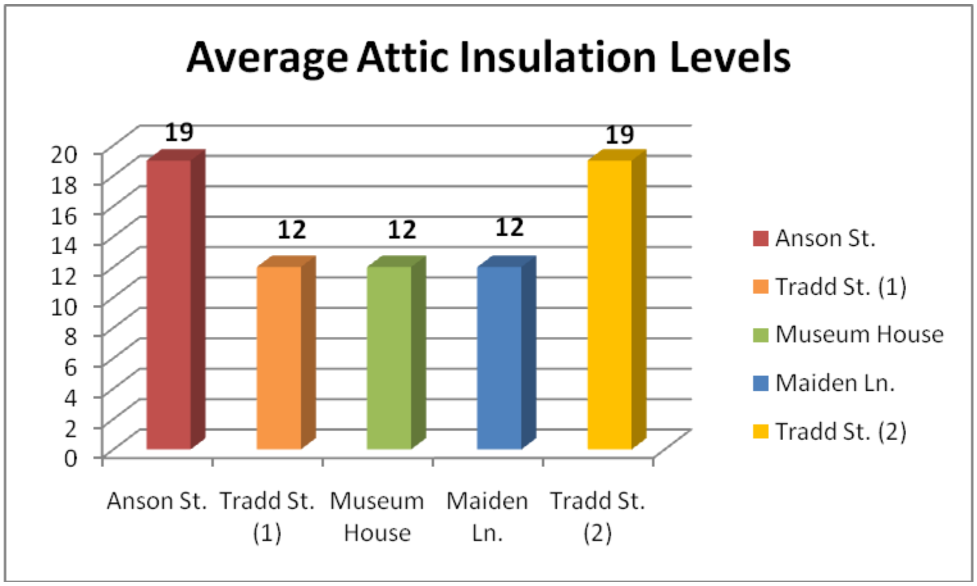


Duct Blaster testing on the duct systems at the Anson Street residence revealed extremely high levels of leakage. This data point is an extreme outlier and is not typical of the homes in the study. In the case of this residence, a duct had broken loose from the system and needed immediate repair. The residence at Tradd Street (2), again, exemplifies the level of energy efficiency that can be achieved through careful, accurate installation of HVAC components. A 4% duct leakage is the goal for all residences. It is rare that leakage levels less than this figure are found in duct systems installed outside of the building envelope. However, the 3% leakage level found in the duct systems in Tradd Street (2) indicates the HVAC contractor took special pains to dramatically seal the duct systems. As a result, the corresponding HVAC system runs more efficiently and energy consumption is reduced.

The data from Tradd Street (2) further suggests the efficiency capability of historic structures. Low levels of leakage found in this building's HVAC system indicate an area for efficiency gains that do not cause adverse impacts to the historic integrity of the building. Homeowners should expect the attention to detail exemplified by a responsible tradesman at Tradd Street (2). Duct blaster testing can help to assure this attention to detail during the HVAC replacement process. Homeowners can ask for a guarantee of 4% leakage or less from HVAC contractors. By commissioning a duct blaster test after work is complete, the homeowner can ensure that their contractor meets an appropriate level of quality.

Attic Insulation Levels in Case Study Buildings

Insulation levels in attics and floors have a heavy influence on the energy efficiency of the building. The graph below depicts the average R-value, or level of insulation, found in the attics of each building within the study. Greater amounts of insulation in an attic spaces provide greater protection against heat gain through the ceiling.

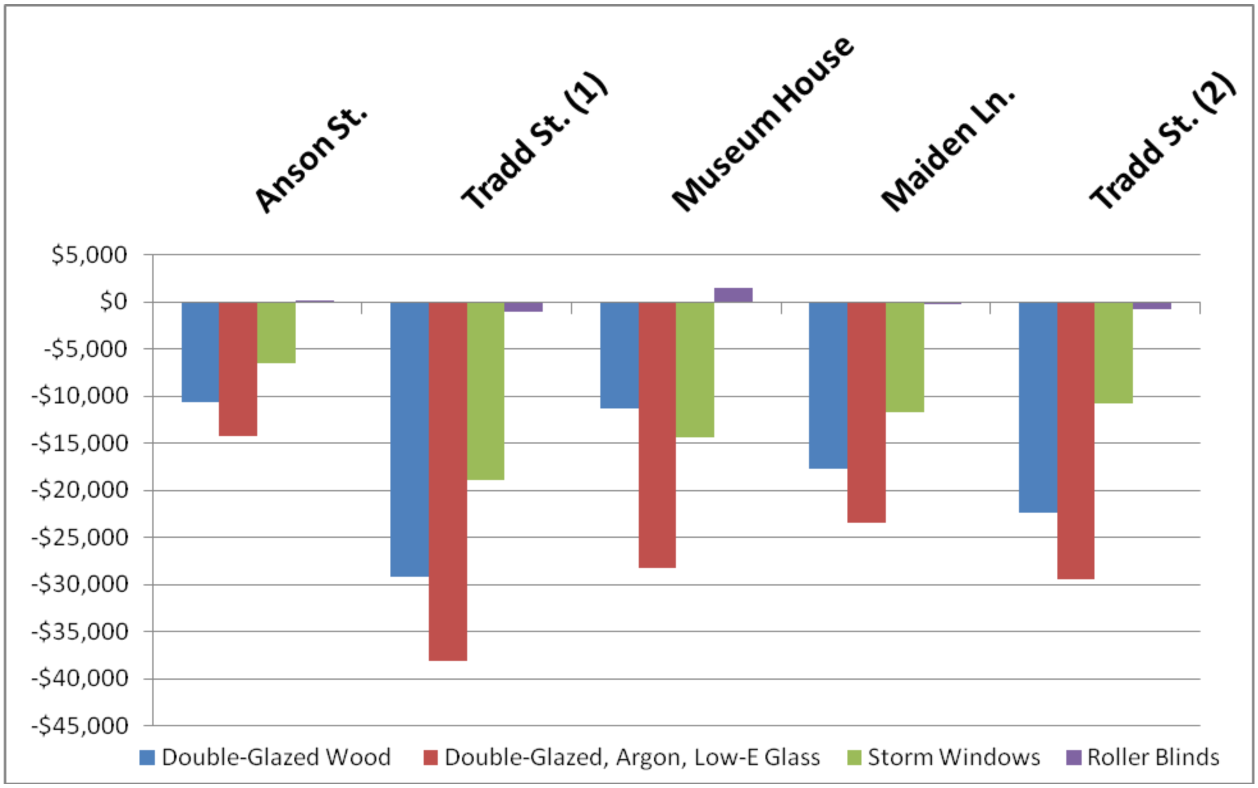


Though the insulation levels vary between the buildings in the study, it should be noted that none of the buildings had insulation levels on par with the current building code recommended level of R-30. This represents an easy upgrade that can be performed within the confines of historic preservation principles without any adverse impacts to the historic character of the building.

Cost/Benefit Analysis: Windows

Windows are often a contentious topic from a historic preservation perspective. Homeowners often wish to replace windows because they have been told that new windows will help to reduce energy costs. While replacement windows *can* reduce energy costs, a homeowner needs to be certain that the expected savings will outweigh the cost of improvement. The following graph depicts the net monetary loss from window replacement in the study set. Based on the analysis in this study, window replacement would not produce a positive cost benefit to the homeowner in any of these homes. In all cases in this study, the high cost to replace historic wood windows with modern double-glazed wood windows surpassed the resulting energy savings over the useful life of the window.

Cost/Benefit Analysis: Windows



Double-glazed wood windows are perhaps the least obtrusive window replacement if a property owner desires to replace the existing historic windows. However, the decision to replace existing windows of the homes in the study would never yield a positive return on investment. The net monetary loss for a double-glazed wood window replacement ranges from $10,686 to $29,210 within the homes in the study.

Double-glazed, argon gas filled, low-E windows are perhaps the most energy efficient windows on the market at the time of this study. However, the graph shows that in all study buildings, the high cost of replacing the existing windows does not rival the smaller cost savings created from reduced energy use. The net monetary loss for a double-glazed, argon gas filled, low-E window replacement ranges from $14,216 to $38,035 within the homes in the study.

Storm windows are certainly a better option for window improvement, and their installation does not require the removal and replacement of the historic window assembly. However, as the above graph shows, in all of the properties in this study the cost to add storm windows to all of the existing fenestration costs more than the energy savings received from the retrofit. The net loss for a storm window addition ranges from $6,556 to $18,952 within the homes in the study. Also, storm windows are typically not allowed by the Board of Architectural Review in the historic district of Charleston.

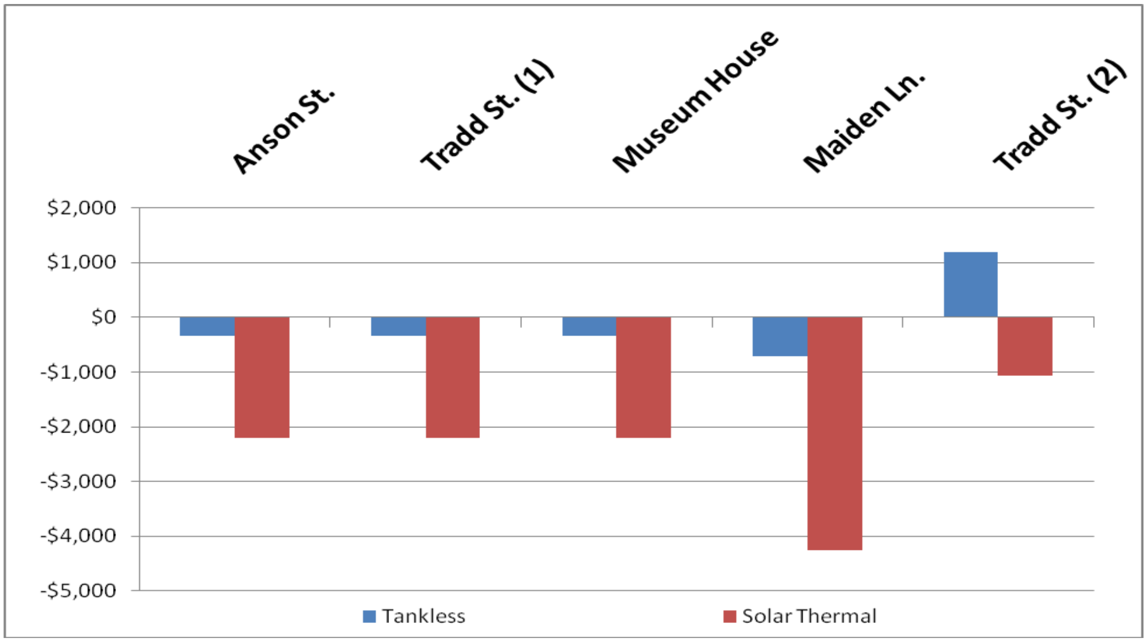
Increasing the shade factor on windows greatly reduces the amount of heat gain a building receives. For example, white, opaque, roller blinds are an inexpensive retrofitting option that can make a significant difference without damaging a historic window. The roller blinds block or reflect a significant portion of the sun's radiant heat, as a result, less heat is gained in the house, and the homeowner saves on heating and cooling costs. In two buildings in the study, Anson St. and the Museum House, the addition of roller blinds to the historic windows offers a positive return on investment. However, in the remaining buildings in the study the roller blind addition yields a net loss ranging from $188 to $1,093.

The window data suggests that homeowners should never replace windows based solely potential energy savings. Instead, window replacement should occur in situations where the window cannot be repaired to function properly. Following this procedure will ensure that the homeowner rehabilitates a historic home as cost effectively as possible while protecting the historic windows.

Net Savings: Water Heating

The graph below depicts the net monetary savings/loss that results from upgrading water heating units to more efficient models, such as tankless water heaters or solar power. Each of the homes in the case study had traditional tanked models of water heaters. These units heat water continuously in a tank at a specified temperature, regardless of the call for hot water. In contrast, a tankless model actively heats water only when called for by a user. Tankless models drastically reduce standby energy loss and have higher efficiencies than traditional tanked systems.

Net Savings: Water Heating



Only in the case of the residence at Tradd St. (2) did a tankless retrofit make sound financial sense. However, these figures may change with a larger sample size. Due to the high cost of tankless water heaters, replacement of these fixtures should not be based on energy savings. A homeowner should wait until replacement is necessary and then upgrade to a tankless system.

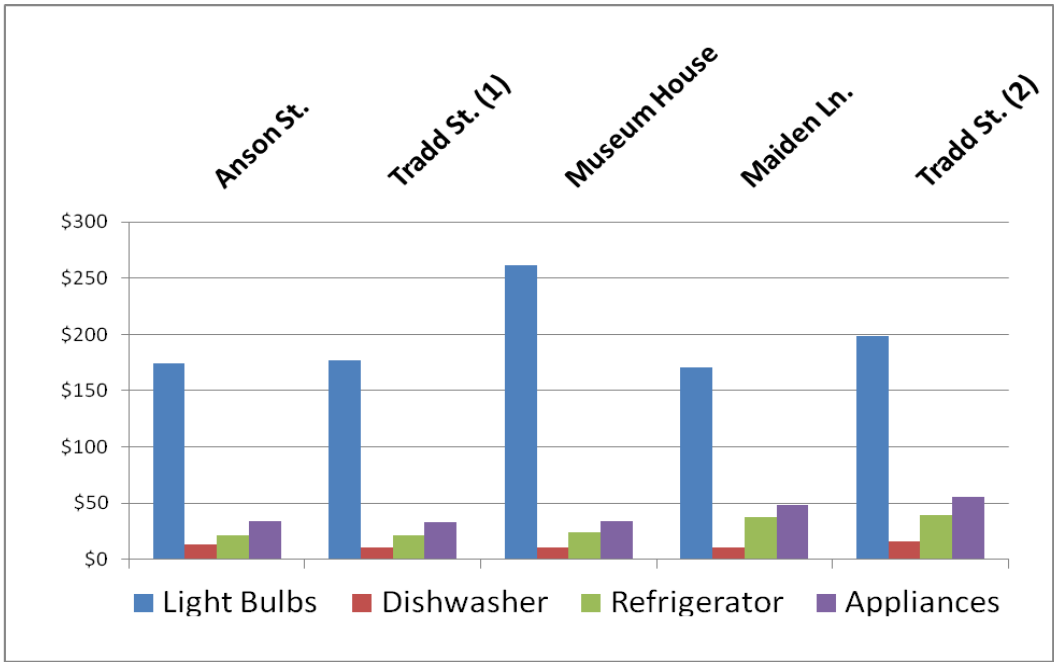
Using solar panels, solar thermal water heating systems preheat water before it enters a storage tank. In our climate, the solar panels are capable of producing enough hot water so that auxiliary tank water heating is virtually unnecessary. In each of the cases, a solar water heater reduced water heating costs to zero. However, due to the high cost of replacement, the replacement did not return a positive return on investment.

Tax incentives are available to reduce the installation costs of solar water heating by 60%. These incentives depend greatly on the homeowner's level of income and tax structure, so these figures are not included in this report. A larger sample size may reveal cost-effective opportunities for solar water heating.

Energy Savings from Lights and Appliances

Energy consumption from lighting and appliances typically comprises the second largest user of energy in the average American household. Changes to lighting and appliances are not usually constrained by historic preservation principles, so upgrading to more efficient lighting strategies or appliances are often easy for a homeowner to accomplish.

Savings from Lights and Appliances



Replacing light bulbs with equivalent compact fluorescents (CFL) yields the greatest savings to investment ratio of all of the improvements in this report. Based on the relative low cost of investment, the CFL replacement is a sound financial investment across all of the homes in the case study.

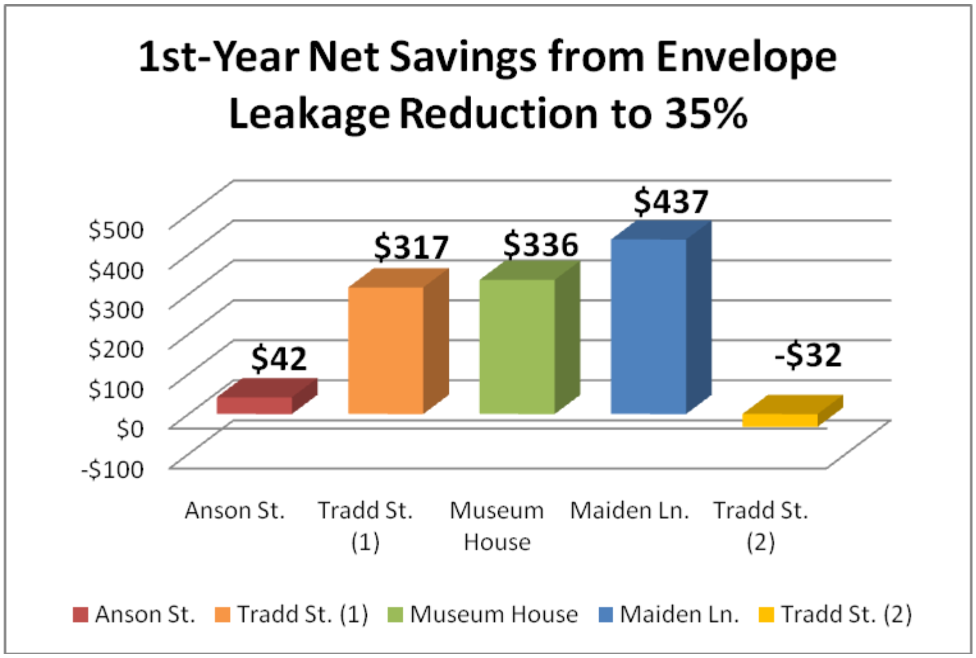
Upgrading kitchen appliances to Energy Star-rated machines can provide savings in energy consumption. The above graph shows the effect of each of these retrofits for each house in the study. The term “appliances” refers to the combined effect of upgrading the dishwasher and refrigerator at the same time. Due to the high cost of appliances, replacement of these fixtures should not occur based solely on energy savings. A homeowner should wait until replacement is necessary and then upgrade to an Energy Star Rated appliance.

Savings Figures for Suggested Repairs

The following sections analyze the savings associated with recommended repairs of historic homes. Each of the recommendations follows the *Secretary of the Interior's Standards for Rehabilitation*.

First Year Net Savings: Reductions in Envelope Leakage

The following graph depicts the net savings from air sealing the building envelope to a significant level. This type of repair can include caulking, spray foaming, and weather-stripping around windows and doors, as well as blocking large holes in the envelope with sheet goods like plywood, sheet rock, or foam board insulation. The recommended level of leakage is 35% based on the interior volume of each house. The following chart shows the estimated energy cost savings from reducing envelope leakage to 35% after the first year.



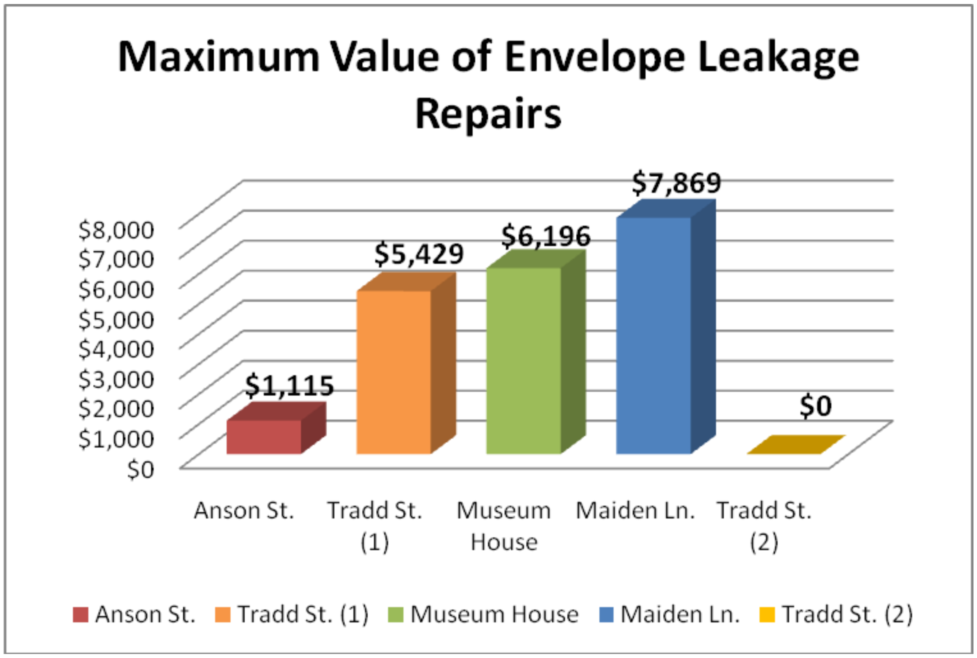
Depending on the current level of envelope leakage, the investment may be better suited to some structures more than others. For instance, the envelope leakage at Tradd St. (2) was already so low that reducing the envelope leakage further made little difference to that building's energy costs. In the case of this building, the cost of the repairs outweighed the benefit. As a result, researchers do not recommend further reductions in envelope leakage at this property.

Blower door testing was not performed on the Museum House. The Museum curators felt that the testing procedure would cause damage to the historic collection. As a result, a stand in value of 65% leakage was used for the estimates based on RESNET protocol. Sixty-five percent envelope leakage rate is not the worst possible result, but it is considered the maximum allowable leakage by current building codes.

Of the remaining residences, Maiden Lane could reap tremendous benefits from reduced envelope leakage. Maiden Lane recorded almost 150% envelope leakage during pressure testing. As a result, air sealing has the potential to dramatically reduce energy consumption at minimal cost. This repair is also financially advantageous for the Anson St. and Tradd St. (1) residences.

Maximum Value of Envelope Leakage

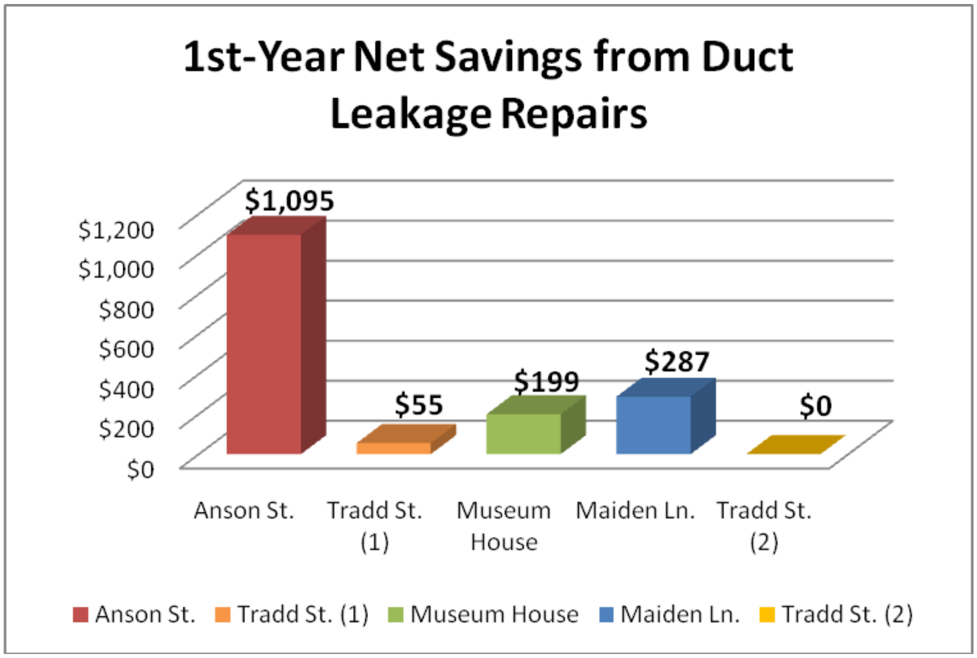
One of the greatest concerns property owners have when retrofitting their buildings is the cost of the changes. "Present Value" describes the future value of an upgrade in today's dollars. More specifically, present value depicts the maximum amount of money a homeowner can spend on an improvement and still have a positive return on the investment over the life of a 30-year mortgage. While many alterations have the potential to provide significant energy savings each year, the cost to make that change must be proportionately smaller than the energy savings to provide any realized gain. Present value offers perspective to the homeowner as to the maximum worth of any particular improvement. The following graph depicts the maximum value of envelope leakage repairs- the maximum amount a homeowner can spend on improving envelope leakage and still have a positive return on their investment.



Tradd Street (2) already has low levels of envelope leakage. Repairs to the air barrier are not viable because the cost of any repair outweighs the benefit. As a result, its maximum value is zero. The remaining homeowners could benefit dramatically from improvements to the air barrier. Homeowners at the residence on Maiden Lane could spend up to $7,869 on envelope leakage improvements and still break even financially.

First Year Net Savings: Duct Leakage Repairs

The following graph depicts the First year savings from duct leakage repairs. These figures assume the repair costs will be amortized over the life of a 30-year mortgage. The following graph depicts the net savings from reducing duct leakage to 4% based on the square footage.

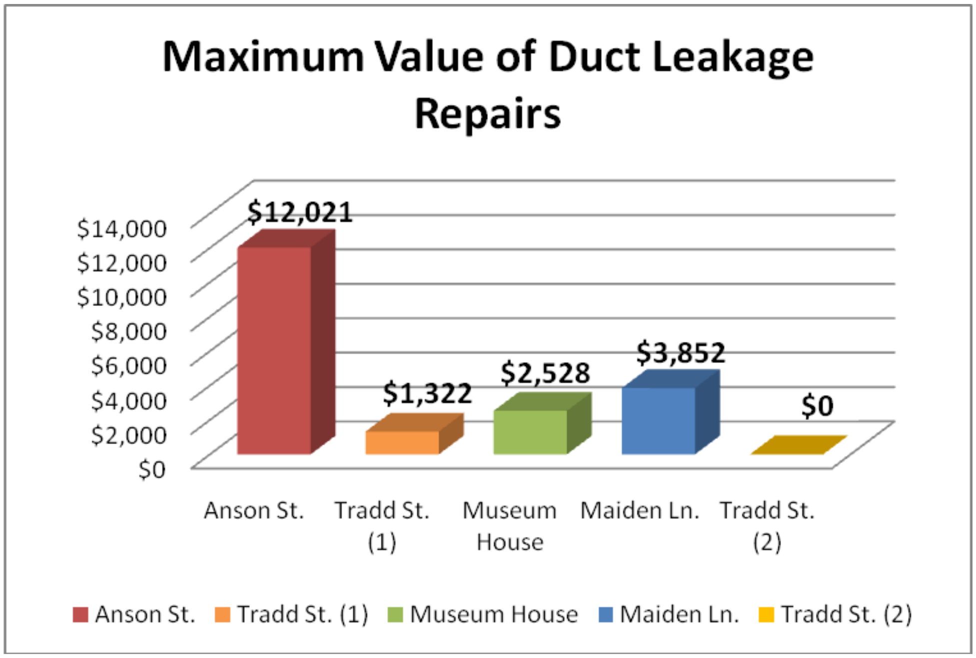


The duct leakage in the mechanical systems at the Tradd St. (2) already measured below the 4% level. As a result, the net savings and maximum value of the repair is $0. By contrast, the duct leakage measurement at the home on Anson St. is an extreme outlier. Because a duct had broken loose from the return plenum, the leakage was drastic and not representative of the sample. The duct has since been repaired and is within the limits one would expect from a typical contractor.

Since, duct blaster testing was not performed on the Museum House, a stand in value of 20% leakage was used for the estimates based on RESNET protocol. A 20% duct leakage is not the worst possible result, but it is considered the maximum allowable leakage by current building codes.

Maximum Value: Duct Leakage

The graph below shows the present value of duct leakage repairs, or the maximum amount the property owners in this case study could spend on reducing their duct leakage to 4% or less based on square footage service by the HVAC system. These figures assume the cost will be amortized over the life of a 30-year mortgage.



Again, the figures for Anson St. represent an outlier. The graph shows the impact and importance of this building feature. The Anson St. homeowner could spend up to $12,021 on this repair and still break even. Fortunately, the repair will likely cost less than $1,000.

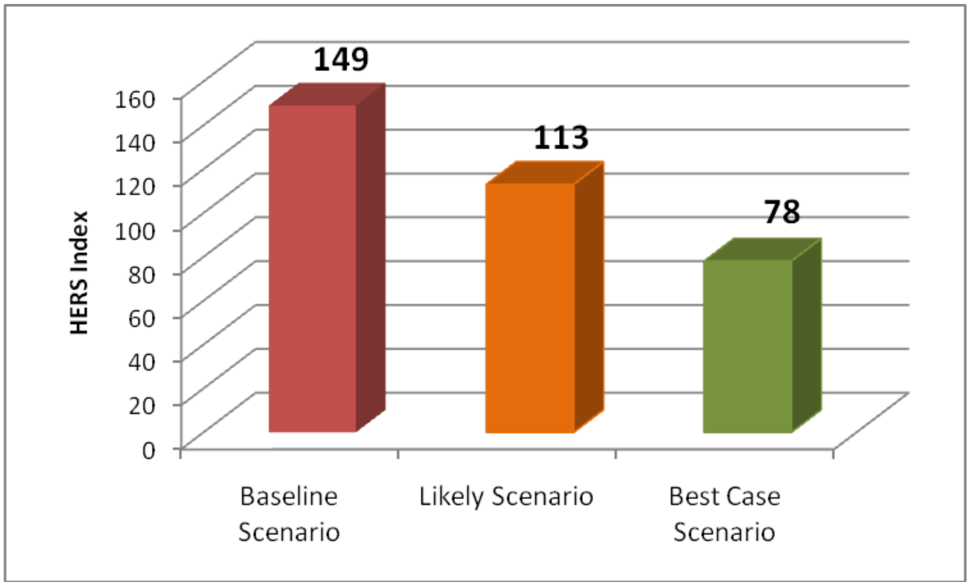
The figures for Tradd St. (2) and the Museum House are also not representative of the sample. The leakage rates at Tradd St. (2) are low enough to indicate that the sample is an outlier in the data set. Since duct blaster testing could not be performed on the Museum House, the savings figures are based on the standard RESNET protocol.

The remaining homes in the study indicate that the maximum value of the repair is less than the estimated cost of improvement. This indicates the repair would return a positive cash flow over the life of a 30-year mortgage and would be an advisable repair.

Improvement Scenarios

For each building, a “likely” and “best case” scenario of the building profile was created to model for possible future improvements. The “likely” case included the improvements that a typical property owner would probably undertake that are relatively simple and inexpensive to complete. The “best case” scenario included all of the improvements that provided the most energy savings regardless of their cost or feasibility. The three graphs below use averages from each home in the case study to show the effect these improvements could have on the overall ratings of the buildings.

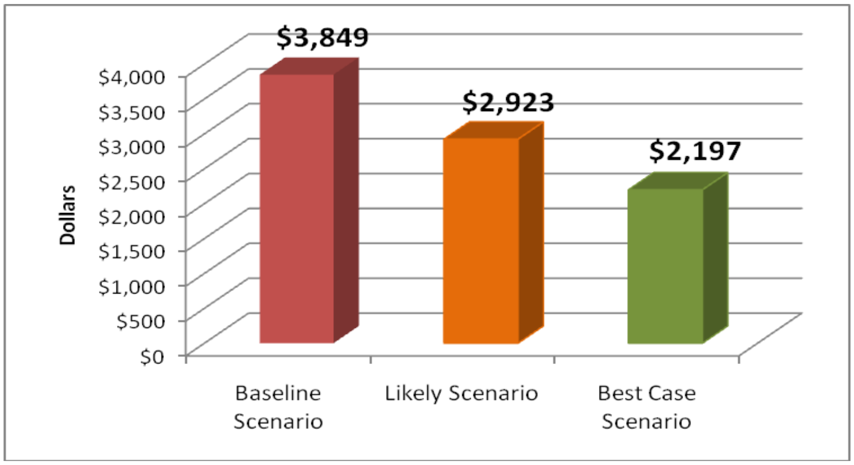
Home Energy Rating System Improvement Scenarios



The graph above depicts the average baseline HERS rating for each of the homes in the case study. Each building was then analyzed based on the “likely” improvement scenario and the “best case” improvement scenario. The likely improvement scenario, on average, reduces the HERS rating to 113. These results indicate a 36% average increase in efficiency. Each of the improvements within this scenario produce a positive return on investment and have the capability of dramatically improving energy efficiency.

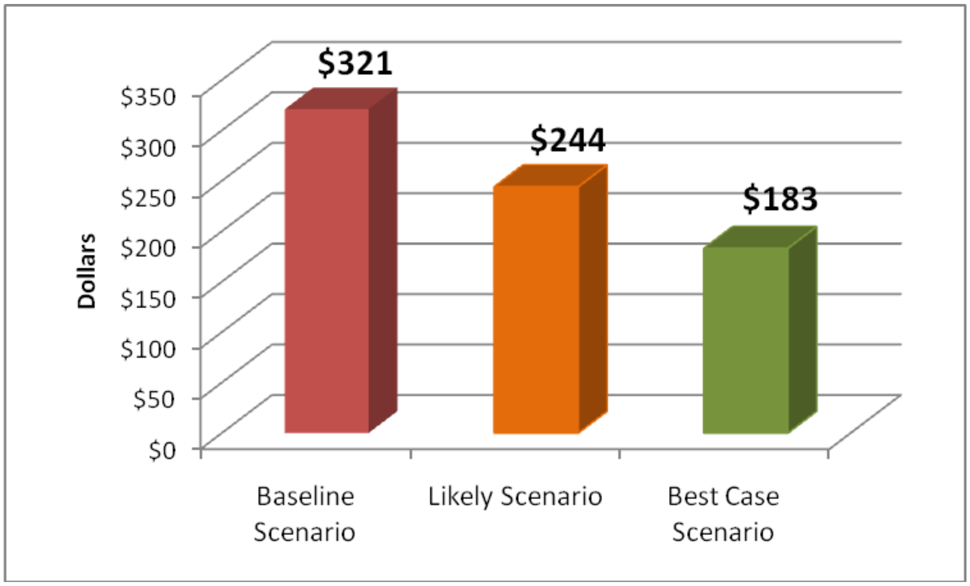
The best case scenario, on average, has the potential to reduce the HERS rating to levels below the requirement for the Energy Star green building program. On average, these repairs reduce the HERS Index to 78, which is 22% more efficient than the standard new American home and up to 71% more efficient than the baseline. Each of the improvements in this scenario fit within the confines of the *Secretary of the Interior’s Standards for Rehabilitation*. Though the improvements do not offer a positive return on investment due to the high cost of implementation, the data suggests that historic homes are capable of surpassing the energy efficiency levels of newly built homes.

Annual Energy Cost Reductions for Improvement Scenarios



The "Annual Energy Cost Reductions" graph above depicts the average, relative energy savings from the three improvement scenarios. The average annual energy cost for the homes in the study is $3,849. On average, the likely scenario has the potential to reduce annual energy costs to $2,923. The best case scenario can reduce annual energy costs to $2,197. This represents a $1,652 annual energy savings.

Monthly Energy Cost Reductions (Per Month)



The “Monthly Energy Cost Reductions” graph depicts the average monthly energy savings from the three improvement scenarios. On average, the likely scenario has the potential to reduce energy costs by $77 per month. The best case scenario can reduce monthly energy costs by $138.

Summary

All the recommendations in this report have been based both on established preservation guidelines and the economic considerations of any repairs. If a repair could not produce a positive return on investment, it was not included in the list of recommendations. Second, the recommendations stayed within the confines of the *Secretary of the Interior's Standards for Rehabilitation*. If a repair did not follow these standards, it was not included as a recommended improvement in this report.

Surprisingly, most of the economic considerations and arguments for improving the building envelope reinforce the preservation-minded approach. A repair involving replacement windows represents a good example of this finding. The research in this study found that window replacement was unadvisable from a financial perspective. The high up-front costs of wholesale window replacement rarely realize a positive cash flow over the life of a typical 30-year mortgage. The argument for window replacement may stem more from product advertising than from legitimate building science and cost benefit analyses.

Discussion

Envelope Leakage

Reducing envelope leakage should be the primary focus when dealing with energy efficiency. The study set fell generally within the anticipated leakage rates of historic buildings with one unusual finding: The Tradd Street (2) Residence had exceptionally low envelope leakage, testing at 42% air leakage to the outside of the building. This figure is quite low considering no extraordinary measures have been taken to retrofit the house or seal it to an exceptional degree.

This finding suggests that historic buildings are and can be capable of reaching envelope leakage levels competitive with modern construction by focusing on the air sealing details. Further, Tradd Street (2) also has no reported moisture issues. This indicates that low levels of envelope leakage commensurate with new construction are achievable in historic buildings without corresponding moisture issues that are typically feared when a building is sealed tightly.

Strategic improvements can be made to levels of envelope leakage by identifying and sealing leakage pathways through the ceiling and floors first. These areas are easily accessed and are appropriate repairs from a preservation perspective. Air sealing wall systems should focus on identifying and sealing pathways on the interior of the house. Leakage pathways in wall systems are often plumbing or electrical penetrations as opposed to windows and doors. As a result, many pathways can be repaired through the judicial application of caulk, spray foam, or weather-stripping. Again, this study shows that window replacement is not necessary to achieve reduced levels of envelope leakage and energy consumption.

Duct Leakage

Reducing duct leakage is perhaps the most preservation-friendly aspect of energy efficiency retrofitting for historic homes. Duct systems can be sealed and insulated without affecting the historic fabric of a building and this improvement makes a significant impact on the energy consumption of the building overall. By reducing duct leakage to 4% or less, the building can more effectively use the conditioned air to heat and cool the livable space in the house and prevent the loss of conditioned air to the outside of the house. Where possible, duct systems should be located within the conditioned area of the building to ensure that even if leakage occurs, it is contributing to the heating or cooling of the space.

Duct blaster testing on the Anson Street house reported egregiously high levels of leakage attributed to a detached return duct. Fortunately, the process of duct blaster testing revealed the problem and the homeowner was able to have the system easily repaired so that it could function properly. This provides an argument for performing blower door and duct blaster testing on historic buildings at regular intervals to identify and repair issues. Furthermore, pressure testing can offer a method for homeowners to guarantee quality workmanship from a contractor.

In contrast to Anson Street, the Tradd Street (2) had exceptionally low levels of duct leakage. This finding depicts the energy saving potential of quality HVAC installation and workmanship. This level of quality and attention to detail should be expected by every homeowner, and pressure testing offers the most convenient process for quality control.

Windows

Windows are a hot topic in historic preservation, especially with the increase in concern for energy efficiency in recent years. The data in this study suggests that single-glazed wood windows should not be replaced based on expected energy savings alone. According to the cost estimates and modeled energy savings, replacement windows will not return a positive cost benefit. Installing storm windows also provided a negative return on investment for all of the houses in the study. For this reason, both window replacement and storm windows were found to be economically impractical. The research further suggests that budgets for rehabilitation could be spent more appropriately on air sealing and insulation.

Heat gain through existing windows can also be mitigated at a relatively low cost. Installing blinds can create a valuable decrease in energy consumption, especially in a hot, humid climate such as Charleston. Curtains and other window treatments also provide much of the same effect as blinds, but may be more expensive.

Leaky historic windows can be rehabilitated to reduce envelope leakage. Rehabilitating windows with air sealing measures like weather-stripping and gaskets can reduce the leakage through the window. The installation of appropriate flashing around a window is another measure that can have a tremendous impact on the relative leakiness of a window. Flashing will prevent water damage and air leakage between the window assembly and the rough opening in the wall. These air sealing measures can be accomplished in a historically sensitive manner that has little impact on the historic fabric of the home.

Unfortunately, the actual amount of envelope leakage lost through windows and doors on historic structures has not been adequately studied. The majority of the research on this topic has been conducted on new buildings with contemporary windows and doors. This topic is discussed further in the "areas for further research" section of this report.

HVAC

Due to the high complexity of HVAC systems across different buildings, it is very difficult to recommend a specific type of system. Of course, when a property owner chooses a new system, they should choose the most efficient system they can afford, but the cost effectiveness of this choice cannot be determined except on a specific, case-by-case basis. This is not an area where trends are particularly helpful and, therefore, it has not been generalized in the study results.

In an effort to guarantee the purchase and installation of the most efficient heating and cooling system, homeowners should commission a Home Energy Rating and improvement analysis from the growing green collar industry of Certified Home Energy Raters. Raters can develop an energy model to accurately depict home energy use and work with the homeowner to determine which HVAC system is most appropriate for a household budget.

Water Heating

In every case, employing a solar heating unit *with the assistance of economic incentives* provided by the government returned a positive investment over the life of the unit. “Demand-Gas” refers to tankless water heating models that heat water instantly in response to demand instead of constantly heating in the event that the hot water is needed. Despite the fact that tankless water systems are one of the most efficient models to use, only one building, Tradd Street (2), demonstrated a positive return on investment over the life of the unit. All other types of upgraded water heating units were too costly to justify any energy cost savings that they provide.

Appliances and Lights

In all of the buildings studied, there was a negative return on investment for adding Energy Star-rated appliances to the house. While replacing already-functioning appliances for Energy Star may not make sound financial sense, upgrading with more efficient appliances at the end of their life is a logical choice. Lights, on the other hand, are an extremely easy and profitable option for energy retrofitting in a historic structure. In all of the buildings studied, replacing light bulbs with compact fluorescents provided a positive return on investment. In fact, the average net savings of completing this retrofit was $862 with a payback period of one year.

The Building’s Lifecycle

There are two moments in a building’s lifecycle when homeowners have the best opportunity to increase the energy efficiency of a home--when a homeowner decides to repaint the interior of a house and when a new HVAC system is required. At these times, much can be accomplished with air sealing and insulation details.

When a home's interior is repainted, homeowners or contractors can take advantage of a blower door test to identify the leakage pathways through the building shell. Before paint is applied, all forms of air sealing are possible, including caulking and spray foam. After air sealing, paint will hide any of the improvements made. Homeowners should take this opportunity to improve the building envelope through air sealing and the addition of insulation.

When installing a new HVAC system, a contractor will use the building's design characteristics to size a system appropriately. Factors like building orientation, envelope leakage and insulation levels all impact this process. All things being equal, a well-sealed and well-insulated building envelope is easier to heat and cool. Air sealing and insulating before systems are replaced allows for a potential size reduction of the HVAC system, which would save on the installation and operating costs.

If air sealing and insulation occurs after the installation of an HVAC system, the reduced heat gain may cause the HVAC system to short cycle. "Short-cycling" is a process by which the HVAC system will activate, cool a space rapidly, and turn off. Short-cycling is hard on equipment, and can be likened to driving in stop-and-go traffic. Short-cycling shortens the life span of mechanical equipment and increases operational costs. In many instances, short-cycling can inhibit an HVAC system's ability to remove moisture, causing comfort issues in the house.

Therefore, homeowners should take the opportunity to improve the building envelope at these moments in a building's lifecycle in an effort to increase efficiency, be more cost effective and reduce the building's environmental footprint.

Areas for Further Research

With any research there is always more that can be studied to better improve upon the subject. Over the course of this study, it was determined that further understanding of historic windows and their impact on energy use is an area that needs additional independent research. The exact impact of air leakage from historic wood windows on the overall energy use in a building is unknown. This subject could be much better understood from a simple leakage testing conducted exclusively on each window. If the window was tested before and after rehabilitation, the benefits of performing the repair could be better understood. In this way, the cost of rehabilitating a historic window and its subsequent energy savings could be compared to determine whether the action was cost effective.

Additional study is also advisable on the topic of moisture dynamics in historic buildings. Software modeling programs are available that can be used to calculate the coupled heat and moisture transfer in building components. This type of analysis can be used to predict moisture transfer to avoid the common pitfalls in the rehabilitation of a historic property.

Energy efficiency in historic structures has just begun to be seriously studied. This project has only scratched the surface of understanding how energy is used and lost in historic buildings in a warm, humid climate such as Charleston. An abundance of research can certainly still be completed on this topic to reinforce the trends that have already been presented in this study. Because the data set of five buildings is still relatively small, it would be very constructive to continue adding more local historic buildings for testing in order to increase the sample set and better understand the performance of diverse historic buildings representing different construction periods and material types. Increasingly, owners of historic properties have been requesting energy audits and it is expected that interested parties will come forward even more frequently in the future.

With an improved data set, guidelines could be produced that are similar to those found in Great Britain. This information would better guide property owners and contractors alike to more effectively retrofit historic structures by both protecting their materials and improving their impact on energy use in the community. As energy costs continue to rise and sustainability issues are more widely discussed, the importance of retrofitting our existing housing stock will become a central theme in our quest for improved energy efficiency.

Suggested Reading List

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