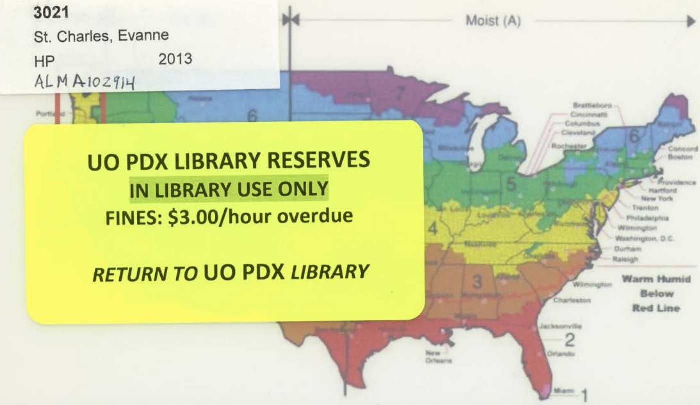

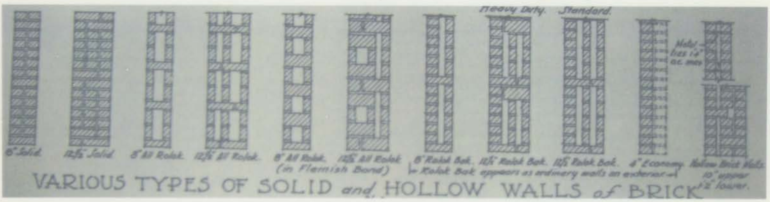

An Energy Reduction Strategy & Retrofit Guidebook for Owners of Historic Brick Buildings: Weighing the Values & Implications of Energy Efficiency & Historic Integrity

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Master's Candidate, Historic Preservation, 2013
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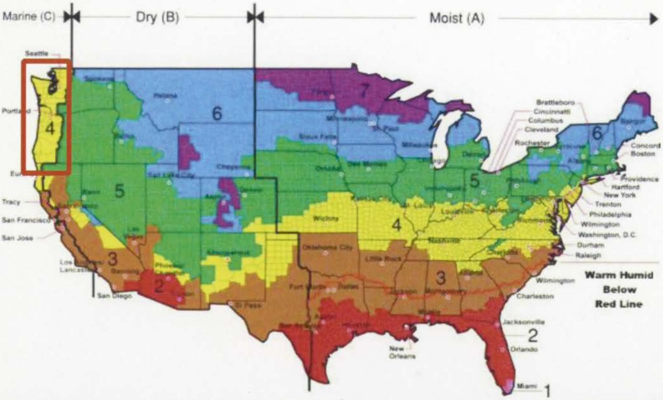

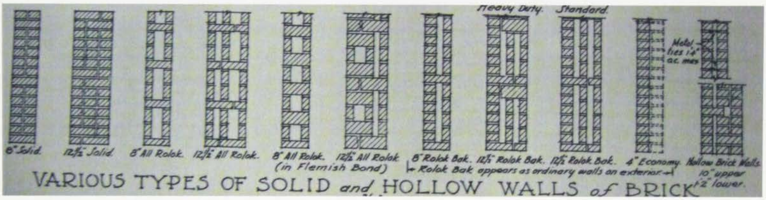

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HOW TO USE THIS GUIDEBOOK

PART A
Identifying the problem

Part A explains the dilemma building owners face when pursuing energy efficiency measures and retrofits in historic buildings, and how a guidebook such as this can aid owners in successfully pursuing their project goals.

PART B
Understanding values and recognizing the choices

Part B outlines the values that are inherent in both historic preservation and energy efficiency, as well as what choices are possible after the building owner determines which objectives are particularly important.

PART C
Presenting the options and determining the best course of action

Part C provides potential approaches for reducing energy use in historic buildings as well as case studies where energy reduction strategies and retrofits have been implemented.

TABLE OF CONTENTS

PART A
CHAPTER ONE: INTRODUCTION & BACKGROUND

With the increasing threat of climate change and the diminishing availability of our natural resources, the need to conserve energy is imperative. Buildings account for approximately 40 percent of the United States' annual energy consumption and produce roughly 37 percent of the United States' greenhouse gas emissions.[1] According to the American Council for an Energy Efficient Economy, as of 2010, the United States was composed of approximately 300 billion square feet of existing buildings.[2] Thus, the existing building stock presents us with a great opportunity.

However, an issue frequently arises when attempting to apply current energy reduction strategies to historic buildings. While often energy efficient retrofits do not consider the values and objectives of historic preservation, preservationists in many instances do not have the informational resources available to apply sound energy reduction measures to their historic buildings. Without a comprehension of how modern approaches to energy efficiency can affect historic buildings, incompatible material use and the improper combination of materials can result in the unintentional loss of historic fabric. The problem that this research addresses is recognizing the tradeoffs and implications of performing energy retrofits in historic brick buildings while maintaining a certain level of integrity and durability in the building.

In order to address the issues that can arise when conducting energy retrofits and additional reduction measures in historic buildings, it is necessary that the building owner be aware of the potential appropriate approaches available that align with the goals of their particular project. Thus, this guidebook was created to address the need for a comprehensive, technical methodology that historic building owners can follow when attempting to improve their building's energy use.

GUIDEBOOK OBJECTIVES

Owners of historic buildings are often faced with making decisions regarding the retrofit of their building without having all of the information necessary to make informed choices concerning what is appropriate for their particular project. Thus, the purpose of this guidebook is to provide a framework for building owners to follow when weighing the potential benefits and tradeoffs between increasing energy efficiency and maintaining the historic integrity of their building. Additionally, the guidebook will aid the building owner in understanding the wide range of methods that are possible in order to significantly reduce the building's energy use while working within the values of historic integrity set by the project.

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[1] U.S. Energy Information Administration, "Frequently Asked Questions," U.S. Department of Energy, http://www.eia.gov/tools/faqs/faq.cfm?id=86&t=1 (accessed November 10, 2012).
[2] Liz Dunn, "Energy Codes and Existing Buildings," (lecture, 2010 National Symposium on Market Transformation, Marriott Wardman Park Hotel, Washington, D.C., March 18, 2010).

SCOPE

This guidebook provides options for whole building energy reduction measures through building envelope retrofits, load reduction strategies, system upgrades and renewable energy. Chapter Four emphasizes retrofits to historic brick wall assemblies because walls are often one of the most controversial characteristics to alter in a historic building, not only because of the issues with historic integrity, but also due to the durability concerns of installing insulation on the interior surface of historic brick.

Chapter Four focuses on brick wall assemblies built between 1900 and 1940 because the building technologies and wall types that existed within this period are essentially the same. Although the material covered may be applicable to buildings constructed outside this period, post-World War II building technology, such as the use of plywood, moisture barriers and less porous cement materials, became much more common, altering the way buildings were constructed. Similarly, buildings erected prior to 1900 employed different construction materials – bricks were less standardized, Portland cement was newly invented in the late 1800s and was rarely found in pre-1900 brick structures, and so on. Solid brick wall assemblies, cavity walls and brick veneer backed by load-bearing concrete are discussed. The guidebook centers on appropriate retrofitting techniques for walls built in the Pacific Northwest, or what the United States Department of Energy refers to as Climate Zone 4C, a marine, mixed climate.[3] In order to address the different levels of retrofitting possible, the combination and application of materials, the types of materials and the ordering of the wall assembly will be considered.

Alterations to the windows of historic buildings are often just as controversial as changing the properties of the wall. The National Trust for Historic Preservation's Preservation Green Lab in Seattle, Washington, recently came out with a report on evaluating the energy performance of window retrofit and replacement. Thus, building owners should refer to this report for further information. The report can be found at: http://ncptt.nps.gov/wp-content/uploads/Main-Report-120919_NTHP_windows-analysis_v3lowres1.pdf.

This guidebook does not aim to provide detailed specifications for particular projects; rather it intends to provide details of possible approaches for reducing a historic building's energy use and potential results. Not all of the procedures described will be appropriate or possible in each situation. With the broad range of energy reduction measures and new techniques that may be possible in the coming years, there will almost always be a suitable measure for each specific building.

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[3] Michael C. Baechler, Jennifer Williamson, Theresa Gilbride, Pam Cole, Marye Hefty, and Pat M. Love, *High-Performance Home Technologies: Guide to Determining Climate Regions by County*, Building America Best Practice Series, 7.1 (Washington, D.C.: U.S. Department of Energy, 2010) http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/ba_climateguide_7_1.pdf (accessed April 28, 2013), 2.

PART B

CHAPTER TWO: PRESERVATION & ENERGY EFFICIENCY: BASIC CONCEPTS & VALUES

HISTORIC BUILDINGS & PRESERVATION DEFINITIONS

According to the National Park Service, all buildings over 50 years of age are eligible to be considered historic. The field of historic preservation aims to protect and enhance buildings of historical, cultural and architectural significance in order to preserve the building's integrity. Although any historic building can maintain cultural, economic and social values, those of particular significance are designated by type – national, state or local.

National Register Listing

The National Register of Historic Places is the official federal list of historic places that are considered significant to preserve at the local, state or national level.[4] Although any listed property receives at least some amount of protection, those that are nationally listed are considered the most significant of properties on the National Register of Historic Places.

Historic Districts, or a collection of continuous "sites, buildings, structures or objects united historically or aesthetically by plan or physical development," are also applicable for National Register Listing.[5] Although there are typically more relaxed guidelines regarding alterations made to a property listing in a historic district, consultation of the local historic preservation committee or the State Historic Preservation Office is necessary when making changes.

A National Landmark is a nationally significant historic property designated by the Secretary of the Interior because it possesses "exceptional value or quality in illustrating or interpreting the heritage of the United States."[6] Currently, there are less than 2,500 historic properties that are listed as National Historic Landmarks.[7] A National Historic Landmark is considered the highest form of designation listed on the National Register of Historic Places.

Local Landmark Designation

Similar to the National Register, a historic property can be designated a local landmark if it maintains significant architectural, cultural, archeological and/or historic values. Unlike National Register Listing, local landmarks are designated by the city.

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4 National Park Service, "National Register of Historic Places," U.S. Department of the Interior, http://www.nps.gov/nr/ (accessed April 13, 2013).

5 National Park Service, "How to Define Categories of Historic Properties," U.S. Department of the Interior, http://www.nps.gov/nr/publications/bulletins/nrb15/nrb15_4.htm#district (accessed April 13, 2013).

6 National Park Service, "National Historic Landmarks Program," U.S. Department of the Interior, http://www.nps.gov/history/nhl/ (accessed April 13, 2013).

7 National Park Service, "National Historic Landmarks Program."

PRESERVATION VALUES

Integrity

Integrity, as defined by the National Park Service is, "The authenticity of a property's historic identity, evidenced by the survival of physical characteristics that existed during the property's prehistoric or historic period."[8] These characteristics include the property's location, design, setting, materials, feeling, workmanship and association. Integrity is important for maintaining the character of the historic resource. The integrity of a historic property contributes to community identity and sense of place. The historic integrity of a building can also have a positive impact on the value of the property as well as the surrounding neighborhood.

There are four levels of integrity: high, good, fair and poor. Determining the building's level of integrity will help to determine how much of the building can or should change. This will, in turn, affect the type of retrofit and energy reduction measures that are most appropriate for the particular building. In order to decide the level of integrity the building maintains, consultation with a preservation professional is recommended.

Character-Defining Features

Character refers to the visual, physical features and aspects that constitute the appearance of a historic building. Character-defining features include the overall shape (form, massing, rhythm and symmetry) of the building, its craftsmanship, materials (including texture and color), interior spaces, articulation of decorative details, roof type and shape, windows (their pattern and reveals), doors and the various aspects of its site and environment.[9]

The National Park Service's *Preservation Brief 17: Architectural Character – Identifying the Visual Aspects of Historic Buildings as an Aid to Preserving their Character* discusses how to determine the character-defining elements of a building: http://www.nps.gov/tps/how-to-preserve/briefs.htm. However, it is often better to consult a preservation professional in order to ensure that all of the character-defining features of your building are recognized to prevent them from being damaged or destroyed.

PRESERVATION PRINCIPLES

The Secretary of the Interior's Standards

There are two main goals of the *Secretary of the Interior's Standards for the Treatment of Historic Properties* – the preservation of historic materials and the preservation of the building's character – both of which are embodied in the building's integrity.[10] When considering how to

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[8] National Park Service, "National Register Bulletin," U.S. Department of the Interior, http://www.nps.gov/nr/publications/bulletins/nrb34/nrb34_8.htm (accessed November 10, 2012).
[9] Lee H. Nelson, *Preservation Brief 17: Architectural Character - Identifying the Visual Aspects of Historic Buildings as an Aid to Preserving Their Character*, National Park Service (Washington, D.C.: U.S. Department of the Interior, 1988) http://www.nps.gov/hps/tps/briefs/brief17.htm (accessed April 13, 2013).
[10] Nelson, *Preservation Brief 17: Architectural Character - Identifying the Visual Aspects of Historic Buildings as an Aid to Preserving Their Character.*

maintain the building's integrity prior to an energy retrofit, the *Secretary of the Interior's Standards for Rehabilitation* are most applicable. According to the Secretary of the Interior's Standards, rehabilitation is "the act or process of making possible a compatible use for a property through repair, alterations, and additions while preserving those portions or features which convey its historical, cultural, or architectural values."[11] Thus, although it is assumed that at least some alterations or repair will be involved when rehabilitating a historic building, the changes made should not "destroy materials, features or finishes that are important in defining the building's character."[12] Damaging the building's character will in turn affect the integrity of the building.

Although it is often up to the building owner to decide the extent to which historic integrity is valued and must be maintained, in some cases the building is limited as to how much can be altered due to certain historic preservation parameters the owner must follow. The Secretary of the Interior's Standards are a good resource for building owners who wish to understand the parameters the building may be confined to when attempting a retrofit. *The Secretary of the Interior's Standards for Rehabilitation and Illustrated Guidelines on Sustainability for Rehabilitating Historic Buildings* cover the appropriate treatment of windows, weatherization and insulation, heating, ventilating, air conditioning and air circulation, solar technology, wind power, roofs and site features. The sustainability guidelines can be found at: http://www.nps.gov/tps/standards/rehabilitation/sustainability-guidelines.pdf.

ENERGY EFFICIENCY VALUES

There are a number of reasons to consider energy efficient upgrades. Chris Park, a leader at Deloitte Enterprise Sustainability, a subset of the international business organization, Deloitte LLP, that specializes in climate change strategy and sustainability reporting, assurance and compliance, among other things, stated "Green retrofits are the single most important measure that corporations and real estate owners can take to reduce their operating costs, raise commercial property values and achieve important environmental benefits like reduced carbon dioxide emissions."[13]

Operational Costs

Reducing the operational costs of a building is one factor that may play a role in why a building owner attempts energy reduction measures. There are approximately five billion existing

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[11] National Park Service, "Standards for Rehabilitation and Guidelines for Rehabilitating Historic Buildings," U.S. Department of the Interior, http://www.nps.gov/hps/tps/standguide/rehab/rehab_index.htm (accessed November 10, 2012).

[12] Anne E. Grimmer, Jo Ellen Hensley, Liz Petrella, and Audrey T. Tepper, *The Secretary of the Interior's Standards for Rehabilitation & Illustrated Guidelines on Sustainability for Rehabilitating Historic Buildings*, National Park Service (Washington, D.C.: U.S. Department of the Interior, 2011) http://www.nps.gov/tps/standards/rehabilitation/sustainability-guidelines.pdf (accessed April 13, 2013), 7.

[13] Environmental Design + Construction: The official magazine for the LEED Professional, "Deloitte Survey Reveals Competitive Advantages Outweigh Costs Associated with Green Retrofits," Environmental Design + Construction, http://www.edcmag.com/articles/print/deloitte-survey-reveals-competitive-advantages-outweigh-costs-associated-with-green-retrofits-posted-7-30-08 (accessed April 28, 2013).

commercial properties (4.8 million) and industrial facilities (350,000) in the United States.[14] The annual operating cost related to energy use for commercial buildings is $107.9 billion and $94.4 billion for industrial properties.[15] Reducing energy usage by just 10 percent in commercial and industrial properties would save a combined $20 billion.[16] Additionally, a 30 percent reduction in energy use would save $182 billion for the residential sector and $25 billion for institutional buildings in the United States.[17] Thus, pursuing energy reduction measures in an existing building can result in a substantial savings.

Occupant Comfort

Occupant comfort may be the motive for conducting a retrofit, as old buildings can be drafty and unpleasant. Indoor air quality issues, such as leaky, mold-ridden buildings, could be a major reason for pursuing a retrofit. The Lawrence Berkeley National Laboratory's Indoor Air Quality Scientific Findings Resources Bank estimates as much as a 10 percent increase in occupant work performance due to improvements including changes in temperature, ventilation rates and lighting levels as well as a reduction in indoor pollutant sources.[18] A report sponsored by the Massachusetts Technology Collaborative (the state's development organization for renewable energy and the innovation economy) found that a one percent increase in productivity (equal to about five minutes per working day) is equal to approximately $650 per employee per year, or three dollars per square foot per year.[19] Thus, the cost savings of increasing occupant comfort is substantial.

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[14] Commercial Building Energy Consumption Survey, "Table A1. Summary Table for All Buildings (Including Malls), 2003," Energy Information Administration, U.S. Department of Energy, http://www.eia.gov/emeu/cbecs/cbecs2003/detailed_tables_2003/2003set1/2003pdf/a1.pdf (accessed April 28, 2013).; Energy Information Administration, "Table 9.1 Enclosed Floorspace and Number of Establishment Buildings, 2002," U.S. Department of Energy, http://www.eia.gov/consumption/manufacturing/data/2002/pdf/Table9.1_02.pdf (accessed April 28, 2013).

[15] Commercial Building Energy Consumption Survey, "Table C4. Expenditures for Sum of Major Fuels for Non-mall Buildings, 2003," *High-Performance Home Technologies: Guide to Determining Climate Regions by Count*, Energy Information Administration, U.S. Department of Energy, http://www.eia.gov/emeu/cbecs/cbecs2003/detailed_tables_2003/2003set9/2003pdf/c4.pdf (accessed April 28, 2013).; Energy Information Administration, "Table 7.9 Expenditures for Purchased Energy Sources, 2002," U.S. Department of Energy, http://www.eia.gov/consumption/manufacturing/data/2002/pdf/Table7.9_02.pdf (accessed April 28, 2013).

[16] ENERGY STAR program, "The ENERGY STAR Challenge: Build a BetterWorld 10% at a Time," U.S. Environmental Protection Agency, http://www.energystar.gov/ia/business/challenge/get_started/brochure_bifoldlayout.pdf (accessed May 6, 2013).

[17] The Rockefeller Foundation, "United States Building Energy Efficiency Retrofits: Market Sizing and Financing Models," The Rockefeller Foundation, http://dbcca.com/research (accessed April 28, 2013).

[18] Indoor Air Quality Scientific Findings Resources Bank, "Impacts of Indoor Environments on Human Performance and Productivity," Lawrence Berkeley National Laboratory, http://www.iaqscience.lbl.gov/ (accessed April 28, 2013).

[19] George H. Kats. *Green Building Costs and Financial Benefits* (Boston, MA: Massachusetts Technology Collaborative, 2003) http://www.dcaaia.com/images/firm/Kats-Green-Buildings-Cost.pdf (accessed May 19, 2013), 6.

Sustainability
Sustainable development is defined as "development which meets the needs of the present without compromising the ability of future generations to meet their own needs."[20] There are three aspects of sustainability – social sustainability, economic sustainability and environmental sustainability.

Sustainability has become a much talked about topic and popular reason for building owners to carry out energy retrofits as well. Retrofits reduce energy use while allowing the reuse of an existing building, minimizing the need to utilize more resources, materials and energy that it takes to build new. This last concept, known as embodied energy, will be discussed further in the next section.

COMMONALITIES BETWEEN HISTORIC PRESERVATION & ENERGY EFFICIENCY

Resale Value
The resale value of historic and energy efficient buildings are often higher because of the building's cultural significance to the neighborhood and community as well as the energy savings that the building can provide.

Donovan Rypkema, a real estate and historic preservation expert stated, "Virtually every analysis that has been done on the economic impact of [historic district] protection has indicated that values have maintained at worst, and usually are enhanced, because of historic district status."[21] Furthermore, a 2003 study conducted by New York City's Independent Budget Office found that significant price premiums – varying year to year from approximately 23 percent and 72 percent – were associated with properties included in a historic district. An academic study conducted in 2001 by Robin Leichenko, David Listokin and Edward Coulson found that property values in seven of nine Texas cities increased between five and 20 percent for historically designated buildings.[22]

Similarly, a property that is recognized as being energy efficient provides for higher resale values. A study conducted between 2007 and 2012 of 1.6 million Californian homes found that residences labeled energy efficient sold for an average of nine percent more than those not considered energy efficient.[23] Furthermore, a sale price premium of 13 percent was found for offices that earned green ratings between 2007 and 2009.[24]

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[20] The World Bank Group, "What is Sustainable Development," The World Bank Group, http://www.worldbank.org/depweb/english/sd.html (accessed April 28, 2013).
[21] Randall Mason, *Economics and Historic Preservation: A Guide and Review of the Literature* (Washington, D.C.: The Brookings Institution Metropolitan Program, 2005), 7.
[22] Ibid.
[23] Kenneth R. Harney, "Study Finds that Energy-Efficient Homes Often Command Higher Prices," *The Washington Post*, http://articles.washingtonpost.com/2012-07-19/news/35488125_1_energy-star-energy-efficient-homes-leed (accessed April 28, 2013).
[24] Piet Eichholtz, Nils Kok and John M. Quigley, "The Economics of Green Building," *Review of Economics and Statistics* 95, no. 1 (2003): 32.

The benefits of preservation related to the concept of social, environmental and economic sustainability are numerous. Measurable environmental advantages, such as reduced energy use, landfill material and carbon release, quantifiable economic advantages such as higher property values and job creation, and social benefits, including community protection and strengthening sense of place, are some of the ways in which historic preservation and sustainability are associated.

Durability

Durable materials such as brick construction are often inherent in historic buildings, and in order for a historic building to survive, the durability of the building must be maintained. Durability is also a sensible aspect of sustainable building. The use of durable materials in construction requires less energy to maintain, restore and repair the materials. Thus, even though less-durable materials may use less energy to produce initially, the need for recurrent replacement and consequential disposal of the material after removal typically results in a larger overall embodied energy over the life of the material.[25] Because durable materials do not need to be repaired or replaced as often, they are also less expensive in the long run.

Embodied Energy

Embodied energy is the "initial energy investment required to produce a material or product…Thus, the embodied energy of a building reflects the total energy needed to produce all materials or assemblies, transport them to a building site, and assemble a building."[26] It takes approximately five to 15 gallons of oil during the construction process of each square foot of a new building, and construction accounts for approximately five percent of all domestic energy consumption.[27] Although it takes energy to upgrade a building as well, the reuse of existing structures will "save at least one third, and probably one half, of the energy that would be required for new construction."[28] Thus, from a preservation standpoint as well as a sustainability perspective, it is favorable to reuse existing buildings more often than it is to build new.

Similar to the idea of embodied energy is the concept of embodied carbon – the amount of carbon emissions produced through building construction, including the complete cycle of material extraction, fabrication, transportation and final assemblage.[29] A recent study conducted by the National Trust for Historic Preservation's Preservation Green Lab found that "it takes 10 to 80 years for a new building that is 30 percent more efficient than an average-performing existing building to overcome, through efficient operations, the negative climate change impacts

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25 Carroon, *Sustainable Preservation: Greening Existing Buildings* (Hoboken: John, Wiley & Sons, 2010), 8.

26 The Preservation Green Lab, *The Greenest Building: Quantifying the Environmental Value of Building Reuse* (Washington, D.C.: The National Trust for Historic Preservation, 2011) http://www.preservationnation.org/information-center/sustainable-communities/green-lab/lca/The_Greenest_Building_lowres.pdf (accessed April 28, 2013), 20.

27 Carl J. Stein, *Greening Modernism: Preservation, Sustainability and the Modern Movement* (New York: W.W. Norton & Co, 2010), 99.

28 Ibid., 36.

29 Carroon, *Sustainable Preservation: Greening Existing Buildings*, 7-8.

related to the construction process."[30] The extent of emissions reductions depends on a number of factors, including building type and climate.

However, building reuse alone does not significantly reduce climate change emissions. The same study as above found that the combination of building reuse and energy retrofits together offer the most significant emissions reductions with regard to climate change, resource impact and human health.[31]

FUNDING

There are numerous funding sources that exist to help building owners pay for energy retrofits in their existing or historic buildings. Some of the sources are specific to historic buildings, while others are directed towards existing buildings in general. Below are descriptions of a few of the funding sources available that are directed towards homeowners and smaller scale building owners, providing energy savings with little or no upfront costs.

Property Assessed Clean Energy Programs

Property Assessed Clean Energy, or PACE programs "allow local government entities to offer sustainable energy project loans to eligible property owners."[32] Funding is given to property owners for onsite renewable energy projects or energy efficiency retrofits after a voluntary assessment of their property tax bills is conducted. This allows the owner to avoid upfront installation costs.[33] More information regarding the PACE program can be found at: http://energycenter.org/index.php/public-affairs/property-assessed-clean-energy-pace.

Energy Services Agreement

Energy Services Agreement, or ESA, is a contract that "permits energy efficiency to be packaged as a service that building owners pay for through savings, and that generally requires no (or minimal) upfront cost to the owner."[34] An energy audit is typically conducted by the ESA provider to determine cost effective energy efficiency measures that could be implemented. The ESA provider will then pay to have these measures implemented, and the building owner will make payments to the ESA based on the energy savings realized.[35] For more information regarding Energy Service Agreements, follow this link: http://www.nyceec.com/esa/.

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30 The Preservation Green Lab, *The Greenest Building: Quantifying the Environmental Value of Building Reuse*, 8.

31 Ibid.

32 Center for Sustainable Energy California, "Property Assessed Clean Energy (PACE) Programs," Center for Sustainable Energy California http://energycenter.org/index.php/public-affairs/property-assessed-clean-energy-pace (accessed April 28, 2013).

33 Center for Sustainable Energy California, "Property Assessed Clean Energy (PACE) Programs."

34 New York City Energy Efficiency Corporation, "Energy Service Agreements," New York City Energy Efficiency Corporation, http://www.nyceec.com/esa/ (accessed April 28, 2013).

35 New York City Energy Efficiency Corporation, "Energy Service Agreements."

Tax Incentives Assistance Project

The Tax Incentives Assistance Project, or TIAP is a federal government tax incentive program for new or existing commercial buildings. The building may reach a tax deduction up to $1.80 per square foot if the building saves at least 50 percent in heating, cooling, ventilation, interior lighting or water heating energy cost of a building that meets the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) Standard 90.1-2001. Partial tax deductions are offered for projects that produce 20 percent in whole building energy savings for HVAC or lighting systems or 10 percent in whole building energy savings for envelope upgrades.[36] More information regarding the Tax Incentives Assistance Project can be found at: http://energytaxincentives.org/business/commercial_buildings.php.

National Park Service Rehabilitation Tax Credits

The National Park Service provides tax credits for the rehabilitation of historic and non-historic properties. A 20 percent income tax credit is accessible for the rehabilitation of historic, income-producing properties that comply with the *Secretary of the Interior's Standards for Rehabilitation* and are individually listed or are a contributing property of a historic district on the National Register of Historic Places. Historic properties that qualify include commercial, industrial, agricultural or rental residential resources, however non-income-producing private residences do not apply.[37]

A 10 percent rehabilitation tax credit is available for non-historic, non-residential properties that were in service before 1936.[38] More information regarding federal rehabilitation tax credits can be found at: http://www.nps.gov/tps/tax-incentives/taxdocs/about-tax-incentives-2012.pdf.

Historic Preservation Easement Tax Benefits

A historic preservation easement, a voluntary legal agreement permanently protecting a historic property, may provide potential tax benefits for the owner of a historic building. Tax benefits including federal income tax deductions are available to owners of historic buildings that are listed on the National Register of Historic Places and have a preservation easement in place. The value of the easement is typically the "difference between the appraised fair market value of the property prior to conveying an easement and the appraised fair market value of the property after the easement."[39] Further information regarding the potential tax benefits of historic preservation easements can be found at: http://www.nps.gov/tps/tax-incentives/taxdocs/easements-historic-properties.pdf.

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[36] Tax Incentives Assistance Project, "Business Tax Incentives," Energy Tax Incentives, http://energytaxincentives.org/business/commercial_buildings.php (accessed April 28, 2013).

[37] National Park Service, "Historic Preservation Tax Incentives," U.S. Department of the Interior, http://www.nps.gov/tps/tax-incentives/taxdocs/about-tax-incentives-2012.pdf (accessed April 28, 2013), 4.

[38] National Park Service, "Historic Preservation Tax Incentives," 16.

[39] National Park Service, *Easements to Protect Historic Properties: A Useful Historic Preservation Tool with Potential Tax Benefits* (Washington, D.C.: U.S. Department of the Interior, 2010) http://www.nps.gov/tps/tax-incentives/taxdocs/easements-historic-properties.pdf (accessed April 28, 2013), 3-4.

Obsolete Property Rehabilitation Act Exemption

The Obsolete Property Rehabilitation Act, or OPRA, issues "property tax exemptions for commercial and commercial housing properties that are rehabilitated and meet the requirements of the Act."[40] Properties must include a statement of obsolescence by the local assessor and must be located in an established Obsolete Property Rehabilitation District.[41] For additional information regarding OPRA, see: http://www.michigan.gov/taxes/0,1607,7-238-43535_53197-213177--,00.html.

Weatherization Assistance Program

The Weatherization Assistance Program (WAP), funded by the United States Department of Energy and administered by the states, "enables low-income families to permanently reduce their energy bills by making their homes more energy efficient."[42] In the past 33 years, the WAP has provided funding to more than 6.4 million low-income residences, and has resulted in an average of about $437 in energy savings in each household annually.[43] More information on the program can be found at: http://www1.eere.energy.gov/wip/wap.html.

Energy Trust of Oregon

The Energy Trust of Oregon is a nonprofit organization offering Oregon residential and commercial building owners cash incentives for energy efficiency upgrades. Funding is available for a number of energy reduction and retrofit strategies, including lighting upgrades, heating and cooling system upgrades, installing insulation and energy efficiency appliances.[44]

Additional Funding Sources

There are several additional funding sources for energy retrofits and historic rehabilitation efforts. Membership donations, local utility energy savings incentives, grants from local companies, grants for state energy management and conservation offices, grants for state historic funds, private foundation grants and state business energy tax credits are available depending on the geographic location and physical state of the building seeking upgrades.

FRAMEWORK OF PROJECT CHOICES

Decision-Making Model

Although it is possible to reduce energy savings significantly in a historic building, there are nonetheless parameters that are set according to the goals and values of the particular project. There are generally two choices that can be made when pursuing energy savings in a historic building. Both depend on the project goals and how the values are weighed between energy

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40 State of Michigan Department of Treasury, "Obsolete Property Rehabilitation Act Exemption," State of Michigan Department of Treasury, http://www.michigan.gov/taxes/0,1607,7-238-43535_53197-213177--,00.html (accessed April 28, 2013).

41 State of Michigan Department of Treasury, "Obsolete Property Rehabilitation Act Exemption."

42 U.S. Department of Energy, "Weatherization and Intergovernmental Program," U.S. Department of Energy, http://www1.eere.energy.gov/wip/wap.html (accessed April 28, 2013).

43 Ibid.

44 Energy Trust of Oregon, "Take Control of Your Energy Costs," Energy Trust of Oregon, http://energytrust.org/commercial/ (accessed April 28, 2013).

efficiency and historic integrity. It is important to note that in both cases, historic integrity is valued at least to the extent to which the exterior of the building cannot be altered through retrofit measures.

> *Option A*: The historic integrity of the building is highly valued and therefore improvements are confined to stricter parameters regarding the extent to which the interior of the building can be altered.

> *Option B*: The historic integrity of the interior of the building is of lesser importance (due to past alterations, neglect, etc.) and therefore higher energy savings can be achieved through retrofitting the wall assembly as well as pursuing other more extensive energy reduction strategies.

Option A will require that the building owner looks beyond the wall assembly and considers a whole building approach to energy reduction measures. However, as exemplified by the table below, this does not mean that a significant decrease in energy use cannot be obtained through alternative approaches.

Option B will allow for an energy retrofit to the wall assembly in addition to the reduction methods provided in Option A and shown in the table below. The potential possibilities for retrofitting the wall assembly are provided in Chapter Four. If Option B is applicable, the following aspects regarding the wall assembly will need to be understood in order to decide which retrofitted wall assembly is most appropriate to the historic brick building – the type of wall assembly in place, the intent of the retrofit, project parameters and the climate the building is located in.

It must first be determined what type of brick wall assembly is in place. The type of assembly will partially determine what types of materials and combination of materials are compatible with the building envelope in order to improve the energy efficiency of the wall assembly.

The intent of the retrofit will also affect which retrofitted assembly is chosen. Common historic values, such as retaining a similar historic proportion of window fenestration and trim to wall thickness and installing compatible new windows is discussed in *The Secretary of the Interior's Standards for Rehabilitation & Illustrated Guidelines on Sustainability for Rehabilitating Historic Buildings.* The sustainability guidelines should help to determine the extent to which the historic character and integrity of the building is to be maintained according to the goals of the project. An overview of the Standards and a link to the guidelines were provided under preservation values earlier in Chapter Two. Efficiency values, such as reducing operational costs, increasing occupant comfort and reducing the carbon footprint of the building should help to determine which retrofit measures are appropriate for the purposes of the project. Efficiency values were discussed earlier in Chapter Two.

There could be limitations that affect what type of assembly retrofit is possible. Parameters that the building owner may be confined to include, but are not limited to, historic preservation ordinances and easements, National Register listing, community push-back, cost and the availability of labor and services.

Lastly, the climate of where the building is located will affect the type of assembly chosen. For the purposes of this guidebook, considerations regarding the climate and general location are limited to the Pacific Northwest, or climate 4C, what is considered a mixed, marine climate.

Ultimately, it must be decided what aspects of integrity and energy efficiency are most valued in an attempt to find an appropriate balance between the two, and to determine which retrofit is the most compatible. A whole building approach, discussed in Chapter Three, will be provided for projects that cannot reach energy reduction goals through the wall assembly itself, as well as for building owners who are looking to conduct a wall retrofit in addition to other reduction strategies. Chapter Four addresses the different possibilities for wall retrofits, the combination and application of materials, the types of materials and the ordering of the wall assembly.

Table One: Framework of Project Choices

The Building Envelope												
Options	*Air Sealing*	*Window upgrade (glazing film)*	*Window upgrade (interior/ exterior storm)*	*Window upgrade (blinds)*	*Window upgrade (replacement insulated glazing)*	*Window upgrade (high-performance windows)*	*Door upgrade (storm door)*	*Door upgrade (replacement door)*	*Roof upgrade (insulation)*	*Roof upgrade (cool roof)*	*Floor upgrade (insulation)*	*Wall upgrade (insulation)*
A	Y	Y	Y	Y	P	P	Y	P	Y	P	P	N
B	Y	Y	Y	Y	P	P	Y	P	Y	P	Y	Y

Load Reductions, System Upgrades and Renewable Energy										
Options	*Maintenance*	*Occupancy scheduling*	*Behavior changes*	*Natural ventilation*	*HVAC scheduling and upgrade*	*Daylighting strategies*	*Lighting upgrade (high-efficiency sources)*	*Lighting upgrade (controls)*	*Energy efficient appliances*	*Renewable energy*
A	Y	Y	Y	Y	P	Y	Y	Y	Y	P
B	Y	Y	Y	Y	Y	Y	Y	Y	Y	P

PART C

CHAPTER THREE: THE WHOLE BUILDING APPROACH – OPTION A

In some cases, it is not physically or economically feasible to conduct an energy retrofit specific to the wall assembly. In the opinion of the National Park Service, energy efficiency upgrades should be focused on "improvements that will provide the most payback for the money expended and the least compromise to the historic character of the building."[45] Additionally, the National Park Service explains in *Preservation Brief Three: Improving Energy Efficiency in Historic Buildings* that "installing insulation on the interior walls of a historic masonry structure should be avoided when it would involve covering or removing important architectural features and finishes, or when the added thickness would significantly alter the historic character of the interior."[46] It is important to recognize that limitations can exist regarding the extent that which the building can or should be altered. It is also recommended that the building owner seeks professional guidance and refers to the *Secretary of the Interior's Standards for Rehabilitation* to determine which characteristics of the building should be maintained in order to uphold the building's historic integrity to the extent feasible.

There are numerous alternative methods that can substantially reduce the energy usage of a historic building in addition to or, in some cases, instead of retrofitting the wall assembly. It is important to note that any energy savings measures pursued will be most effective if adjusted according to the particular building and project goals at hand. Descriptions of such measures are provided below, however additional, more detailed resources can be found in Appendix A.

ENERGY AUDITS

In order to determine what would be most appropriate to upgrade according to cost-effectiveness and the amount of energy reduction, a professional energy audit should be conducted prior to pursuing energy reduction measures. If hiring a professional energy auditor is too costly, or you are interested in conducting some of your own research on potential energy improvements prior to hiring a professional, there are a number of free energy-modeling software programs available. The user-friendliness of using these web-based tools, as well as their accuracy varies. In addition, the data output is only as accurate as the information inputted into the programs, so correct information is crucial. Five free software programs downloadable from the Internet are described below.

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[45] Jo Ellen Hensley and Antonio Aguilar, *Preservation Brief 3: Improving Energy Efficiency in Historic Buildings*, National Park Service (Washington, D.C.: U.S. Department of the Interior, 2011) http://www.nps.gov/tps/how-to-preserve/preservedocs/preservation-briefs/03Preserve-Brief-Energy.pdf (accessed April 13, 2013), 11-12.
[46] Ibid.

Table Two: Energy Modeling Programs[47]

Program	Building Type	Cost	Computer Platform	Strengths	Weaknesses	Input
COMcheck	Commercial	Free	Windows, Mac OS	User-friendly; comes with software user's guide	Very basic; does not account for energy flow through glazed areas or infiltration rates	Insulation R-value, glazing and door U-values, building location, heating equipment
eQUEST	Residential, Commercial	Free	Windows	User-friendly; provides different levels of data input allowing for different audiences/levels of expertise to use; evaluates whole-building performance	Compliance analysis limited to California Title 24; infiltration and natural ventilation models simplified and limited	Three levels of input covering detailed information (daylight control levels, types of heating and cooling systems, building scheduling, etc.)
HEED	Residential	Free	Windows, Mac OS	User-friendly; offers a basic and advanced option; focuses on cost savings; Spanish version available	Limited HVAC systems; operating schedules limited to residential	Building location, type, square footage, number of stories, window types, insulation R-value
Home Energy Saver	Residential	Free	Internet-based	User-friendly; "unknown" is an option if you are unsure of certain categories (rather than inaccurately guessing); provides general cost savings	Limited to residential buildings; limited control of engineering parameters	Basic descriptions of appliances and building envelope material characteristics
REScheck	Residential	Free	Windows, Mac OS	User-friendly; comes with software user's guide	Very basic; does not account for energy flow through glazed areas or infiltration rates	Insulation R-value, glazing and door U-values, building location, heating equipment

[47] U.S. Department of Energy, "Building Energy Software Tools Directory," U.S. Department of Energy, http://apps1.eere.energy.gov/buildings/tools_directory/alpha_list.cfm (accessed April 28, 2013).

THE BUILDING ENVELOPE

There are many tasks that the building envelope must perform, including controlling airflow, controlling heat transfer and protecting the interior from rain.[48] Insulating the roof, the floor or the walls, using weatherstripping and altering the window to perform better all play a part in how well the building envelope functions. Upgrades and repairs to the building envelope should be considered prior to installing or upgrading new lighting and HVAC systems because a tight, well functioning envelope could reduce the amount of heating and cooling necessary.[49]

Weatherization

Weatherizing a building is one of the most effective and inexpensive methods to reduce a building's energy use as well as a building owner's operating costs.[50] Weatherization is the process of "implementing cost-effective measures to make a building's envelope more energy efficient."[51] This includes reducing air infiltration through the application of caulking and weatherstripping, upgrading windows and doors and installing insulation in attics, basements and walls.

There are several reasons in addition to reducing a building's energy use to pursue methods of weatherization: "It increases comfort, reduces the change of moisture damage in the building structure, [and] discourages mold growth in wall and ceiling cavities." [52]

This chapter covers five methods of weatherization – air sealing, window upgrades, door upgrades, roof upgrades and floor upgrades. Wall retrofits are covered in Chapter Four.

Air Sealing

Reducing air infiltration through the use of weatherstripping, caulking and spray foam is one of the most cost-effective methods of reducing a building's energy usage, resulting in a 10 percent to 20 percent decrease in a building owner's energy bill. According to the U.S. Department of Energy, the savings could be much higher in older buildings with greater levels of air leakage.[53]

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[48] Stein, *Greening Modernism: Preservation, Sustainability and the Modern Movement*, 181.
[49] Center for Climate and Energy Solutions, "Building Envelope," Center for Climate and Energy Solutions, http://www.c2es.org/technology/factsheet/BuildingEnvelope (accessed April 28, 2013).
[50] Bruce Harley, *Insulate and Weatherize: Keeping Warm in Winter and Cool in Summer, Solving Moisture Problems, Finding Hidden Energy Wasters* (Newtown: Taunton Press, 2002), 29.
[51] Technical Preservation Services, "Weatherizing and Improving the Energy Efficiency of Historic Buildings," National Park Service, U.S. Department of the Interior, http://www.nps.gov/tps/sustainability/energy-efficiency/weatherization.htm (accessed April 28, 2013).
[52] Harley, *Insulate and Weatherize: Keeping Warm in Winter and Cool in Summer, Solving Moisture Problems, Finding Hidden Energy Wasters*, 23.
[53] Michael C. Baechler, Theresa Gilbride, Marye Hefty, Pam Cole, Jennifer Williamson, and Pat M. Love, *Retrofit Techniques and Technologies: Air Sealing: A Guide for Contractors to Share with Homeowners*, Building America Best Practice Series, (Washington, D.C.: U.S. Department of Energy, 2010) http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/ba_airsealing_report.pdf (accessed April 28, 2013), i.

In addition to potentially reducing the energy usage and operating costs of a building, sealing air leaks has little if any negative affects on the integrity and durability of a building (as long as it is performed properly). Thus, reducing air infiltration is highly recommended in historic buildings.

The most appropriate materials for sealing air leaks depends on the size and location of the gaps. For openings less than ¼ inch wide, caulking is recommended. For cracks and holes ranging from ¼ inch to one inch, expanding foam sealants work well, and for larger openings, such as plumbing and chimney chases, rigid foam insulation is appropriate.[54] Larger openings can also be caulked if a backer rod is inserted first. The largest amounts of air leakage are most always where the greatest pressure differences are located – at the highest and lowest parts of a building. This is due to the stack effect, which forces out air at the top of the structure and pulls air in from the bottom of the building during winter.[55] Thus, the first source of air leakage that should be addressed is the attic. Areas of great air leakage in attics include access hatches, dropped ceilings, plumbing chases, chimney chases, wiring holes, open soffits and wall studs or additional through-framing extending into the attic. Each of these locations should be sealed with weatherstripping, in the case of access hatches, or caulking and/or spray foam in larger areas of air leaks.

The second large source of air leakage that needs to be addressed is the basement or crawlspace. The basement or crawlspace walls, service penetrations for electricity, telephones and plumbing, sill and band joists and the floor deck are all components that should be caulked.[56]

Leaks can occur in exterior walls where cable, plumbing and telephone services enter the house, where exhaust fans, electrical outlets and switches are located, around rough openings for windows and doors, and where the framing of the house makes transitions (i.e. a cantilevered floor for a balcony).[57] Each of these places should be investigated and sealed if necessary.

The first step in reducing air leakage through windows and doors is to ensure they fit properly in the wall opening. After the window and/or door are fitted appropriately, weatherstripping can be applied. Whereas most modern windows and doors have adequate built-in weather stripping, older ones do not. Thus, the incorporation of weatherstripping on the top and both sides of the window/door, as well as a door sweep

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[54] American Council for an Energy-Efficient Economy, "The Building Envelope: Walls, Attic, Basement, Doors and Windows," American Council for an Energy-Efficient Economy, http://aceee.org/consumer/building-envelope (accessed April 28, 2013).

[55] Harley, *Insulate and Weatherize: Keeping Warm in Winter and Cool in Summer, Solving Moisture Problems, Finding Hidden Energy Wasters*, 30.

[56] Harley, *Insulate and Weatherize: Keeping Warm in Winter and Cool in Summer, Solving Moisture Problems, Finding Hidden Energy Wasters*, 42-47.

[57] Ibid., 47-48.

at the bottom of a swinging door will reduce air leakage.[58] In addition to the performance improvements for windows discussed below, window sashes can be tightened "with leaf-type or v-seal weatherstripping and pulley seals," and caulking or spray foam should be applied between the window frame and trim, and between the trim and the wall.[59]

See Appendix A for more information regarding the appropriate types of caulking and sealants, as well as proper methods of weatherizing a historic building.

<u>Window Upgrades</u>
Windows are usually as controversial to alter as the wall assembly. Building owners frequently presume that replacing older, drafty windows is the only option for saving energy, an assumption "actively promulgated and reinforced by companies selling replacement windows and by the availability of federal tax incentives for installing new, high performance windows."[60] However, this is simply not true. There are several available options for increasing a window's efficiency while maintaining the original fabric that should be considered prior to replacing historic windows.

Preservation Green Lab, a subset of the nationwide non-profit, National Trust for Historic Preservation, recently partnered with Cascadia Green Building Council and a Seattle-based energy efficiency consulting firm, Ecotope, to produce the report, *Saving Windows, Saving Money: Evaluation the Energy Performance of Window Retrofit and Replacement*. Key findings of this report include that retrofits to historic windows can attain comparable performance results to new replacement windows. Furthermore, most retrofit options provide a better return on investment than replacement windows.[61] Lastly, the reuse of existing historic windows reduces waste and the need for additional material resources.

There are several methods of significantly increasing the energy performance of windows without adversely impacting the integrity of the building. In addition to installing weatherstripping, below is a list of different possible performance upgrades.

- Glazing film
- Interior/exterior storm windows
- Blast curtains and shades
- Secondary glazing

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[58] Ibid., 48.
[59] Ibid., 99.
[60] The Preservation Green Lab, *Saving Windows, Saving Money: Evaluating the Energy Performance of Window Retrofit and Replacement* (Washington, D.C.: The National Trust for Historic Preservation, 2011) http://ncptt.nps.gov/wp-content/uploads/Main-Report-120919_NTHP_windows-analysis_v3lowres1.pdf (accessed April 28, 2013), 11.
[61] The Preservation Green Lab, *Saving Windows, Saving Money: Evaluating the Energy Performance of Window Retrofit and Replacement*, 7.

- Replacement insulated glazing[62]
- Modern roller blinds[63]

From a preservation perspective, windows are often a major character-defining feature of a building, and maintaining them will help to preserve the historic integrity of the building. Additionally, replacing historic windows is typically very costly with an unclear advantage of significant energy savings. The payback period of good-priced, self-installed, replacement windows is "unlikely to be within 20 years," and the payback period for hiring someone to install inexpensive replacement windows is "more likely to be 40 years or more," which is much longer than the presumed service life of the windows themselves.[64]

If the original window is severely deteriorated and beyond repair, a window replacement will be necessary. Replacement windows should match the original in size, shape, decorative details, proportions, material and the configuration of windowpanes and muntin profiles as closely as possible. Working with a restoration carpenter and/or attaining materials from a historic parts warehouse to create a customized window close to the original is preferred over buying a generic, prefabricated window.

Appropriate methods for retrofitting and creating in-kind window replacements are not part of the scope of this guidebook. See Appendix A for additional resources regarding cost-effective, energy saving methods of upgrading historic windows.

<u>Door Upgrades</u>
Comparable to windows, doors, particularly those on the main façade, are features contributing to the overall historic character of a building. Main entry doors are often more elaborate and decorative than side, rear or service doors, and should be maintained when possible. The largest source of heat loss in historic doors is typically around the doorframe.[65] In addition to applying weatherstripping, caulking the joints between the door surround and the opening will reduce air leakage. The addition of a storm door can also reduce a building's heat loss. However, storm doors should be compatible with the material, design, size and color of the existing door.[66]

[62] Caroline Alderson, "Technical Preservation Guidelines: Upgrading Historic Building Windows," Center for Historic Buildings (Washington D.C.: U.S. General Services Administration, 2009) http://www.gsa.gov/graphics/pbs/Windows.pdf (accessed April 28, 2013), 1.
[63] Historic Scotland, *Short Guide: Fabric Improvements for Energy Efficiency in Traditional Buildings* (Edinburgh: Historic Scotland, 2012) http://www.historic-scotland.gov.uk/fabric_improvements.pdf (accessed May 6, 2013), 14.
[64] Harley, *Insulate and Weatherize: Keeping Warm in Winter and Cool in Summer, Solving Moisture Problems, Finding Hidden Energy Wasters* (Newtown: Taunton Press, 2002), 90.
[65] Ibid., 7.
[66] District of Columbia, *The District of Columbia Historic Preservation Guidelines: Windows and Doors for Historic Buildings* (Washington, D.C.: District of Columbia, 2012) http://www.chrs.org/documents/HPO%20docs/Windows_and_Doors.pdf (accessed April 28, 2013), 19.

For additional information regarding upgrading historic doors to increasing energy savings, see Appendix A.

Roof Upgrades

Roofs can be key character-defining aspects of a historic building, but typically only if the roof can be seen from the street level. The roof shape (gabled, hipped, mansard, flat, etc.) and the roof treatment (slate, cedar shake, tile, metal, skylights, chimneys, dormers, etc.) can be important historic features of the roof that should be maintained to the extent possible.

Roofs account for approximately 25-30 percent of heat loss and 40 percent of air infiltration in a building.[67] Thus, the addition of insulation is an effective method of improving a building's energy savings. If the roof is insulated, weatherization should occur after in order to ensure a more airtight envelope.[68]

There are several features that are often part of a roof that are integral to the historic character of the roof and that can aid in serving functional needs, such as providing ventilation and shade, shedding water and maintaining a comfortable, energy efficient building. Examples include wide eaves that provide shade and reduce heat gain, built-in gutters that keep water from collecting and chimneys that, although they can be a source of heat loss, provide ventilation that is often necessary in order to maintain the drying capabilities of a historic structure.[69]

The roof is considered the "first line of defense between any building and the elements," thus a roof that works well is essential to the survival of a building.[70] A strategy to address moisture and air infiltration, sealing ductwork and air leaks, and if appropriate, the installation of insulation is crucial to creating a more efficient roof.[71]

Below are problems that building owners should be aware of according to the type of roofing in place. The lists were taken from the National Trust for Historic Preservation's guidebook, *Start with the Roof: A Guide for Keeping Weather Tight*.

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[67] Stationary Office of Ireland, *Energy Efficiency in Traditional Buildings*, Advice Series (Dublin: Government of Ireland, 2010), http://www.seai.ie/Grants/Better_energy_homes/contractor/Newsletter/Energy_Efficiency_in_Traditional_Buildings.pdf (accessed April 28, 2013), 29.; Sarah Elizabeth Welniak, "Energy Efficiency in Historic Structures" (master's thesis, Clemson University and The College of Charleston, 2009), 36.

[68] National Trust for Historic Preservation, *Start with the Roof: A Guide for Keeping Weather Tight* (Washington, D.C.: National Trust for Historic Preservation, 2009) http://www.preservationnation.org/information-center/sustainable-communities/buildings/weatherization/roofing/additional-resources/nthp_roofing.pdf (accessed April 28, 2013), 1.

[69] Ibid., 12.

[70] Stationary Office of Ireland, *Roofs: A Guide to Repair of Historic Roofs*, Advice Series (Dublin: Government of Ireland, 2010), Advice Series http://www.dublincity.ie/Planning/HeritageConservation/Conservation/Documents/Roofs%20-%20A%20Guide%20to%20the%20Repair%20of%20Historic%20Roofs.pdf (accessed April 28, 2013), 5.

[71] National Trust for Historic Preservation, *Start with the Roof: A Guide for Keeping Weather Tight*, 2.

HVAC efficiency, the Oakridge National Laboratory's and Lawrence Berkeley National Laboratory's Roof Savings Calculator (http://www.roofcalc.com/) can help determine energy savings particular to the project.[74]

A vegetated, or green, roof can help reduce operational costs and energy usage. Roof vegetation, through shading and evapotranspiration, can help reduce the surface temperature of the roof up to 50 degrees Fahrenheit compared to conventional dark roofs.[75] A study conducted in Chicago estimated an annual savings of $3,600 in heating and cooling loads due to the installation of a green roof on the City Hall, and a study in Toronto, Canada estimated a 16 percent decrease in heating and cooling loads with the application of a green roof on a commercial building.[76] Green roofs can improve occupant comfort and reduce heat stress due to heat waves as well.[77] Like cool roofs, green roofs should be installed on a historic building in a manner that reduces the visibility of the vegetated roof from street level. Thus, it is typically only appropriate to install on historic buildings with flat roofs and/or parapet walls.

Specific details regarding the potential appropriate methods to retrofit a roof are not in the scope of this guidebook. However, helpful resources on this topic can be found in Appendix A.

Floor Upgrades

The ground floor in a building is the only floor that needs to be addressed during energy efficiency upgrades. Approximately 15 percent of a building's heat loss occurs at the ground floor.[78] In addition to the weatherization process of basement space, insulation can be applied to ground floors to reduce the building's energy loss. Whereas insulation can often be installed successfully below a suspended floor, insulation is most effective when installed on top of solid floors. However, due to the potential for damage of existing historic fabric, installing insulation on solid floors should not be performed unless the original flooring has already been compromised.

Appendix A provides further information regarding how install insulation and what the best insulation materials are for conducting energy efficiency floor upgrades.

Wall Upgrades

Wall upgrades are covered extensively in Chapter Four.

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74 Urban and Roth, *Guidelines for Selecting Cool Roofs*, 3.

75 Climate Protection Partnership Division, *Reducing Urban Heat Islands: Compendium of Strategies* (Washington, D.C.: U.S. Environmental Protection Agency, 2008) http://www.epa.gov/heatisland/resources/pdf/GreenRoofsCompendium.pdf (accessed April 28, 2013), 2.

76 Ibid., 6.

77 Ibid., 8.

78 Stationary Office of Ireland, *Energy Efficiency in Traditional Buildings*, 46.

LOAD REDUCTIONS, SYSTEM UPGRADES & RENEWABLE ENERGY

In addition to the repairs and alterations that can be made to the building envelope to increase its energy efficiency, there are several additional whole building energy reduction measures that can be implemented to further increase the efficiency of your building, without significantly impacting its historic character.

Maintenance

Continuous building maintenance should be implemented in order to maximize efficiency and energy strategies. Commercial buildings can save five to 20 percent on annual utility bills through low-cost operations and maintenance improvements. Furthermore, most operational improvements can be implemented quickly after opportunities are identified. Larger up-front costs are typically necessary to conduct initial assessment and tune-up improvements, however future energy efficiency work often consists of low-cost operation and maintenance upgrades.

There are two major components that are important for an effective maintenance program. First, the program should address maximizing the efficiency of equipment, including HVAC and lighting systems, as well as the effectiveness of the building envelope in decreasing the building's energy use (i.e. cleaning windows to increase daylight, replacing weatherstripping to reduce air leakage, repointing mortar and repairing flashing to prevent water infiltration, etc.). Second, a preventative maintenance program should be in place for "periodically reviewing and monitoring the operating sequences, strategies and schedules to ensure that the facility operates as efficiently as possible," as well as to identify future upgrades.[79]

A building maintenance program requires little material investment and has the potential to significantly reduce building operation costs and energy usage. Additionally, continuous maintenance has no adverse effects on the historic character of the building and can help to maintain the building's durability and historic fabric. Therefore, having a maintenance program in place in a historic building is recommended.

Further information regarding effective maintenance programs can be found in Appendix A.

Occupancy Scheduling

Efficient occupancy scheduling can have a significant impact on reducing energy load requirements. Occupant's schedule can be altered according to seasonal changes. For instance, if occupants shift their work schedule an hour earlier in the summer and changing air conditioning schedules if present, cooling loads will be reduced while improving occupant comfort. Occupancy scheduling has no impact on the historic character of a building and therefore can be implemented in any building.

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[79] Portland Energy Conservation, Inc., *Fifteen O&M Best Practices for Energy Efficient Buildings* (Washington, D.C.: U.S. Environmental Protection Agency, 1999) http://www.energystar.gov/ia/business/15best.pdf (accessed April 28, 2013), 33.

Behavior Changes

One of the most cost-effective methods of reducing energy use in a building is to focus on energy conservation through the modification of occupant behavior.

Informing occupants about the energy-saving benefits of turning off lights when leaving a room, unplugging devices that are not in use and setting idle computers to sleep or hibernate can contribute to energy and cost savings. However, conservation efforts are only as effective as those who are responsible for the conservation. Active intervention to educate and possibly incentivize building occupants is necessary to create a successful conservation program.

Behavior changes have no impact on the historic character of a building and are thus recommended in any structure.

Natural Ventilation

Natural ventilation is the "use of a building's form, organization, and openings in conjunction with naturally occurring phenomena such as the wind or warm air buoyancy to supply air to its occupants and to remove heat both from the occupants and the building."[80] Natural ventilation can help reduce operating costs and energy use in a building through decreasing or eliminating the power used by heating and cooling equipment, as well as potentially increasing occupant productivity through improved indoor environmental quality. Approximately ten percent of the total energy used in U.S. buildings is for cooling, and approximately three percent is for ventilation.[81] Thus, the use of natural ventilation, if appropriate, can significantly decrease energy costs.

Historic buildings were often naturally ventilated through the use of operable windows and transoms as well as airshafts. Consequently, the use of natural ventilation will often be compatible in historic buildings, with no adverse affects to the integrity of the building. Adequate ventilation, whether mechanical or natural, is important in historic buildings, and over-sealing them can potentially cause condensation and other associated problems.

For more information regarding natural ventilation and compatibility in historic buildings, see Appendix A.

Heating, Ventilating and Air Conditioning (HVAC) Scheduling and Upgrades

In addition to weatherizing the building envelope in order to reduce heating and cooling loads, there are two additional steps the building owner should consider: properly insulating and sealing the connecting ductwork as well as proper sizing of HVAC equipment.[82]

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[80] G.Z. Brown, Jeff Kline, Gina Livingston, Dale Northcutt, and Emily Wright, *Natural Ventilation in Northwest Buildings*, Energy Studies in Buildings Laboratory (Eugene, OR: University of Oregon, 2004), 6.

[81] Office of Energy Efficiency and Renewable Energy, *2011 Buildings Energy Data Book* (Washington D.C.: U.S. Department of Energy, 2012) http://buildingsdatabook.eren.doe.gov/docs/DataBooks/2011_BEDB.pdf (accessed April 28, 2013), 1.1.4.

[82] Sarah Elizabeth Welniak, "Energy Efficiency in Historic Structures" (master's thesis, Clemson University and The College of Charleston, 2009), 40.

In the average house, approximately 20 percent of the air moving through a duct system is lost through holes, leaks and poorly connected ducts. This results in an "inefficient HVAC system, high utility bills, and difficulty keeping the housing comfortable, no matter how the thermostat is set."[83] Inefficiencies can be solved by sealing ducts with mastic sealant or foil tape, as well as by insulating all the accessible ducts in the attic, crawlspace, garage or basement. Connections at vents and registers should be well sealed where they meet the walls, ceilings and floors.[84]

Efficient HVAC scheduling can potentially have significant energy and cost savings with an almost immediate payback. Even if individual equipment systems are well maintained and perform efficiently, unless occupant needs and control strategies are periodically assessed, equipment may be operating more than necessary. Proper scheduling will ensure that systems are operating at the appropriate level in order to meet occupant needs or to fulfill their intended purposes.[85]

The following is a list of scheduling action steps taken from Portland Energy Conservation's *Fifteen O&M Best Practices for Energy Efficient Buildings*.[86]

- Develop procedures to regularly assess optimum start/strop strategies, time-of-day schedules, temperature setups and setbacks, freeze protection, lockouts and additional parameters that turn equipment on and off
- Review programmable and mechanical time clock settings, lighting photocells, integral equipment controls, sweeps, occupancy sensors and additional on/off controls to ensure proper functioning
- Turn off HVAC equipment and lights in unused or unrented spaces
- Perform walkthroughs periodically to see if equipment is on that does not need to be; pay attention to tenant plug loads such as computers, printers and copiers
- Survey or interview occupants periodically to determine if their comfort levels are being met

Scheduling does not negatively affect the historic character and integrity of the building, and is therefore a recommended method of increasing the energy efficiency in historic buildings.

Proper sizing of HVAC equipment can be decided upon by the results of an energy audit. The tightness of the building envelope will affect the sizing of the equipment. Thus, appropriate sizing of the heating and cooling systems should be determined after implementing weatherization measures. Weatherization efforts will result in reduced load requirements, and consequentially, the size and cost of HVAC system upgrades. It is important to reduce the amount of conditioning provided because more conditioning than the building requires can potentially result in condensation inside the building envelope and consequentially, the rot and decay of historic materials.[87]

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[83] ENERGY STAR Program, "A Guide to Energy-Efficient Heating and Cooling," (Washington, D.C.: U.S. Environmental Protection Agency, 2009), http://www.energystar.gov/ia/partners/publications/pubdocs/HeatingCoolingGuide%20FINAL_9-4-09.pdf (accessed May 6, 2013), 10.

[84] Ibid.

[85] Portland Energy Conservation, Inc., *Fifteen O&M Best Practices for Energy Efficient Buildings*, 29.

[86] Ibid.

[87] Welniak, "Energy Efficiency in Historic Structures," 40-41.

The efficiency of the HVAC system should be assessed prior to replacement, either through commissioning or other less expensive means of inspection. Additionally, supplementing HVAC systems with less energy-intensive measures, such as attic and ceiling fans and programmable thermostats should be considered prior to replacing existing equipment. Commissioning as well as supplemental measures have the potential to result in significant energy savings with smaller up-front costs than buying an entirely new system.

With regard to preservation issues, retaining or installing duct-less air conditioners may be a more sensitive approach than installing a ducted, central HVAC system that may damage the historic fabric.[88] Additionally, ductless systems reduce the amount of heat lost through leaky, poorly connected ducts. In order to retain the building's historic integrity, new ducts and HVAC systems should not be visible from the exterior.

More information regarding HVAC scheduling, upgrades and preservation sensitivity issues can be found in Appendix A.

Daylighting Strategies and Lighting Upgrades

Daylighting, or the use of natural light from windows and light wells, has the potential to reduce energy usage and operating costs in a building. However, savings cannot be reliably be realized unless daylighting strategies are combined with automated dimming or switching of electric lights. Studies have shown up to a 40 percent decrease in electricity used for lighting and an additional two to three percent of energy savings due to reduced cooling loads through the implementation of daylighting controls.[89] In order to reduce glare, historically appropriate awnings as well as operable blinds are recommended. Tinted windows are typically not appropriate for historic buildings.

Historic buildings often have an abundance of daylight available through windows, glazed doors, transoms and light wells. It is acceptable in some instances to add more windows and skylights, provided that the windows are not installed on the primary façade and the skylights are not visible from the exterior ground level. Existing openings should also be maintained. Further information regarding appropriate historic window alterations are discussed in the previous Building Envelope section.

Lighting comprises approximately 10 percent of a household's energy budget and 35 percent of a commercial building's electricity usage. Furthermore, lighting uses approximately 18 percent of the electricity produced in the United States, with another four to five percent used to remove the waste heat created by those lights.[90] Thus, lighting upgrades can substantially increase energy savings in a historic building.

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[88] Grimmer, et.al., *The Secretary of the Interior's Standards for Rehabilitation & Illustrated Guidelines on Sustainability for Rehabilitating Historic Buildings*, 11.

[89] Lawrence Berkeley National Laboratory, *Daylight in Buildings: A Source Book on Daylighting Systems and Components* (Washington, D.C.: International Energy Agency, 2009) http://gaia.lbl.gov/iea21/ieapubc.htm (accessed April 28, 2013), 5-11.

[90] ENERGY STAR Program, *ENERGY STAR Building Manual: Lighting* (Washington, D.C., U.S. Environmental Protection Agency, 2006) http://www.lumenergi.com/sites/default/files/downloads/1-

Lighting has the potential to increase worker productivity and decrease the number of absences by improving visual comfort and performance on visual tasks, as well as reducing eye fatigue. A study conducted in a mail-processing center in Reno, Nevada witnessed a six percent increase in worker productivity with improved lighting conditions.[91] Because adding electric lighting to increase light levels with increase energy use and cooling loads in the summer, electric lighting should be considered in accordance with daylighting strategies.

Although lighting alterations are not as detrimental to the historic character of the building as window or roof replacements, lighting fixtures as well as the quality of light they produce nonetheless contribute to the character and authenticity of a historic building. Thus, an attempt to maintain similar lighting as what was in place historically is recommended.

Light level reductions in overly lit areas, lighting controls (occupancy sensors, dimming controls, daylighting controls, etc.) and high-efficiency light sources (i.e. LEDs, CFLs, high efficiency incandescent lamps, etc.) are a few methods of decreasing the energy used to light a building. Those who choose to install high-efficiency light sources should try to maintain the same historic color of the lighting. For example, the use of golden glass sconces can create the same "golden glow" that might have existed with original lighting.[92] If the historic fixtures are still in place, it is recommended that they be retrofitted with the new efficient bulbs rather than installing new fixtures.

Appendix A provides additional information regarding how to implement new daylighting strategies and utilize existing sources of daylighting, as well as how to conduct lighting upgrades in a historic building, while maintaining the integrity and historic character of the building.

Energy Efficient Appliances
Energy Star® is a joint program between the United States Environmental Protection Agency and the United States Department of Energy that "help save [consumers] money and protect the environment through energy efficient products and practices."[93] Energy Star® products, such as refrigerators, water coolers, dishwashers, and so on, help save approximately one-third of an owners' energy bill with similar savings of greenhouse gas emissions.[94]

Table Four includes a list of Energy Star® appliances and the approximate amount of energy and cost savings over an average product lifespan of 15 years. The savings are based on

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Energy-Star-Building-Manual-2006.pdf (accessed May 6, 2013), 3-4.; U.S. Department of Energy, "Tips: Lighting," U.S. Department of Energy, http://energy.gov/energysaver/articles/tips-lighting (accessed May 6, 2013).
[91] ENERGY STAR Program, *ENERGY STAR Building Manual: Lighting*, 6.
[92] Cheryl Rezabek, Jim Mapp, Barbara Smith, and Jim Cavallo, "Energy Efficiency Lighting in Historic Buildings," (Washington, D.C.: American Council for an Energy Efficient Economy, 2008) http://www.aceee.org/files/proceedings/2008/data/papers/4_288.pdf (accessed April 28, 2013), 288.
[93] ENERGY STAR Program, "About ENERGY STAR," U.S. Environmental Protection Agency, http://www.energystar.gov/index.cfm?c=about.ab_index (accessed May 6, 2013).
[94] Ibid.

household energy costs, however commercial building owners can expect to see similar if not better savings.

Table Four[95]

Product	Energy Savings	Cost Savings (over 15 years)
Refrigerator	15%	$200-$1,500
Freezer	10%	$900
Clothes Washer	20%	$1,650
Dishwasher	$10%	$600

There are few if any negative impacts of using energy efficient appliances in historic buildings. Energy efficient appliances do not physically impact historic materials and are therefore recommended whenever possible.

For further information regarding energy efficient appliances, see Appendix A.

Renewable Energy

Although renewable energy sources, such as wind and solar, are not considered methods for increasing energy efficiency, they are nonetheless important to touch upon because of the potential adverse effects they can have on the historic character of a building. Renewable energy sources should only be considered after implementing energy efficiency measures.

Both solar panels and wind turbines should be placed in a manner that they do not compromise the historic character of the building or the site. Solar panels are appropriate on flat roofs and/or roofs with parapet walls so that the panels cannot be seen from the street level. If the building does not have a flat roof, it may be appropriate to install the panels on the rear portion of the roof so that they are not visible from the primary elevation. If the surroundings of the building are of particular importance to its historic character, wind turbines should be installed where they do not compromise the historic features of the site.

The *Secretary of the Interior's Standards for Rehabilitation & Illustrated Guidelines and Sustainability* provide more detailed descriptions of appropriate methods for installing renewable energy sources on the building or the site it is located.

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95 Matt Goering, "Pros, Costs, & Cons: Energy Star Appliance," Home Advisor, http://www.homeadvisor.com/article.show.Pros-Costs-and-Cons-Energy-Star-Appliances.16819.html (accessed May 6, 2013).; ENERGY STAR Program, "Dishwashers for Consumers," U.S. Environmental Protection Agency, http://www.energystar.gov/index.cfm?fuseaction=find_a_product.showProductGroup&pgw_code=DW (accessed May 6, 2013).

CHAPTER FOUR: WALL ASSEMBLY RETROFITS – OPTION B

Wall assembly retrofits are often one of the more controversial alterations to conduct in a historic building. As described by Dr. John Straube, principal of Building Science Corporation and a professor of building science at the University of Waterloo, Canada, "Exterior insulation provides the highest level of durability, energy efficiency, and comfort with the least technical risk" because insulation, air and water control layers can be made continuous to protect the building from rain, condensation and temperature swings, thermal bridging is eliminated, and thermal mass advantages are increased.[96] However, as Dr. Straube, as well as most all professionals who have been involved in retrofitting historic structures, recognizes that adding insulation to the outside of the building is rarely acceptable because it will compromise the historic character of the building. Thus, this guidebook focuses on methods to retrofit the interior surface of the exterior wall assembly.

Retrofitting exterior wall assemblies from the interior may still be controversial in a historic building because it often requires that the interior finishes are removed or covered up to create a space into which insulation can be placed. Additionally, the wall may have to be built out considerably, altering the dimensions of the room and the proportion of window fenestration and trim to wall thickness. Although it is necessary to consider how an interior wall retrofit will compromise the aesthetic features of the historic building, it is of equally if not greater importance to recognize the durability risks that are present when retrofitting the wall assembly from the interior.

It cannot be stressed enough that there is not a one-size-fits-all approach to addressing these risks because each building may be affected differently. Retrofits need to respond to the building's current condition and integrity, the characteristics of the brick in place, the particular climate, the building's orientation, exposure to rain, and so on. Thus, it is important to conduct an assessment of your building prior to deciding what wall assembly materials and characteristics are most appropriate for the project.

OLD BUILDINGS VS. NEW BUILDINGS – PRESERVATION SENSITIVITY & THE ISSUE OF DURABILITY

Often, older buildings function differently than new buildings. This is particularly clear in historic masonry wall assemblies, including stone, concrete and brick, which store moisture very differently than their modern counterparts (see Table Five). Ventilation and permeable materials allow old buildings to dry to the interior and exterior, while new buildings are equipped with air and vapor barriers, insulation and sealants in order to reduce heat loss and moisture penetration. An older building's ability to dry across the wall assembly aids in reducing the

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[96] John Straube, Kohta Ueno, and Christopher Schumacher, *Internal Insulation of Masonry Walls: Final Measure Guideline* (Westford, MA: Building Science Press, 2007) http://www.buildingscience.com/documents/reports/rr-1105-internal-insulation-masonry-walls-final-measure-guideline/view?searchterm=internal%20insulation%20masonry%20walls%20final%20measure (accessed May 6, 2013), 4.

likelihood of moisture accumulation to occur. Consequently, the addition of a vapor barrier and impermeable membranes must be applied with caution, and ventilation is often necessary.

Table Five[97]

Historic Masonry Wall	Modern Masonry Wall
Massive construction, thick walls	Comparatively slender construction
Porous, highly permeable materials	Porous materials with relatively impermeable finishes
Materials with ability to absorb a substantial amount	Materials with limited ability to absorb moisture
Moisture can move through and evaporate from the wall easily	Moisture within the wall does not easily evaporate
Construction can absorb slight amounts thermal and moisture transfer	Well insulated construction but prone to cracking due to harder, brittle materials (cracks permit water penetration)
Ventilation often required to prevent moisture buildup	Ventilation of cavities not required
Damp-proof course often absent	Damp-proof course essential
No vapor barriers	Vapor barriers integrated into construction

Assessment Tools – Understanding Your Building

Prior to pursuing any type of retrofit on a historic building, the current condition of the building should be assessed. There are a number of assessment tools that should be used if possible in order to help determine whether retrofitting your brick building will cause durability issues. It is highly recommended that a preservation professional as well as a building science expert be consulted to help determine if your building can be insulated without compromising the integrity and durability of the building.

Brick testing, visual inspection, infrared imaging and hygrothermal modeling are a few methods that can be used in order to locate existing problems that should be alleviated prior to the retrofit, as well as to help make decisions regarding what materials are most appropriate for the retrofit. These techniques are most valuable when used together to determine the best course of action. In addition to conducting an assessment to determine necessary repairs prior to retrofitting a historic building, it is recommended that the building owner budgets for routine maintenance as well as for monitoring the insulated wall assembly post-retrofit. More information regarding building maintenance can be found in the section on Maintenance in Chapter Three, as well as Appendix A.

<u>Brick Testing</u>

Testing your building's brick is important in order to determine its physical properties and level of durability. Although the Pacific Northwest has a fairly mild climate, freeze-thaw

[97] Dennis Urquhart, *Guide for Practitioners: Conversion of Traditional Buildings* (Edinburgh: Historic Scotland, 2007) http://www.historic-scotland.gov.uk/conversionoftraditionalbuildings1and2.pdf (accessed April 28, 2013), 31.

cycles are still possible. Susceptibility to freeze-thaw issues becomes greater with the addition of insulation. Appendix B includes more detailed information regarding the various methods of brick testing to determine the brick's level of durability. Consulting a professional is recommended as well.

Visual Inspection

Prior to conducting any type of retrofit work on a building, it is recommended that the building be first inspected for cracks, staining, missing bricks, missing mortar, and so on. These problems need to be addressed to help make the building more airtight, as well as to limit the possibility of increased water infiltration and subsequent damage to the potentially newly insulated assembly.

If your building does not show signs of the issues outlined in Table Six, there is a better chance that the building can be insulated without compromising the durability of the historic fabric. The parapet is a good place to examine to see how your building's brick has held up against colder temperatures (it is not heated) and rain penetration. If the parapet is in good condition, it is more likely that the brick will not be compromised when insulated.[98] If your building has experienced several of the issues described in the table, it is more likely that insulating the building will only exacerbate the problems further. If you still want to insulate your building, greater care must be taken to monitor and maintain the wall assembly to ensure degradation does not occur.

Table Six

Brick Inspection Checklist						
Exterior Wall (above grade)	*North*	*South*	*East*	*West*	*Roof/ Parapet Level*	*Additional Notes*
Cracked Units						
Loose Units						
Spalled Units						
Staining						
Efflorescence						
Plant Growth						
Missing/Clogged Weepholes						
Water Penetration						
Missing flashing						
Missing/deteriorated Mortar						
Corrosion/Rot (of embedded beams)						
Faulty gutters						
Interior Wall (above grade)						
Staining						
Flaking, chipped, warped or blistered finishes						
Musty smells						

[98] John Straube, interview by Martin Holladay, in "Insulating Old Brick Buildings," Green Building Advisor, http://www.greenbuildingadvisor.com/blogs/dept/musings/insulating-old-brick-buildings (accessed April 28, 2013).

Infrared Imaging

An infrared, or IR, camera is a nondestructive tool used to help determine the presence and extent of moisture accumulation, heat loss, air leakage, missing insulation, thermal bridging and other conditions occurring in the wall assembly. Infrared cameras use thermographic imaging to generate accurate readings of surface temperatures and temperature distribution.[99] Infrared imaging uses a false color or grayscale to indicate surface temperature which can be used to locate areas of heat loss and moisture problems.[100] An IR camera is helpful when determining problems that should be alleviated prior to a retrofit (or through retrofitting measures) and that cannot be located through visual inspection alone. Similar to the visual inspection, if the infrared imaging shows signs of moisture accumulation, there is an increased likelihood that insulation could further exacerbate the problem in the wall assembly. The application of infrared imaging is discussed in more detail in the supplementary document, *Building Case Studies: The Application of Infrared Imaging and Hygrothermal Modeling in Historic Brick Buildings*, as it was utilized to assess retrofits in the case study buildings described in Chapter Five.

Hygrothermal Modeling

Hygrothermal modeling is the computer simulation of heat and moisture behavior of multi-layer building components exposed to natural climate conditions. The German software program, WUFI (Wärme Und Feuchte Instationär), is one of the most widely used because of its accuracy as well as its availability. WUFI can specifically be used to assess the drying time of masonry with trapped construction moisture; the influence of bulk water, such as driving rain, on exterior building components; the risk of interstitial condensation; the effects of repairs and retrofits; and the hygrothermal performance of wall assemblies under particular climate zones.[101]

Although hygrothermal modeling can be useful to determine potential appropriate retrofit techniques, particularly when paired with more detailed data through brick testing, the modeling is not sufficient on its own to accurately predict how the building will actually perform. The one-dimensional analysis of WUFI does not account for air movement and two-dimensional effects of heat transfer through walls (i.e. thermal bridging), both of which have significant affects on moisture accumulation in assemblies.[102] Furthermore, the effectiveness of hygrothermal modeling is directly related to the accuracy and detail of information input to the program– the specific characteristics of the brick and mortar

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[99] Elisabetta Rosina and Jonathan Spodek, "Using Infrared Thermography to Detect Moisture in Historic Masonry: A Case Study in Indiana," *Association for Preservation Technology Bulletin* 34 (2003): 11.

[100] Forward-Looking Infrared Radar Systems, Inc., *Thermal Imaging Guidebook for Building and Renewable Energy Applications: An Informative Guide for the Use of Thermal Imaging Cameras for Inspecting Buildings, Solar Panels and Windmills* (Portland: FLIR Systems AB, 2011), 5.

[101] Oak Ridge National Laboratory Building Technologies Research and Integration Center, "WUFI Design Tool," Oak Ridge National Laboratory, http://www.ornl.gov/sci/ees/etsd/btric/wufi/tool.shtml (accessed November 19, 2012).

[102] Bradford S. Carpenter, Niklas W. Vigner, Christina T. Parker, and Marcin Pazera, "The Designer's Dilemma: Modern Performance Expectations and Historic Masonry Walls," (lecture, Symposium on Building Envelope Technology, San Antonio, TX, November 8, 2010).

and the extent of rain wetting that occurs in the building location are necessary in order to get particularly accurate results. The application of WUFI will be discussed in more detail in the supplementary document, *Building Case Studies: The Application of Infrared Imaging and Hygrothermal Modeling in Historic Brick Buildings*, as it was utilized to assess retrofits in the case study buildings described in Chapter Five.

Moisture Accumulation

Moisture accumulation is the largest threat to a historic building's durability, accounting for up to 80 percent of damage in building envelopes.[103] The build-up of moisture is of particular concern in wet climates such as the Pacific Northwest. The western half of Northern California, Oregon and Washington, including cities such as Eugene, Portland and Seattle, is predominantly located in the U.S. Department of Energy's Climate Zone 4C, which experiences colder wintertime temperatures and has a humid marine climate.[104] Whereas Eugene and Portland receive approximately 45 inches of rain per year, Seattle receives an average of 38 inches of rain annually.[105] Typical moisture phenomena include wintertime condensation, summer inward vapor drive and simulated drying following a wetting event, all of which can cause problems such as mold growth, rot in wood beams, corrosion in metal ties and general fabric degradation.[106] In the interviews conducted for this guidebook, all of the professionals (architects, engineers, building scientists and preservationists) stressed the importance of controlling water penetration, particularly in a climate such as the Pacific Northwest.[107]

There are four major sources of moisture in above-grade building enclosures:

1. Precipitation (particularly driving rain)
2. Water vapor
3. Built-in and stored moisture
4. Ground water[108]

Water vapor can move via vapor diffusion or through air transport. Vapor diffusion, or the movement of vapor across a space, occurs when there is a moisture concentration or thermal gradient. Thus, water is transported through vapor diffusion from an area of higher vapor pressure or temperature to an area of lower vapor pressure or temperature. Similarly, water is

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[103] Mark Bomberg and W.C. Brown, "Building Envelope and Environmental Control: Part 1-Heat, Air and Moisture Interactions," Institute for Research in Construction (Ontario, Canada, 1993) http://www.sesfoam.com/wp-content/uploads/2013/04/5_BLDG_ENV.pdf (accessed April 28, 2013), 4.
[104] Jonathan Smegal and John Straube, *High-R Walls for the Pacific Northwest – A Hygrothermal Analysis of various Exterior Wall Systems* (Westford, MA: Building Science Press, 2010) http://www.buildingscience.com/documents/reports/rr-1014-high-r-walls-pacific-northwest-hygrothermal-analysis/view (accessed May 6, 2013), 12.
[105] Current Results, "Average Annual Precipitation for Oregon." Current Results: Research News and Science Facts. http://www.currentresults.com/Weather/Oregon/average-yearly-precipitation.php (accessed May 5, 2013); City of Seattle. "Seattle Monthly Averages and Records." City of Seattle. http://www.seattle.gov/html/weather_averages.htm (accessed May 4, 2013).
[106] Smegal and Straube, *High-R Walls for the Pacific Northwest – A Hygrothermal Analysis of various Exterior Wall Systems*, 13.
[107] Interviews with historic preservationists, architects, engineers and building science professionals, December 20, 2012 to March 21 2013.
[108] Straube, Ueno, and Schumacher, *Internal Insulation of Masonry Walls: Final Measure Guideline*, 14.

transported through the air from an area of higher air pressure to an area of lower air pressure.[109]

In historic brick buildings, wetting and moisture transport through the methods discussed above is natural because brick is a porous material – it takes in and releases moisture fairly easily. However, issues arise when the wall is not able to dry. There are four general ways an enclosure can dry (see Figure One):

1. Evaporation to the inside or outside surfaces
2. Vapor transport by air leakages (through cracks and holes) and/or diffusion (through pores in the material) to the interior or exterior of the building
3. Drainage through cracks and openings
4. Ventilation[110]

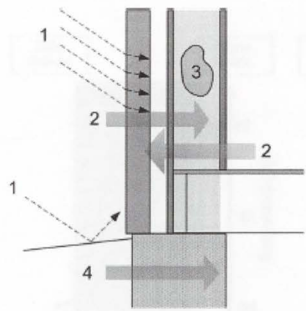

Figure One: Ways a building enclosure can dry (listed above). From: *Internal Insulation of Masonry Walls: Final Measure Guideline*, 15.

Solid masonry walls (including solid brick wall assemblies as well as brick veneer backed by load-bearing concrete) are typically limited to the first two drying processes (unless retrofitted to accommodate drainage or ventilation). Brick cavity walls may utilize all four methods to dry.

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[109] Joseph Lstiburek, *Insulation, Sheathing, and Vapor Retarders* (Westford, MA: Building Science Press, 2008) http://www.buildingscience.com/documents/reports/rr-0412-insulations-sheathings-and-vapor-retarders/view?searchterm=insulation,%20sheathing%20and%20vapor%20retarders (accessed May 6, 2013), 2.

[110] Straube, Ueno, and Schumacher, *Internal Insulation of Masonry Walls: Final Measure Guideline*, 15.

In historic brick buildings, the walls originally had few problems drying because vapor, air and consequently, water, were free to move both inward and outward without barriers blocking their path (i.e. through chimneys, uninsulated walls, etc.). Modern materials, such as Portland cement, sealants, insulation, vapor barriers, etc. are often more impermeable, hindering the ability for air and vapor to move, and hence the capacity for the building to dry. Thus, the types of modern materials applied in historic buildings should be chosen carefully (i.e. choose the material that allows some drying capability).

Insulation also causes the interior surface of the brick wall to become colder because less heat escapes from the interior of the building (see Figure Two). When temperature decreases, the relative humidity and potential for reaching a point of saturation becomes greater (temperature and relative humidity are inversely related). This decrease in temperature (and increase in relative humidity) can result in condensation and, if conditions are cold enough, frost. Hence, the type and thickness of the insulation needs to be considered in order to reduce the possibility of condensation and freeze-thaw damage.

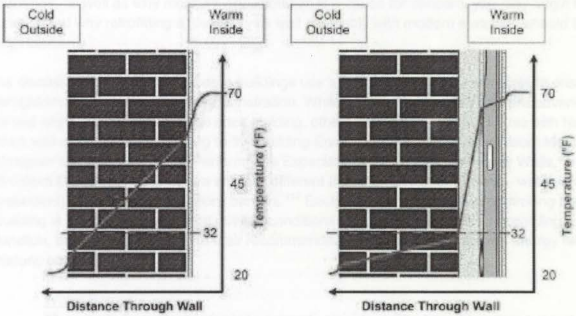

Figure Two: The addition of insulation causes of the interior surface of the brick wall to become colder, and there is a greater potential for condensation and freeze-thaw damage to occur. From: *Internal Insulation of Masonry Walls: Final Measure Guideline*, 17.

Mario Gonçalves, a Senior Building Science Consultant and President of Patenaude-JBK, Inc., in Varennes, Quebec, provides a list of steps that should be taken to reduce the likelihood of moisture accumulation beyond the brick's storage capacity. Many of the recommendations Gonçalves makes are reiterated in works by other building science experts, including John Straube, Joseph Lstirurek and William (Bill) Rose. With the exception of properly balancing the mechanical system, all of these recommendations can be addressed through appropriate treatment of the building envelope.

- Minimize rain penetration (keep water off the building)
- Minimize penetration of water (i.e. groundwater) and indoor humidity into the assembly through air infiltration and exfiltration (have an air barrier in place to minimize the air pressure differential across the assembly)
- Minimize the temperature drop across the wall assembly (find the appropriate balance between durability, thermal performance and comfort goals)
- Minimize the air pressure difference across the exterior wall (balance mechanical systems so that there is a relatively neutral air pressure differential)
- Reduce penetration of indoor humidity into the assembly through water vapor transport (install a vapor barrier to control vapor diffusion)**[111]

**The recommendation of installing a vapor barrier is as controversial as installing insulation in historic brick buildings and will be discussed further below.

Available Retrofit Materials and the Appropriate Course of Action
Now that it is understood how historic buildings respond to moisture differently than modern buildings, as well as why moisture accumulation is a cause for concern, you may begin to understand why retrofitting a historic brick wall assembly with modern materials should be done with caution.

As discussed in Table One, modern buildings use a number of different materials to ensure airtightness and prevent moisture penetration. While some of these materials are advantageous to use when retrofitting a historic brick building, others are not appropriate to use with historic brick wall assemblies. According to the Building Envelope Technology Symposium lecture, "The Designer's Dilemma: Modern Performance Expectations and Historic Masonry Walls," by Bradford Carpenter, et. al., there are four different building envelope barriers – water, air, vapor (retarders) and thermal (insulation) barriers.[112] Each barrier plays a role in controlling how the building is affected by inside and outside conditions. Each will be described according to their function, the types available and their recommended use when conducting an energy retrofit in historic brick buildings.

<u>Water Barrier</u>
The intent of a water barrier is to prevent rainwater infiltration. A modern example of a water barrier is a rain screen in a cavity wall. Although historic buildings do not have dedicated water barriers, features such as overhangs, ledges and cornice pieces serve as inherent water barriers that keep rain from permeating the wall assembly. However, these features must be maintained in order to be successful. Repairing and/or installing flashing and gutters that do not compromise the historic character of the building's exterior are recommended as an additional method of preventing rainwater penetration.

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[111] Mario Gonçalves, "Insulating Solid Masonry Walls," (lecture, Building Envelope Forum, Vancouver, B.C., March 19, 2003).
[112] Carpenter et. al., "The Designer's Dilemma: Modern Performance Expectations and Historic Masonry Walls."

If you are not able to manage the amount of bulk water (rain water) penetrating your brick building, it is recommended that you do not install insulation.[113]

Air Barrier

The purpose of an air barrier is to reduce heat loss and moisture accumulation via air transport by resisting the air pressure differences that act on them.[114] Modern air barriers include fluid applied membranes, adhered sheet materials, gypsum board and building wrap. Most of these materials need to be used in combination with tape and/or caulking to ensure the air barrier is sealed correctly.

Air barriers should prevent heat loss as well as moisture transport through the air. However, they should not be used to prevent moisture transport via vapor diffusion, which is the intent of a vapor retarder/barrier. For more information regarding the difference between air barriers and vapor barriers, see Appendix B.

Jeremy Shannon, an architect and owner of Prospect Architecture in Brooklyn, New York, uses a liquid air barrier, such as StoGuard, in historic brick row houses being retrofitted to Passive House standards. In an interview with him, he described how he applies the liquid air barrier to the interior surface of the exterior wall assembly prior to installing insulation. This way, the barrier is continuous, and, if the building is remodeled in the future, the air barrier will still be in place.[115] However, this method only works if the interior of the building is completely gutted prior to the retrofit.

An air barrier should be installed in a historic brick building when conducting an energy retrofit. Air barriers can be installed anywhere in the wall, however they need to be continuous to ensure an airtight assembly, and it is preferable to have more than one air barrier in place (i.e. a liquid-applied air barrier on the interior surface of the brick as well as interior gypsum board sealed from top to bottom). Having an airtight assembly requires that the mechanical system is working correctly to ensure that the indoor air quality is not compromised. William Rose, a research architect and professor at the University of Illinois at Urbana-Champaign, recommends the Canada Mortgage and Housing Corporation's *Best Practice Guides* for information regarding how to install and effective air barrier.[116]

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[113] Terry Brennan, interview by Martin Holladay, in "Insulating Old Brick Buildings," Green Building Advisor, http://www.greenbuildingadvisor.com/blogs/dept/musings/insulating-old-brick-buildings (accessed April 28, 2013).

[114] Joseph Lstiburek, "Understanding Air Barriers," *Building Science Digest* 104 (October 2006) http://www.buildingscience.com/documents/digests/bsd-104-understanding-air-barriers/?searchterm=air%20vs.%20vapor%20barrier (accessed April 28, 2013).

[115] Jeremy Shannon, interview by author, Eugene, OR, March 20, 2013.

[116] William B. Rose, *Water in Buildings: An Architect's Guide to Moisture and Mold* (New York: John, Wiley & Sons, 2005), 178.

Vapor Retarder
The function of the vapor retarder is to reduce the transport of moisture via vapor diffusion. Modern examples of types of vapor retarders include sheet metal, some insulation materials, rubber membranes, polyethylene barriers, some paints, etc. There are three classifications of vapor retarders – Class I, Class II and Class III. A Class I vapor retarder is also known as a vapor barrier. Each class is categorized by how permeable the material is. A "perm" is the unit of measurement used to characterize the water vapor permeance of a material.[117]

- Class I (impermeable): 0.1 perm or less
- Class II (semi-impermeable): 1.0 perm or less and greater than 0.1 perm
- Class III (semi-permeable): 10 perm or less and greater than 1.0 perm

In recent years, vapor barriers (Class I vapor retarders) have been linked to an increase in moisture problems in buildings. Rather than preventing wall assemblies from getting wet, they often prevent them from drying. This is due to the fact that vapor barriers are installed improperly, they are in the wrong place in the wall assembly, or they have been damaged by putting nails through them, installing electrical fittings, etc. If moisture is able to bypass the vapor barrier due to these imperfections, there is a chance that the moisture will not be able to escape, and the wall cannot dry.

Vapor barriers should be installed on the warm side of the wall assembly in order to impede vapor diffusion, which occurs from areas of higher temperatures, to areas of lower temperatures (as discussed in the section on Moisture above). Thus, in cold climates, vapor barriers should be installed near the interior surface of the exterior wall assembly to prevent vapor diffusion from the inside to the outside. In hot humid climates, vapor barriers should be installed near the exterior surface of the wall assembly to prevent vapor diffusion from occurring to the interior of the building. However, the issue of where to install the vapor barrier becomes more complicated in mixed or marine climates, such as that of the Pacific Northwest, because the warm side of the wall assembly changes throughout the year. Installing a vapor barrier on the interior of the assembly may cause problems in the warmer months because of the summer inward vapor drive discussed in the section on Moisture. The vapor drive towards the interior of the building in the summer would not be able to dry to the interior because of the vapor barrier. This could in turn cause mold growth in the wall assembly, particularly if the building is air-conditioned. Installing a vapor barrier near the exterior surface could similarly cause problems in the winter because the wall would not be capable of drying to the exterior.

Due to the potential for moisture accumulation and subsequent damage when using a Class I vapor retarder (vapor barrier), Joseph Lstiburek, forensic engineer and principal of the Building Science Corporation, recommends avoiding the use of vapor barriers where Class II or III vapor retarders will provide acceptable performance (i.e. in mixed

[117] Lstiburek, "Understanding Air Barriers," 3.

climates).[118] Of the eight professionals (architects, engineers, preservationists and building scientists working in the Pacific Northwest or in similar climates) interviewed for this guidebook, seven out of the eight recommended using materials that had a higher degree of vapor permeability.[119]

If the exterior sheathing of the wall assembly is greater than 1.0 perm in Climate Zone 4C (marine), Lstiburek suggests that a Class III vapor retarder is often acceptable.[120] This applies to historic brick buildings because brick has a much higher perm rating than 1.0 (closer to 40 perms). A Class II vapor retarder can be used as well, however a Class I vapor barrier should be avoided. Table Seven provides examples of Class I, II and III vapor retarders, as seen in *Fine Homebuilding* magazine.

Table Seven[121]

Material	Class
Polyethylene Sheet	I (vapor impermeable)
Non-perforated Aluminum Foil	I (vapor impermeable)
Extruded Polystyrene (+1inch thick)	II (vapor semi-impermeable)
Kraft Facing on Fiberglass Batts	II (vapor semi-impermeable)
Latex paint	III (vapor semi-permeable)
Building Paper	III (vapor semi-permeable)
Plywood	III (vapor semi-permeable)

In cases where air pressure control and interior moisture control are possible, Lstiburek recommends considering the adoption of a "'flow-through' approach by using permeable building materials on both the interior and exterior surfaces of building assemblies to allow water vapor by diffusion to 'flow-through' the building assembly without accumulating" (Figure Three, left assembly).[122] William Rose explains that in mixed climates, a vapor retarder is not necessary with compact construction (i.e. solid masonry walls), and with cavity construction, a "higher-permeance vapor retarder system such as kraft facing or insulation may be used."[123] Thus, whether or not your building needs a vapor retarder will be based to some degree on the type of wall assembly in place, among other factors.

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118 Lstiburek, "Understanding Air Barriers," 4.

119 Interviews with historic preservationists, architects, engineers and building science professionals, December 20, 2012 to March 21 2013.

120 Lstiburek, "Understanding Air Barriers," 28.

121 Rob Yagid, "What's the Difference: Vapor Barriers and Vapor Retarders?," *Fine Homebuilding*, http://www.finehomebuilding.com/item/5090/whats-the-difference-vapor-barriers-and-vapor-retarders (accessed April 23, 2013).

122 Joseph Lstiburek, *Moisture Control for Buildings* (Westford, MA: Building Science Press, 2002) http://www.buildingscience.com/documents/reports/rr-0205-moisture-control-for-buildings/view?searchterm=moisture%20control%20for%20buildings%20lstiburek (accessed May 6, 2013), 5.

123 Rose, *Water in Buildings: An Architect's Guide to Moisture and Mold*, 182.

Government organizations in the United Kingdom (which has a comparable climate to that of the Pacific Northwest) provide similar recommendations regarding the use of vapor open assemblies in their guide, *Fabric Improvements for Energy Efficiency in Traditional Buildings*. The organization, Historic Scotland, states that it is "vital to choose an appropriate vapor permeable material to avoid creating a vapor barrier which could lead to build up of moisture and associated decay within the wall."[124] Historic Scotland tested five different vapor permeable insulation types with a vapor open, mass masonry wall assembly, finding no moisture issues over the course of a year.[125]

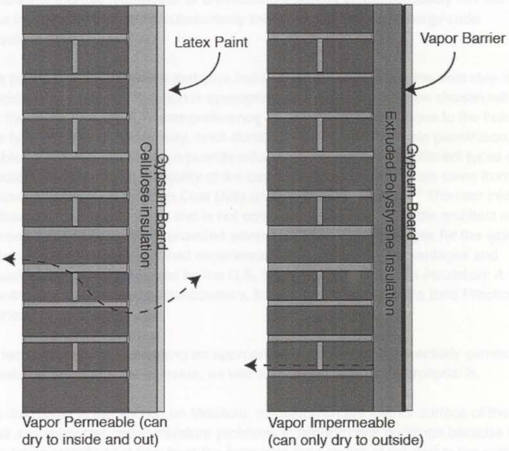

Figure Three: The left assembly can dry both to the interior and exterior because the materials are permeable, whereas the assembly on the right can only dry to the exterior because impermeable materials are used.

It is recommended that a building science professional be consulted prior to determining what type of vapor retarder you should use in your historic building. There are some cases in which vapor barriers should be used, such as rooms with a high indoor humidity level (i.e. greenhouses, kitchen restaurants, or rooms with an indoor pool) or in very cold

124 Historic Scotland, *Short Guide: Fabric Improvements for Energy Efficiency in Traditional Buildings*, 21.
125 Ibid.

climates. However, because moisture problems related to vapor diffusion from the interior is often negligible, a semi-permeable (Class III) vapor retarder is often acceptable. The use of a vapor barrier in not recommended because it could potentially do more harm than good.[126]

Thermal Barrier

The purpose of the thermal barrier, or insulation, is to reduce heat transfer through the wall assembly. Historic brick buildings rely to some extent on their wall thickness to offer some resistance to heat loss and heat gain.[127] However, the average R-value, or the amount of thermal resistance, of uninsulated masonry is approximately R-1 (for a brick four inches thick), which is substantially lower than the current energy code requirements.[128]

If a professional determines that your building is safe to insulate, the next step is to decide which type of insulation is appropriate. The type of insulation chosen will depend on the project's budget, owner preference and characteristics unique to the building (i.e. the type of brick wall assembly, brick durability, susceptibility to rain penetration, etc.). Tables Eight through Thirteen provide information regarding the different types of insulation available. The majority of the cost and R-value information came from *RS Means Building Construction Cost Data* unless otherwise noted.[129] The cost information is based on national values, and is not corrected for location. Seattle architect and preservationist, Brian Rich, provided advantages and disadvantages for the typical insulation materials he has had experience with.[130] Additional advantages and disadvantages were provided by the U.S. Department of Energy's *Insulation: A Guide for Contractors to Share with Homeowners*, from the Building America Best Practice Series.[131]

In terms of durability, choosing an appropriate insulation type essentially comes down to insulation thickness and R-value, as well as how permeable the material is.

As discussed in the section on Moisture, insulation on the interior surface of the exterior wall assembly can cause moisture problems in historic brick buildings because the insulation retards heat flow from the interior to the exterior of the wall in the winter. The thicker and the more resistant the insulation is to heat flow, the greater likelihood

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126 Martin Holladay, "Vapor Retarders and Vapor Barriers: Answers to Persistent Questions about Vapor Diffusion," Green Building Advisor, http://www.greenbuildingadvisor.com/blogs/dept/musings/vapor-retarders-and-vapor-barriers (accessed April 28, 2013).

127 Carpenter et. al., "The Designer's Dilemma: Modern Performance Expectations and Historic Masonry Walls."

128 Straube, Ueno, and Schumacher, *Internal Insulation of Masonry Walls: Final Measure Guideline*, i.

129 Waier Phillip, Charest Adrian, and RS Means Engineering Department, *RS Means Construction Cost Data 2013* (Hoboken, NJ: John, Wiley & Sons, 2013).

130 Brian D. Rich, Richaven PLLC, interview by author, email interview, March 13, 2013.

131 Michael C. Baechler, K.T. Adams, M.G. Hefty, T.L. Gilbride, and Pat M. Love, *Insulation: A Guide for Contractors to Share with Homeowners*, Building America Best Practice Series 17 (Washington, D.C.: U.S. Department of Energy, 2012), 14.

moisture accumulation will occur.[132] The bricks stay wetter for longer, which can lead to mold growth, freeze/thaw damage, rotting wood joists and beams that are embedded in the brick, and corroding metal ties holding cavity walls together. Thus, choosing the right type of insulation and ensuring that the wall is monitored and maintained post-retrofit is crucial.

The permeability of the insulation also plays a role regarding whether or not unwanted moisture buildup is possible. Some insulation types, such as extruded polystyrene insulation (XPS), are considered semi-impermeable (Class II) vapor retarders. As discussed in the Vapor Retarder section above, this means that the wall assembly is not as easily allowed to dry to the interior when semi-impermeable insulation is installed on the interior surface of the exterior wall assembly. Furthermore, if moisture gets through small cracks and holes inside the building (which are practically inevitable), it can get trapped and accumulate between the insulation and the interior of the brick. The selection and design of the insulation should take into account the drying-out process both before and after installation.[133]

[132] Martin Holladay, "Insulating Old Brick Buildings," Green Building Advisor, http://www.greenbuildingadvisor.com/blogs/dept/musings/insulating-old-brick-buildings (accessed April 28, 2013).
[133] English Heritage, *Energy Efficiency in Historic Buildings: Early Cavity Walls*, (London: English Heritage, 2010) http://www.english-heritage.org.uk/publications/eehb-early-cavity-walls/eehb-early-cavity-walls.pdf (accessed April 28, 2013),12.

Table Eight

Rigid Insulation							
Insulation Type	Thickness	Width	R-value	Total Cost per sq. ft. (including material & labor)	Total Cost per sq. ft. (including material, labor, overhead & profit)	Advantages	Disadvantages
Fiberglass	1"	varies	4.3	$0.84	$1.08	Higher density insulation available; air barrier if seams are properly sealed[134]	Can have formaldehyde as a binder; Performance degrades when wet; must be ventilated; can have gaps in the insulation; does not conform to irregular surfaces; produces toxic smoke when burned[135]
	1-1/2"	varies	6.5	$1.08	$1.34		
	2"	varies	8.7	$1.36	$1.68		
	2-1/2"	varies	10.9	$1.46	$1.80		
	3"	varies	13	$1.91	$2.30		
Extruded polystyrene (XPS)	1"	varies	5	$0.97	$1.26	Easy to handle and install; waterproof; high compressive strength; Air barrier if seams are properly sealed[136]	Air gaps between boards lead to cold zones; melts when exposed to high temperatures; does not conform to irregular surfaces; produces toxic smoke when burned[137] higher CO2 emissions[138]
	2"	varies	10	$1.54	$1.92		
	3"	varies	15	$1.98	$2.40		
Expanded polystyrene (EPS)	1"	varies	3.9	$0.69	$0.95	Easy to handle and install; waterproof; high compressive strength; air barrier if seams are properly sealed[139]	Air gaps between boards lead to cold zones; does not conform to irregular surfaces; produces toxic smoke when burned[140]
	2"	varies	7.7	$0.97	$1.29		
	3"	varies	11.5	$1.21	$1.55		
Polyisocyanurate (ISO)[141]	varies	varies	5.5-6/inch	$0.7 per sq ft.*		High R-value sustained over time; air barrier if seams are properly sealed[142]	Air gaps between boards lead to cold zones; does not conform to irregular surfaces; produces toxic smoke when burned[143]

*Cost does not include labor

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134 Baechler, et. al., *Insulation: A Guide for Contractors to Share with Homeowners*, 14.
135 Ibid.
136 Ibid, 17.
137 Ibid.
138 David White, "Insulation GWP Tool" (Eugene: University of Oregon, 2013).
139 Baechler, et. al., *Insulation: A Guide for Contractors to Share with Homeowners,* 17.
140 Ibid.
141 Rick Arnold, "Which Insulation Should I Choose?," *Fine Homebuilding*, http://www.finehomebuilding.com/item/4822/which-rigid-insulation-should-i-choose (accessed April 28, 2013).
142 Baechler et. al., *Insulation: A Guide for Contractors to Share with Homeowners*, 17.
143 Ibid.

Table Nine

Blanket Insulation							
Insulation Type	Thickness	Width	R-value	Total Cost per sq. ft. (including material and labor)	Total Cost per sq. ft. (including material, labor, overhead and profit)	Advantages	Disadvantages
Fiberglass	6"	11"	21	$0.81	$1.03	Varying densities available; Relatively easy to install[144]	Can have formaldehyde as a binder; Performance degrades when wet or compressed; Must be ventilated; can have gaps in the insulation; not air-tight[145]
		15"	21	$0.77	$0.96		
		23"	21	$0.72	$0.90		
	9"	11"	30	$0.96	$1.22		
		15"	30	$0.91	$1.14		
		23"	30	$0.87	$1.07		
	12"	11"	38	$1.11	$1.39		
		15"	38	$1.11	$1.38		
		23"	38	$1.06	$1.31		
Mineral wool, kraft faced	6"	varies	19	$0.61	$0.78	Relatively easy to install[146]	Not air-tight[147]
	10"	varies	30	$0.86	$1.03		
Cotton (recycled blue jeans)[148]	3-1/2"	varies	13	$1.20 per sq. ft.*		Recycled content; Easy installation	Can be flammable if not treated; Performance degrades when wet; Must be ventilated; not air-tight[149]
	5-1/2"	varies	19				

*Cost does not include labor

144 Baechler et. al., *Insulation: A Guide for Contractors to Share with Homeowners*, 14.
145 Ibid.
146 Ibid.
147 Ibid.
148 NAHB Research Center, "Toolbase Tech Specs: Alternative Insulation Materials," Partnership for Advancing Technology in Housing http://www.toolbase.org/pdf/techinv/insulationalternatives_techspec.pdf (accessed April 28, 2013).
149 Baechler et. al., *Insulation: A Guide for Contractors to Share with Homeowners*, 14.

Table Ten

Poured Loose-Fill Insulation							
Insulation Type	Thickness	Width	R-value	Total Cost per sq. ft. (including material and labor)	Total Cost per sq. ft. (including material, labor, overhead and profit)	Advantages	Disadvantages
Cellulose fiber	varies	varies	R3.8/inch	$2.47	$3.51		
Ceramic type (perlite)	varies	varies	R3.2/inch	$7.80	$9.35		
Fiberglass wool	varies	varies	R4/inch	$2.23	$3.24		
Mineral wool	varies	varies	R3/inch	$2.19	$3.20		
Polystyrene	varies	varies	R4/inch	$4.55	$5.80		

*Cost does not include labor

Table Eleven

Sprayed Insulation							
Insulation Type	Thickness	Width	R-value	Total Cost per sq. ft. (including material and labor)	Total Cost per sq. ft. (including material, labor, overhead and profit)	Advantages	Disadvantages
Closed cell, spray polyurethane foam	varies	varies	~ 6-6.5/in.	$0.70	$0.83	Effective air barrier; not highly flammable, high R-value; Fills small cavities and spaces around wiring, plumbing, etc.[150]	Low permeability can lead to moisture problems; Produces toxic smoke when burned; Higher CO2 emissions[151]
Open cell, spray polyurethane foam	varies	varies	~ 3.5/in.	$ ~ .49	$ ~ .58	Higher vapor permeability; Fills small cavities and spaces around wiring, plumbing, etc.[152]	Produces toxic smoke when burned; Higher CO2 emissions[153]
Open cell, spray polyicynene foam[154]	varies	varies	~3.6/in.	~$1.25-2 per sq. ft.*		Higher vapor permeability; Effective air barrier; not highly flammable; fills small cavities and spaces around wiring, plumbing, etc.[155]	Produces toxic smoke when burned

*Cost does not include labor

[150] Baechler et. al., *Insulation: A Guide for Contractors to Share with Homeowners*, 15.
[151] White, "Insulation GWP Tool."
[152] Baechler et. al., *Insulation: A Guide for Contractors to Share with Homeowners*, 15.
[153] White, "Insulation GWP Tool."
[154] All-in-One Insulation, Inc., "Bursting the Bubble: Icynene and Sprayed Foam Insulation," All-in-One Insulation, Inc., http://allinoneinsulation.com/2012/02/bursting-the-bubble-icynene-and-sprayed-foam-insulation/ (accessed April 28, 2013).
[155] Baechler et. al., *Insulation: A Guide for Contractors to Share with Homeowners*, 15.

Table Twelve

Blown Insulation							
Insulation Type	Thickness	Width	R-value	Total Cost per sq. ft. (including material and labor)	Total Cost per sq. ft. (including material, labor, overhead and profit)	Advantages	Disadvantages
Cellulose	5-3/16"	varies	19	$0.68	$0.84	Easy installation	Compresses and looses effectiveness over time; Performance degrades when wet; Can be Flammable in not treated; must be ventilated
	6-1/2"	varies	22	$0.86	$1.09		
	8-11/16"	varies	30	$1.07	$1.33		
	10-7/8"	varies	38	$1.47	$1.82		
Fiberglass	8-4/5"	varies	19	$0.84	$1.11		
	10"	varies	22	$1.02	$1.33		
	11-1/2"	varies	26	$1.22	$1.60		
	13"	varies	30	$1.34	$1.74		
	16"	varies	38	$1.66	$2.17		

Table Thirteen

New Insulation Materials						
Insulation Type	Thickness	Width	R-value	Cost (not including labor)	Advantages	Disadvantages
Aerogel blankets[156]	varies	varies	10/inch	$ 3-5 per sq ft.*	Higher vapor permeability[157]	Cost
Vacuum Insulated Panels[158]	varies	varies	30-40/inch	$3-5 per sq. ft.*		

*Cost does not include labor

156 Aspen Aerogels, "Aerogels," Aspen Aerogels, Inc., http://aerogel.com/?nr=0 (accessed April 28, 2013).
157 Historic Scotland, *Short Guide: Fabric Improvements for Energy Efficiency in Traditional Buildings*, 14.
158 NAHB Research Center, "Vacuum Insulation Panel (VIP): Special Core Panel Enclosed in an Air-tight Envelope," NAHB Research Center http://www.toolbase.org/Technology-Inventory/Interior-Partitions-Ceilings/vacuum-insulation-panel (accessed April 28, 2013).

Insulation – Where to Put it

If Your Building Has Cavity Wall Construction…

Early brick cavity wall assemblies were tied together in two ways – with bricks bonded into both leaves of the wall or with metal (typically wrought iron) ties (see Figure Four).[159] If bricks were used as ties, the cavity cannot be continuous because the bonding brick can transfer moisture across the cavity, and should therefore be treated as a solid brick wall assembly.[160]

Insulating brick cavity wall assemblies held together by metal ties can be done two ways – insulating in the cavity itself or insulating in the interior as you would a solid brick wall (see Figure Five).

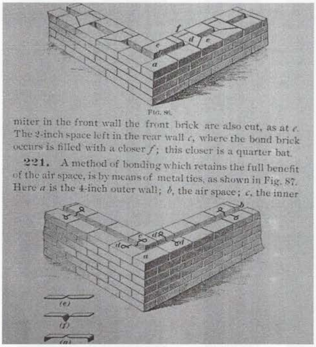


Figure Four: Examples of historic cavity walls. From: *Masonry, Carpentry, Joinery: The Art of Architecture, Engineering and Construction in 1899*.

The major benefit of insulating the cavity in historic brick buildings is that it reduces the need to alter the historic character of the wall because the historic fabric will not be covered or removed to install the insulation. If possible, it is recommended that a few bricks on the outer leaf of the cavity wall be removed in order to blow in insulation, rather than drilling holes in the assembly. If the top of the cavity is accessible from the attic, it is possible to pour in loose-fill insulation.

Although less visually intrusive, installing insulation in the wall cavity can cause durability issues. If the insulation is not installed properly, unfilled air pockets may be left, or the insulation could settle to the bottom of the cavity, creating cold bridging and surfaces for condensation to occur. Tools such as thermal imaging or a borescope (an optical device that allows you to see inside the cavity through the small spaces provided to blow in insulation) can be used to ensure there are no gaps in the blown in insulation. If the exterior leaf of the cavity wall experiences driving rain or is consistently damp due to other factors, the cavity may be allowing moisture to accumulate and be released through weep holes, rather than causing the interior leaf to be wet. Filling the cavity may prevent the ability for the accumulated moisture on the interior surface of the exterior leaf

159 English Heritage, *Energy Efficiency in Historic Buildings: Early Cavity Walls*, 6-7.
160 Ibid., 8.

to be released or dry. Additionally, insulation may create a bridge for moisture to transfer from the outer to the inner leaf. It is recommended that the cavity be at least two inches wide (to reduce the possibility of moisture transfer), and that insulation is only installed in the cavity if driving rain and consistent dampness is not a problem.[161] If moisture is already an issue in your cavity wall assembly, insulating on the interior surface of the brick is still an option.

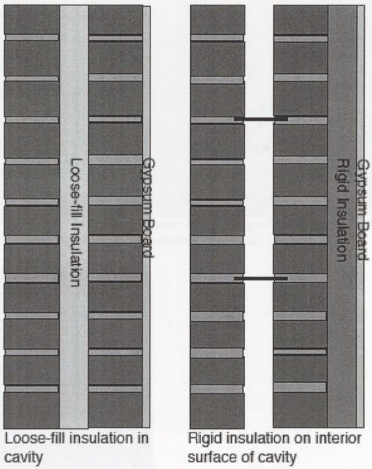


Figure Five: Two methods of insulating brick cavity walls.

[161] English Heritage, *Energy Efficiency in Historic Buildings: Early Cavity Walls*, 15-16.

If Your Building Has Brick Veneer Over Concrete Wall Construction…

Although brick and concrete do not have identical moisture and heat transfer properties, they are typically similar enough that a solid wall with brick veneer and concrete backing can be treated like a solid brick wall assembly (see Figure Seven). It is also worth noting that in all of the works cited regarding the treatment of insulating masonry wall assemblies, the term "masonry" applies to a variety of materials, including brick and concrete, and the materials are not treated differently.

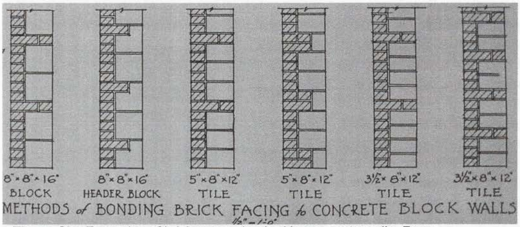
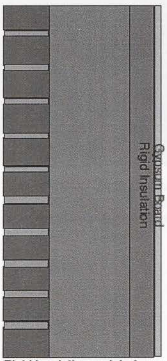


Figure Six: Examples of brick veneer backed by concrete walls. From: *Architectural Graphic Standards*, 1932-1952 editions.



Rigid insulation on interior surface of load-bearing concrete with brick veneer

Figure Seven: Insulation on load-bearing concrete with brick veneer.

If Your Building Has A Solid Brick Wall Assembly…

There are a few different application methods available when insulating a historic solid brick wall assembly (see Figure Eight). If the original lath and plaster is in place, it is possible to use blown in insulation in order to maintain the original finishes and interior historic fabric. As with cavity insulation, it is important to ensure the space between the wall and the lath and plaster is completely filled to avoid thermal bridging.

If the original interior finish is not in place, or has been significantly compromised, it is possible to apply insulation directly to the masonry, with or without framing. Rigid board insulation can be installed using adhesive without the need for framing. The interior finish (i.e. plaster) can then be applied directly to the board. If the space is available and concerns regarding preserving the proportions and interior finishes are not an issue, a stud wall can be constructed, within which several types of insulation, including rigid, batt, sprayed or blown insulation, can be installed. It is important to place the studs one to two inches away from the wall so that insulation is in continuous contact with the interior surface of the brick (see Figure Eight, right wall assembly). This will help to reduce thermal bridging and provide a better air barrier.

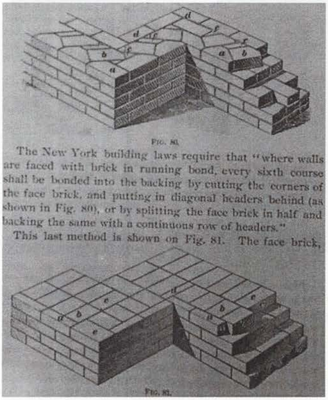


FIG. 80.

The New York building laws require that "where walls are faced with brick in running bond, every sixth course shall be bonded into the backing by cutting the corners of the face brick, and putting in diagonal headers behind (as shown in Fig. 80), or by splitting the face brick in half and backing the same with a continuous row of headers."

This last method is shown on Fig. 81. The face brick,

FIG. 81.

Figure Three: Examples of historic solid brick walls. From: *Masonry, Carpentry, Joinery: The Art of Architecture, Engineering and Construction in 1899.*

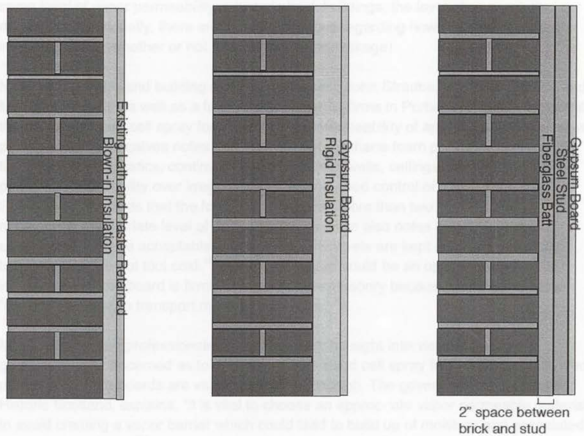


Figure Eight: Methods of insulating solid brick wall assemblies.

Choosing an Insulation – What the Experts Say
Although the majority of experts believe that it is important to use insulation with at least some level of vapor permeability in historic brick buildings, the level of permeability is debatable. Additionally, there are differing opinions regarding how air-permeable the insulation is (i.e. whether or not it helps reduce air leakage).

Notable engineers and building scientists, including John Straube, Joseph Lstiburek and Mario Goncalves, as well as a few local engineering firms in Portland, Oregon, advocate the use of a closed cell spray foam with a vapor permeability of approximately one to two perms-inch.[162] Gonçalves notes that sprayed polyurethane foam provides, "excellent air tightness characteristics, continuity at junctions with walls, ceilings, floor and window perimeter, applicability over irregular surfaces and good control of total thickness."[163] Straube recommends that the foam not be applied more than two inches thick to maintain an appropriate level of drying for the wall. He also notes that lower density spray foams may be acceptable if indoor humidity levels are kept lower and outside temperatures are not tool cold.[164] Rigid foam board could be an option, however it is imperative that the board is firmly attached to the masonry because gaps could allow "convective loops to transport moisture and heat."[165]

More conservative professionals, including six of the eight interviewees for this guidebook, are concerned as to whether or not closed cell spray foam and rigid extruded polystyrene foam boards are vapor permeable enough. The government organization, Historic Scotland, explains, "it is vital to choose an appropriate vapor permeable material to avoid creating a vapor barrier which could lead to build up of moisture and associated decay with the wall."[166] The organization recommends natural materials such as wool, blown cellulose or wood fiberboard.[167] New York City architect, Chris Benedict, and Brooklyn architect, Jeremy Shannon have noted their success with cellulose as well. Benedict, in an article for *Home Energy Magazine*, explains that as long as the interior surface (i.e. gypsum board) is carefully caulked and sealed to provide a sufficient air barrier, using a vapor permeable material such as insulation should not be a problem.[168]

Shannon explained in the interview for this guidebook, spray foams could potentially contract and pull away from the brick surface, leaving air gaps where condensation can

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[162] Interview with Portland engineer, Eugene, OR, March 21, 2013.; Straube, Ueno, and Schumacher, *Internal Insulation of Masonry Walls: Final Measure Guideline*, 27; Carpenter et. al., "The Designer's Dilemma: Modern Performance Expectations and Historic Masonry Walls."
[163] Carpenter et. al., "The Designer's Dilemma: Modern Performance Expectations and Historic Masonry Walls."
[164] Straube, Ueno, and Schumacher, *Internal Insulation of Masonry Walls: Final Measure Guideline*, 27.
[165] Ibid., 24.
[166] Historic Scotland, *Short Guide: Fabric Improvements for Energy Efficiency in Traditional Buildings*, 21.
[167] Ibid., 21.
[168] Chris Benedict, "Insulating Residential Masonry Buildings in Cold Climates," *Home Energy Magazine*, March 1, 2010, http://www.homeenergy.org/show/article/nav/walls/id/700 quoted in Martin Holladay, "Insulating Old Brick Buildings," http://www.greenbuildingadvisor.com/blogs/dept/musings/insulating-old-brick-buildings (accessed April 28, 2013).

occur.[169] Both Shannon and Straube recommend a liquid-applied, highly vapor-permeable air and water barrier to be installed on the interior surface of the exterior wall assembly in order to prevent air leakage that can occur with certain insulation installments.[170]

It is recommended that a building professional be consulted when choosing which type of retrofit technique is appropriate for your particular building. However, there are a few key considerations to keep in mind:

- If you are not able to manage bulk water issues (rain penetration), you should not insulate your building; having a successful water barrier is crucial to maintaining your buildings condition
- Creating a good air barrier will be much more significant than using a vapor barrier for reducing the amount of moisture accumulation that occurs
- Vapor barriers could potentially do more harm than good, so it is important that if a vapor retarder is used, it is at least partially permeable (Class II, and preferably Class III)
- Thicker insulation will reduce heat loss more, but will also cause your bricks to be colder and wetter for longer; it is important to find a balance between appropriate insulation R-values and the brick's ability to dry
- The type of insulation used will need to be chosen on a case-by-case basis; BUT the insulation should be vapor permeable enough to allow drying; it should also serve to some extant as an air barrier to prevent air leakage

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[169] Jeremy Shannon, interview by author, Eugene, OR, March 20, 2013.
[170] Jeremy Shannon, interview by author, Eugene, OR, March 20, 2013.; Straube, Ueno, and Schumacher, *Internal Insulation of Masonry Walls: Final Measure Guideline*, 24.

Five case study buildings have been prepared to demonstrate how different energy reduction measure can successfully be implemented in historic buildings. For more information regarding the infrared imaging and hygrothermal modeling conducted in each of the buildings, please refer to: "Building Case Studies: The Application of Infrared Imaging and Hygrothermal Modeling in Historic Brick Buildings".

Building Backgrounds

Fenton Hall

Figure Nine: Fenton Hall. Photo by author.

Fenton Hall was built in 1906 on the University of Oregon campus. The building was originally constructed for library purposes, and was designed by architect Yousa D. Hensill. The building is approximately 20,000 square feet, and now houses the Math Department. The majority of Fenton is composed of an unreinforced, solid brick wall assembly, three-wythes thick (see Figure Ten). However, reports indicated that in some areas, such as the entrance to the first floor, the brick wall has a cavity 4.5 inches thick between the first and second wythe of brick. During its 2011 renovation, a 4.5-inch air space followed by steel-backed gypsum board (for the seismic upgrade) was constructed on the interior.[171]

[171]SRG Partnership, Inc., *University of Oregon: Fenton Hall Renovation Study* (Portland, OR, 2008), 3-3.

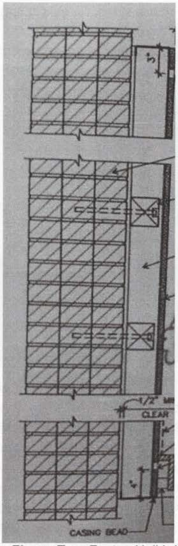

Figure Ten: Fenton Hall brick wall section. From: *Fenton Hall Deferred Maintenance Plans*, 2010.


Figure Eleven: Fenton Hall historically appropriate awnings. Photo by author.

The following energy upgrades were conducted during Fenton's renovation:[172]

- Air sealing
- Installation of a cool roof
- Chilled beam cooling system
- Utilizing return chilled water to reduce building cooling loads
- Awning installation (Figure Eleven)
- Insulated glazing
- Floor insulation

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[172] Solarc Architecture/Engineering, Inc., *Preliminary Energy Analysis Report: SEED Program: Fenton Hall* (Eugene, OR: University of Oregon, 2010), 2-4.

Peterson Hall

Figure Twelve: Peterson Hall. Photo by author.

Peterson Hall was constructed in 1916 on the University of Oregon campus, and is approximately 19,000 square feet. The building was originally built to accommodate the School of Education, and was the first building on campus designed by architect, Ellis F. Lawrence. It is now part of the Lillis Business Complex, housing offices, classroom space, and the Oregon MBA program. Peterson maintains an unreinforced, load-bearing brick wall assembly, which is four-wythes thick on the first floor and three-wythes thick on the second and third floors. During its 2007 renovation, rigid polystyrene insulation was added to the interior of the brick assembly on the first floor, and fiberglass batts were installed on the second and third floors.[173]

The following energy upgrades were conducted during Peterson's renovation:[174]

- Air sealing
- Roof insulation
- Installation of a cool roof
- Wall insulation
- Insulated glazing (Figure Thirteen)
- Electric lighting upgrades (efficient lamps and controls)
- Daylight harvesting
- HVAC upgrades

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[173]Michael W. Graney, *Energy Analysis Report: Oregon Department of Energy State Energy Efficient Design Program, for the Lillis Business Complex Phase 2* (Eugene, OR, 2008), 5.; Greg Williams, interview by author, November 19, 2012.

[174] Graney, *Energy Analysis Report: Oregon Department of Energy State Energy Efficient Design Program, for the Lillis Business Complex Phase 2*, 5.

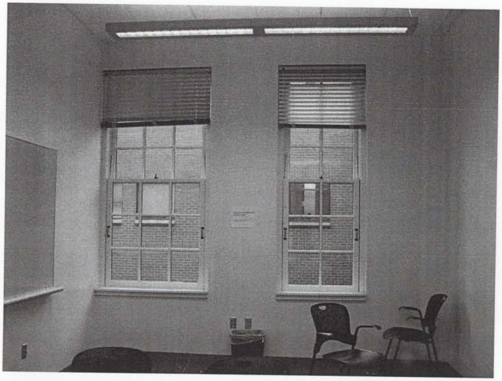

Figure Thirteen: Peterson Hall new insulated glazing. Photo by author.

Anstett Hall

Figure Fourteen: Anstett Hall. Photo by author.

Anstett Hall, first known as Commerce Hall and then as Gilbert Hall, was constructed in 1921 on the University of Oregon campus. The building, roughly 19,000 square feet, originally housed the School of Business, and was designed by Ellis F. Lawrence. Anstett is now part of the Lillis Business Complex, composed of PhD student offices and tutoring rooms. Anstett has an unreinforced, load-bearing brick wall assembly, which is four-wythes thick on the first floor and three-wythes thick on the second and third floors. During its 2010 renovation, rigid polystyrene insulation was added to the interior of the brick assembly on the first floor, and fiberglass batts were installed on the second and third floors.[175]

The following energy upgrades were conducted during Anstett's renovation:[176]

- Air sealing
- Roof insulation
- Installation of a cool roof
- Wall insulation
- Insulated glazing
- Lighting upgrades (efficient lamps and controls) (Figure Fifteen)

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[175]David Adam Singer, "Historic Structures Report: The Education Building and Commerce Hall, (The West and East Wings of the Gilbert Complex) on the University of Oregon Campus, Eugene)" (master's terminal project, University of Oregon, 2000), 78.; Greg Williams, interview by author, email interview, November 19, 2012.

[176] Graney, *Energy Analysis Report: Oregon Department of Energy State Energy Efficient Design Program, for the Lillis Business Complex Phase 2*, 5.

- Daylighting strategies
- HVAC upgrades

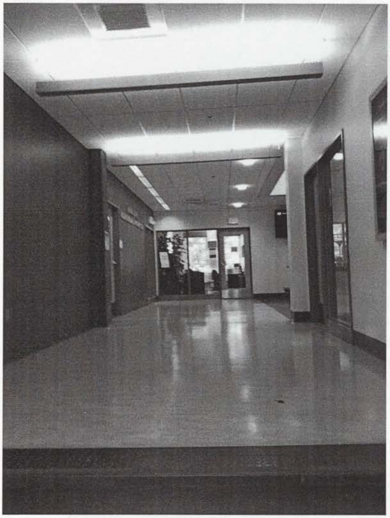

Figure Fifteen: High-efficiency lamps in Anstett and Peterson. Photo by author.

Lincoln Hall

Figure Sixteen: Lincoln Hall. Photo by author.

Lincoln Hall was built in 1911 as the Portland School District's Lincoln High School. The 145,000-square-foot space is now occupied by Portland State University, and houses the college's Performing Arts Program. Lincoln was renovated in 2011, and is the first LEED Platinum building on the university campus. The building is composed of an unreinforced, solid brick wall assembly, which is approximately three-wythes thick (see Figure Seventeen). The exterior walls remain uninsulated.[177]

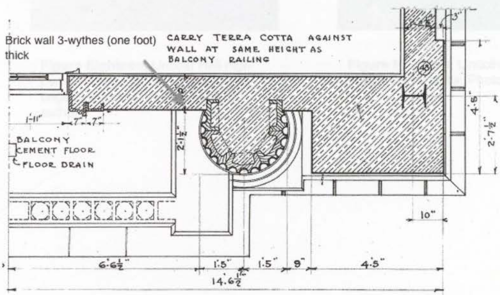

Figure Seventeen: Plan detail of Lincoln Hall brick wall. From: *Lincoln Hall Plans*, 1911.

The

[177]Ron Blaj and Jennifer Sharp, interview by author, Portland, OR, December 12, 2012.; *Lincoln Hall Plans*, Portland, OR, 1911.

following energy upgrades were conducted during Lincoln's renovation:[178]

- Air sealing
- Roof insulation
- HVAC upgrades
- High performance windows (Figure Eighteen)
- Daylighting strategies (restored light wells) (Figure Nineteen)

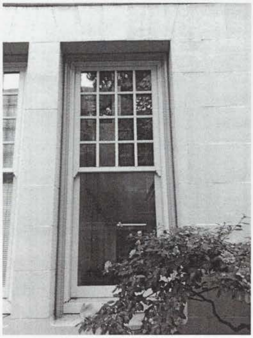

Figure Eighteen: Lincoln Hall high performance windows (replicas of original wood windows). Photo by author.

Figure Nineteen: Lincoln Hall restored light wells. Photo by author.

[178] Ron Blaj and Jennifer Sharp, interview by author, Portland, OR, December 12, 2012.

Shattuck Hall

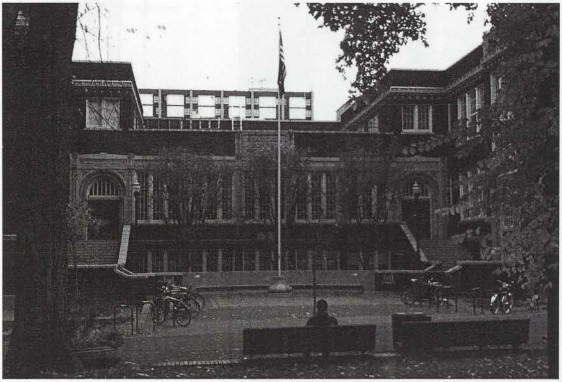

Figure Twenty: Shattuck Hall. Photo by author.

Shattuck Hall was built in 1914 as Shattuck Elementary School. The 60,000-square-foot building is now occupied by Portland State University, and is the home of the university's Department of Architecture and Public Safety Office. Shattuck was renovated in 2010, and received LEED Gold for New Construction. The building consists of five inches of brick veneer backed by nine inches of unreinforced concrete (see Figure Twenty-One). The exterior walls remain uninsulated.[179]

[179]Ron Blaj and Jennifer Sharp, interview by author, Portland, OR, December 12, 2012; *Shattuck Hall Plans*, Portland, OR, 1914.

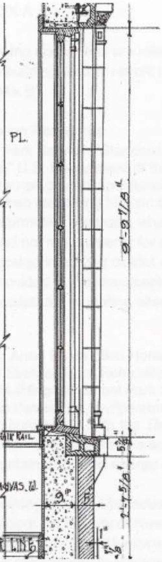

Figure Twenty-One: Shattuck Hall wall section detail. From: *Shattuck Hall Plans*, 1914.

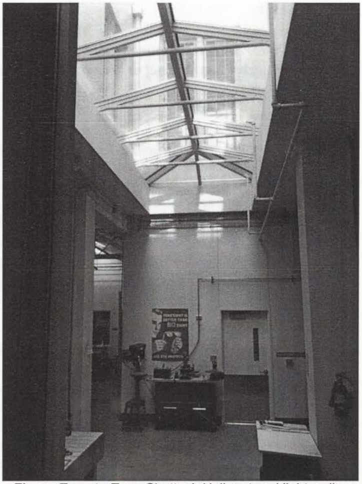

Figure Twenty-Two: Shattuck Hall restored light wells. Photo by author.

The following energy upgrades were implemented during Shattuck's renovation:[180]

- Air sealing
- Roof insulation
- Radiant heating and cooling ceiling panels
- HVAC upgrades
- Daylighting upgrades (restored windows and light wells) (Figure Twenty-Two)
- Lighting upgrades (efficient lamps, occupancy sensors

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[180] Kent Duffy, Jon Mehlschau, and Nick Collins, "Sustainable Foundations: Portland State University's Shattuck Hall," *High Performance Buildings*, Winter, 2011, 7-18.

APPENDIX A

The following documents are related to general retrofitting measures in historic buildings as well as whole building energy retrofit techniques (retrofits specific to the wall assembly are discussed in Appendix B).

Preservation Resources

National Park Service. "Standards for Rehabilitation and Guidelines for Rehabilitating Historic Buildings." U.S. Department of the Interior. http://www.nps.gov/hps/tps/standguide/rehab/rehab_approach.htm

When retrofitting historic buildings, these guidelines should be your main source of information regarding what is and is not appropriate to do. Although these are guidelines and not requirements for most historic buildings, if your building is individually listed or located in a listed district on the National Register of Historic Places, the information provided in this document is what your local historic preservation committee will find acceptable regarding alterations to your building.

Grimmer, Anne E., Jo Ellen Hensley, Liz Petrella, and Audrey T. Tepper. *The Secretary of the Interior's Standards for Rehabilitation & Illustrated Guidelines on Sustainability for Rehabilitating Historic Buildings*. National Park Service. Washington, D.C.: U.S. Department of the Interior, 2011. http://www.nps.gov/tps/standards/rehabilitation/sustainability-guidelines.pdf

In conjunction with the *The Secretary of the Interior's Standards for the Rehabilitation of Historic Properties* (the source above), this document provides guidelines specific to sustainability and energy retrofits of historic buildings.

Whole Building Energy Upgrades

The Municipal Art Society of New York. *Greening NYC's Historic Buildings: Green Rowhouse Manual*. New York: The Municipal Art Society of New York, 2012. http://mas.org/preservation/greenmanual/

This guide covers building envelope retrofits as well as whole building energy reduction strategies. Although some of the codes, resources and wall retrofitting techniques are specific to New York City, information regarding material costs and suitable approaches to upgrading historic buildings are comparable to retrofits across the United States.

The Building Envelope

Changeworks. *Energy Heritage: A Guide to Improving Energy Efficiency in Traditional and Historic Homes*. Ediburgh: Edinburg World Heritage, 2011. http://www.changeworks.org.uk/uploads/83096-EnergyHeritage_online1.pdf

The guide describes the types of issues that affect energy efficiency upgrades in historic buildings and the different opportunities that are appropriate for upgrading through focusing on building envelope efficiency measures.

Historic Scotland. *Short Guide: Fabric Improvements for Energy Efficiency in Traditional Buildings*. Edinburgh: Historic Scotland, 2012. http://www.historic-scotland.gov.uk/fabric_improvements.pdf

Although aimed towards building owners and codes particular to Scotland, this guide provides more detailed descriptions regarding appropriate types of energy upgrades to roofs and lofts, floors, windows, doors, and chimneys and flues in historic buildings. This document is useful in presenting a general outline regarding how to implement particular measures, and what types of materials are acceptable for retrofitting.

Stationary Office of Ireland. *Energy Efficiency in Traditional Buildings*. Advice Series. Dublin: Government of Ireland, 2010. http://www.seai.ie/Grants/Better_energy_homes/contractor/Newsletter/Energy_Efficiency_in_Traditional_Buildings.pdf

Although focused on buildings constructed in Dublin, the document is useful in understanding how your building's site and climate (wind, humidity, solar radiation, building orientation) affects energy movement through the building. It also provides descriptions regarding basic building physics, tools for assessing your building's performance, and general guidelines on how to make your building more energy efficient through upgrading the envelope.

Air Sealing

National Renewable Energy Laboratory. *Weatherize Your Home – Caulk and Weatherstrip*. Washington, D.C.: U.S. Department of Energy, 2001. http://www.nrel.gov/docs/fy01osti/28039.pdf

This article describes where it is common to find air leaks, as well as common caulking and weatherstripping products and how to apply them.

Baechler, Michael C., Theresa Gilbride, Marye Hefty, Pam Cole, Jennifer Williamson, and Pat M. Love. *Retrofit Techniques and Technologies: Air Sealing: A Guide for Contractors to Share with Homeowners*. Building America Best Practice Series. Washington, D.C.: U.S. Department of Energy, 2010. http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/ba_airsealing_report.pdf

This guide helps homeowners identify methods to increase the energy efficiency and comfort of their homes, and it describes the steps to take to seal air leaks while ensuring good indoor air quality and adequate ventilation. It emphasizes the use of a hired professional in conducting energy reduction measures.

ENERGY STAR Program. *A Do-it-Yourself Guide to Sealing and Insulating With ENERGY STAR®: Sealing Air Leaks and Adding Attic Insulation*. Washington, D.C.: U.S. Environmental Protection Agency and U.S. Department of Energy, 2008. http://www.energystar.gov/ia/partners/publications/pubdocs/DIY_Guide_May_2008.pdf

This guide helps owners to learn how to detect air leaks and seal them. Because the guide focuses on a do-it-yourself approach, a detailed, step-by-step process is provided.

Harley, Bruce. *Insulate and Weatherize: Keeping Warm in Winter and Cool in Summer, Solving Moisture Problems, Finding Hidden Energy Wasters*. Newtown: Taunton Press, 2002.

This book provides a detailed, step-by-step approach to insulating and weatherizing your home.

Window Upgrades

Alderson, Caroline. "Technical Preservation Guidelines: Upgrading Historic Building Windows." Center for Historic Buildings. Washington D.C.: U.S. General Services Administration 2009. http://www.gsa.gov/graphics/pbs/Windows.pdf

This succinct document provides descriptions of the types of window retrofit measures that are available. Although it does not outline the energy or cost savings of each strategy, it is useful to understand what is appropriate for historic windows.

Baker, Peter. *Measure Guideline: Wood Window Repair, Rehabilitation and Replacement.* Building America Best Practices Series. Washington, D.C.: U.S. Department of Energy, 2012. http://www.nrel.gov/docs/fy13osti/55219.pdf

This document outlines steps that contractors and homeowners can take in order to decide which window retrofitting strategies are most applicable to their particular project. Although the document is not focused specifically on historic windows, the author recognizes that a building's historic character might affect which of the eight energy reduction methods discussed are pursued.

District of Columbia. *The District of Columbia Historic Preservation Guidelines: Windows and Doors for Historic Buildings.* Washington, D.C.: District of Columbia, 2012. http://www.chrs.org/documents/HPO%20docs/Windows_and_Doors.pdf

These guidelines describe historic window and door types, and the elements that each are composed. Maintenance and repair, appropriate alterations and how to thermally upgrade windows and doors are also covered.

The Preservation Green Lab. *Saving Windows, Saving Money: Evaluating the Energy Performance of Window Retrofit and Replacement*. Washington, D.C.: The National Trust for Historic Preservation, 2011. http://ncptt.nps.gov/wp-content/uploads/Main-Report-120919_NTHP_windows-analysis_v3lowres1.pdf

This study examines several window improvement options, from simple, inexpensive measures to more costly methods that require greater alterations. The report is particularly helpful to building owners in the Pacific Northwest because Portland is one of the climates studied to determine what retrofitting measure are most effective.

Door Upgrades

District of Columbia. *The District of Columbia Historic Preservation Guidelines: Windows and Doors for Historic Buildings*. Washington, D.C.: District of Columbia, 2012. http://www.chrs.org/documents/HPO%20docs/Windows_and_Doors.pdf

See information under Window Upgrades section.

Historic Scotland, *Managing Change in the Historic Environment: Doorways*. Edinburgh: Historic Scotland, 2009. http://www.historic-scotland.gov.uk/managing-change-consultation-doorways.pdf

Although this guide is focused on historic codes in Scotland, information regarding how to identify, repair and upgrade historic doors for energy efficiency is applicable in the United States as well.

Roof Upgrades
Urban, Bryan, and Kurt Roth. *Guidelines for Selecting Cool Roofs*. Building Technologies Program. Washington, D.C.: U.S. Department of Energy, 2010. http://www1.eere.energy.gov/femp/pdfs/coolroofguide.pdf

These guidelines describe what a cool roof is, the types of cool roofs available, how to select the appropriate cool roof, precautions and considerations prior to installation and additional resources. Although cool roofs can potentially reduce a building's energy use, they are not always suitable for historic buildings.

Climate Protection Partnership Division. *Reducing Urban Heat Islands: Compendium of Strategies*. Washington, D.C.: U.S. Environmental Protection Agency, 2008. http://www.epa.gov/heatisland/resources/pdf/GreenRoofsCompendium.pdf

This document focuses on the types of green roofs, the benefits and costs of installing green roofs, a general description of installing a green roof and additional resources. Although green roofs have the potential for reducing a building's energy usage, they are not always appropriate for historic buildings.

National Trust for Historic Preservation. *Start with the Roof: A Guide for Keeping Weather Tight*. Washington, D.C.: National Trust for Historic Preservation, 2009. http://www.preservationnation.org/information-center/sustainable-communities/buildings/weatherization/roofing/additional-resources/nthp_roofing.pdf

This guide provides building owners with steps to identify where and if their roof is falling and/or is energy efficient. The document discuss when roofs are character-defining features and should be preserved or replaced in kind as well as how to appropriately install solar panels on historic roofs.

Stationary Office of Ireland. *Roofs: A Guide to Repair of Historic Roofs*. Advice Series. Dublin: Government of Ireland, 2010. http://www.dublincity.ie/Planning/HeritageConservation/Conservation/Documents/Roofs%20-%20A%20Guide%20to%20the%20Repair%20of%20Historic%20Roofs.pdf

This guide is useful for historic roof assessments, conducting repairs and appropriate technologies that can be applied to roofs to make them more energy efficient.

Floor Upgrades
English Heritage, *Energy Efficiency in Historic Buildings: Insulating Solid Ground Floors*. London: English Heritage, 2011. http://www.climatechangeandyourhome.org.uk/live/content_pdfs/786.pdf

Even though this guide is focused on English building codes, the information regarding the appropriateness of retrofitting solid ground floors in historic buildings is still applicable to American historic structures. The guide presents advice regarding different retrofitting methods, materials and associated risks with insulating ground floors.

English Heritage, *Energy Efficiency in Historic Buildings: Insulation of Suspended Timber Floors*. London: English Heritage, 2011.
http://www.climatechangeandyourhome.org.uk/live/content_pdfs/783.pdf

Even though this guide is focused on English building codes, the information regarding the appropriateness of retrofitting suspended timber floors in historic buildings is still applicable to American historic structures. The guide presents advice regarding different retrofitting methods, materials and associated risks with insulating suspended timber floors.

Maintenance

Portland Energy Conservation, Inc. *Fifteen O&M Best Practices for Energy Efficient Buildings*. Washington, D.C.: U.S. Environmental Protection Agency, 1999.
http://www.energystar.gov/ia/business/15best.pdf

This booklet provides strategies for integrating energy-efficient practices into operation and maintenance programs.

The United States Environmental Protection Agency provides a maintenance checklist at the following link:

http://www.energystar.gov/ia/partners/publications/pubdocs/HeatingCoolingGuide%20FINAL_9-4-09.pdf?b8f0-b31a

Natural Ventilation

Brown, G.Z., Jeff Kline, Gina Livingston, Dale Northcutt, and Emily Wright. *Natural Ventilation in Northwest Buildings*. Energy Studies in Buildings Laboratory. Eugene, OR: University of Oregon, 2004.

This document discusses the basics of natural ventilation, the benefits and feasibility of using natural ventilation and tools to maximize the potential for natural ventilation, specifically in the Pacific Northwest.

HVAC Scheduling and Upgrades

Portland Energy Conservation, Inc. *Fifteen O&M Best Practices for Energy Efficient Buildings*. Washington, D.C.: U.S. Environmental Protection Agency, 1999.
http://www.energystar.gov/ia/business/15best.pdf

See Maintenance above.

ENERGY STAR Program. "A Guide to Energy-Efficient Heating and Cooling." Washington, D.C.: U.S. Environmental Protection Agency, 2009.
http://www.energystar.gov/ia/partners/publications/pubdocs/HeatingCoolingGuide%20FINAL_9-4-09.pdf

This guide provides information for homeowners regarding how to best maintain their HVAC systems and steps that should be taken to improve the efficiency of such systems. Although directed towards homeowners, much of the information is applicable to other building owners as well.

Daylighting Strategies and Lighting Upgrades

Lawrence Berkeley National Laboratory. *Daylight in Buildings: A Source Book on Daylighting Systems and Components.* Washington, D.C.: International Energy Agency, 2009. http://gaia.lbl.gov/iea21/ieapubc.htm

This document discusses how to effectively use daylighting strategies to reduce energy use and improve occupant comfort. Case studies that utilize traditional and innovative daylight systems are provided.

ENERGY STAR Program. *ENERGY STAR Building Manual: Lighting*. Washington, D.C., U.S. Environmental Protection Agency, 2006. http://www.lumenergi.com/sites/default/files/downloads/1-Energy-Star-Building-Manual-2006.pdf

This guide describes steps for choosing efficient light sources, luminaires and lighting controls, as well as how to create an operation and maintenance plan for lighting.

U.S. Department of Energy. "Tips: Lighting." U.S. Department of Energy. http://energy.gov/energysaver/articles/tips-lighting

This webpage provides tips for saving energy through various types of efficient light sources.

Energy Efficient Appliances

ENERGY STAR Program. "Find ENERGY STAR Products." U.S. Department of Energy. http://www.energystar.gov/index.cfm?c=products.pr_find_es_products

This webpage lists a variety of products that are ENERGY STAR certified for their efficiency. Most of the products include a description of how much money can be saved by replacing inefficient appliances with the ENERGY STAR equivalent.

APPENDIX B

The following documents are related to the specific methodologies and durability issues that can occur when retrofitting historic brick wall assemblies.

Brick Testing

Lstiburek, Joseph. "Insight: Thick as a Brick." *Building Science Insight* 47 (March 2011) 1-6. http://www.buildingscience.com/documents/insights/bsi-047-thick-as-brick/files/BSI-047_Thick_as_a_Brick_rev.pdf

This article discusses the importance and complexities of brick testing prior to insulating an existing building.

Straube, John, P. Mensinga and C. Schumacher. *Assessing the Freeze-Thaw Resistance of Clay Brick for Interior Insulation Retrofit Projects*. Westford, MA: Building Science Press, 2010. http://www.buildingscience.com/documents/reports/rr-1013-freeze-thaw-resistance-clay-brick-interior-insulation-retrofits

This report summarizes various methods of brick testing and provides a recommendation as to which approach is preferred. Additionally, the authors suggest using the preferred approach together with hygrothermal modeling when designing retrofit insulation projects.

Moisture

Rose, William B. *Water in Buildings: An Architect's Guide to Moisture and Mold*. New York: John, Wiley & Sons, 2005.

Rose provides a technical, scientific explanation for moisture accumulation in buildings. He has a brief description regarding how retrofitting techniques can cause moisture accumulation, particularly in historic buildings.

Smith, Baird M. *Moisture Problems in Historic Masonry Walls: Diagnosis and Treatment*. National Park Service. Washington D.C.: U.S. Department of the Interior, 1984.

This document provides a detailed description regarding how to assess and treat moisture problems, particularly in historic masonry buildings.

Embedded Framing

Ueno, Kohta. *Masonry Wall Interior Insulation Retrofit Embedded Beam Simulations*. Westford, MA: Building Science Press, 2007. http://www.buildingscience.com/documents/reports/rr-1201-masonry-wall-insulation-interior-embedded-beam-simulations/view?searchterm=embedded%20beam

This report describes research of embedded wood beams in masonry walls using modeling. The report notes the degree of uncertainty and need for further research regarding how wood beams respond to moisture accumulation in masonry structures.

Morelli, Martin, Gregor A. Scheffler, Toke R. Nielsen, and Svend Svendsen. "Internal insulation of masonry walls with wooden floor beams in northern humid climate." *Performance of the Exterior Envelopes of Whole Buildings XI.* Atlanta, GA: American Society of Heating, Refrigeration, and Air-Conditioning Engineers, 2010.
http://www.ornl.gov/sci/buildings/2012/B11%20papers/89_Morelli.pdf

This report provides a solution to avoid moisture issues with wooden beams in masonry while still achieving energy savings.

Harriman, L., G. Bundrette, and R. Kittler. *Humidity Control Design Guide for Commercial and Industrial Buildings*. Atlanta, GA: American Society of Heating, Refrigeration, and Air-Conditioning Engineers, 2001.

William Rose recommends this document for their discussion of the corrosion effects of metal beams in buildings.

Air Barriers

Knight, Kevin D., and Bryan J. Boyle. *Guidelines for Delivering Effective Air Barrier Systems*. Ontario, Canada: Canada Mortgage and Housing Corporation. http://www.cmhc-schl.gc.ca/en/inpr/bude/himu/coedar/upload/Guidelines-for-Delivering-Effective-Air-Barrier-Systems-PDF.pdf

This document provides detailed guidelines for creating efficient air barriers in building envelopes.

Lstiburek, Joseph. *Air Barriers vs. Vapor Barriers*. Westford, MA: Building Science Press, 2008. http://www.buildingscience.com/documents/reports/rr-0004-air-barriers-vs-vapor-barriers/view?searchterm=air%20vs.%20vapor%20barrier

This report provides a brief description regarding the difference between air and vapor barriers, as well as when each is appropriate to use.

Lstiburek, Joseph, "Understanding Air Barriers," *Building Science Digest* 104. October 20, 2006, Building Science Press, http://www.buildingscience.com/documents/digests/bsd-104-understanding-air-barriers/?searchterm=air%20vs.%20vapor%20barrier

Lstiburek describes how air barriers function and provides examples of air barriers.

Vapor Barriers

Lstiburek, Joseph, "Understanding Vapor Barriers," *Building Science Digest 106*. October 24, 2006, Building Science Press, http://www.buildingscience.com/documents/digests/bsd-106-understanding-vapor-barriers/?searchterm=air%20vs.%20vapor%20barrier

This document provides a description of what a vapor barrier is, the different classes of vapor retarders, and when it is appropriate to use a vapor retarder.

Lstiburek, Joseph. *Moisture Control for Buildings*. Westford, MA: Building Science Press, 2002. http://www.buildingscience.com/documents/reports/rr-0205-moisture-control-for-buildings/view?searchterm=moisture%20control%20for%20buildings%20lstiburek

This document description the importance of finding a moisture balance, and when a vapor barrier vs. a vapor retarder is acceptable, depending on the climate.

Insulation

U.S. Department of Energy, *Insulation: A Guide for Contractors to Share with Homeowners*, by Michael C. Baechler, K.T. Adams, M.G. Hefty, T.L. Gilbride, and Pat M. Love, Building America Best Practice Series, 17 (Washington, D.C., 2012)
http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/insulation_guide.pdf

This document provides a detailed description of the typical insulation types available, how to install them and what their advantages and disadvantages are.

John Straube, Kohta Ueno, and Christopher Schumacher, *Internal Insulation of Masonry Walls: Final Measure Guideline* (Westford, MA: Building Science Press, 2007)
http://www.buildingscience.com/documents/reports/rr-1105-internal-insulation-masonry-walls-final-measure-guideline/view?searchterm=internal%20insulation%20masonry%20walls%20final%20measure

This technical report provides current research on the types of insulation and wall assemblies appropriate for retrofitting masonry buildings. The document discusses the use of closed cell spray foam as the preferred type of insulation in existing masonry buildings.

English Heritage, *Energy Efficiency in Historic Buildings: Early Cavity Walls*, (London: English Heritage) http://www.english-heritage.org.uk/publications/eehb-early-cavity-walls/eehb-early-cavity-walls.pdf

This document discusses the durability issues that can occur when insulating historic masonry structures, the different methods of insulating cavity walls and their benefits and drawbacks.

English Heritage, *Energy Efficiency in Historic Buildings: Insulating Solid Walls*, (London: English Heritage)
http://www.english-heritage.org.uk/publications/eehb-insulating-solid-walls/eehb-insulating-solid-walls.pdf

This document discusses the durability issues that can occur when insulating historic masonry structures, the different methods of insulating masonry solid walls and their benefits and drawbacks.

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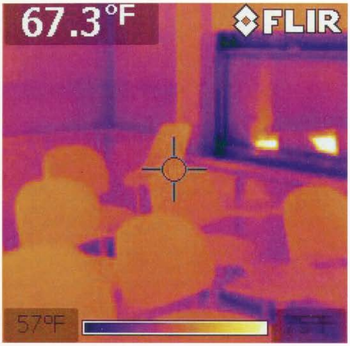

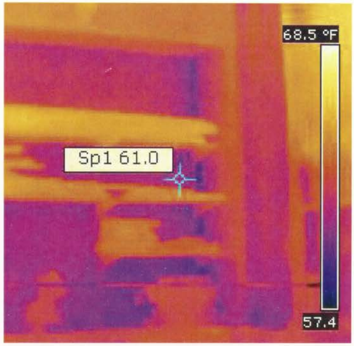

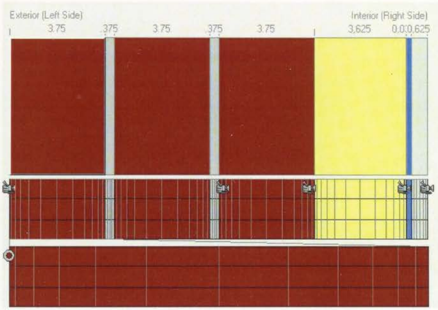

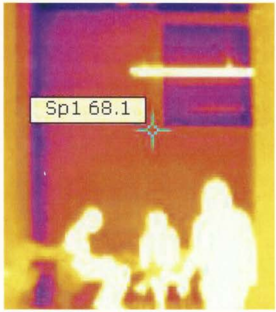

Building Case Studies:

The application of infrared imaging & hygrothermal modeling in historic brick buildings

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TABLE OF CONTENTS

CASE STUDY BUILDINGS AND RESEARCH APPLICATIONS

In conjunction with the document, "An Energy Reduction Strategy and Retrofit Guidebook for Owners of Historic Brick Buildings: Weighing the Values and Implications of Energy Efficiency and Historic Integrity", primary research in the form of infrared imaging and hygrothermal modeling was conducted for five case study buildings to determine the potential durability impacts of the retrofits that were performed in each of the buildings. The application of infrared scanning and hygrothermal modeling was predominately intended as an exercise to determine their relevancy for historic buildings in terms of usability and accuracy. Table One outlines the retrofit methods employed in each of the five cased study buildings.

Table One

Building Name	Fenton Hall 	Peterson Hall 	Anstett Hall 	Lincoln Hall 	Shattuck Hall 
Location	Eugene, OR	Eugene, OR	Eugene, OR	Portland, OR	Portland, OR
Year Built	1906	1916	1921	1911	1914
Year Renovated	2011	2007	2010	2011	2010
Renovation Budget	$8 million	$6.3-6.6 million	$6.5 million	$29 million	$13.6 million
Building Height	3-story	3-story	3-story	4-story	3-story
Square Footage	20,000 sf	19,000 sf	19,000 sf	145,000 sf	60,000 sf
Construction Type	Unreinforced load-bearing brick	Unreinforced load-bearing brick	Unreinforced load-bearing brick	Unreinforced load-bearing brick	Unreinforced load-bearing concrete with brick veneer
Envelope	Metal stud wall with steel-backed gypsum board, no insulation	Metal stud wall with rigid polystyrene insulation on 1st floor and fiberglass batt insulation on upper floors	Metal stud wall with rigid polystyrene insulation on 1st floor and fiberglass batt insulation on upper floors	Stucco over load-bearing brick wall	Stucco over load-bearing concrete wall
Renovation Description	Air sealing, cool roof, chilled beam cooling system, utilizing return chilled water to reduce building cooling loads, awning installation, insulated glazing, floor insulation	Air sealing, roof insulation, cool roof, wall insulation, insulated glazing, lighting upgrades, daylighting, HVAC upgrades, occupancy sensors	Air sealing, roof insulation, cool roof, wall insulation, insulated glazing, lighting upgrades, daylighting, HVAC upgrades, occupancy sensors	Air sealing, roof insulation, HVAC upgrades, high performance windows, daylighting (restored light wells)	Air sealing, roof insulation, radiant heating and cooling ceiling panels, HVAC upgrades, daylighting upgrades (restored windows and light wells), occupancy sensors, energy efficiency lighting

INFRARED IMAGING

Infrared (IR) imaging was used to ascertain the temperature differentials in the five case study buildings in order to determine the effectiveness of the retrofitting techniques conducted in each building.

Table Two: *Contextual Data*

Building Name	Fenton Hall	Peterson Hall	Anstett Hall	Lincoln Hall	Shattuck Hall
Outside Temperature on Day of IR Imaging	45° F (cloudy)	52° F (cloudy)	52° F (cloudy)	50° F (cloudy)	50° F (cloudy)
Date of IR Imaging	02/22/13	02/13/13	02/13/13	02/06/13	02/06/13
Time of IR Imaging	8am to 9am	1pm to 2pm	1pm to 2pm	1pm to 3pm	1pm to 3pm
Indoor Average Set-point Temperature*	68-70° F	68-70° F	68-70° F	68-70° F	68-70° F
# of Rooms Analyzed**	3	3	3	3	3

*The average building temperature indicated is the set point range for the building, however room-by-room, the temperature can differ by up to five degrees Fahrenheit on a daily and hourly basis, depending on occupant comfort level.

**The rooms scanned largely depended on whether or not the room was being occupied (particularly for classes or meetings). In Fenton Hall, the researcher did not to set up a formal tour of the building for various reasons, and consequently was limited to the rooms that were unoccupied and accessible. This is also the reason why the building was scanned earlier in the day than the other buildings.

Due to the mass of the masonry wall assemblies, infrared imaging conducted on the outside of the five case study buildings was not useful in determining how the interior surface of the exterior wall was affected by insulating or not insulating. Thus, the conclusions made regarding the infrared scanning were based on the data collected in the interior of the buildings.

Each room in each of the buildings was typically imaged more than one time because the focus of the camera was fixed and could not be adjusted to capture the entire room in one image. A FLIR (Forward Looking Infrared Radiometer) infrared camera was used.

Methodology
The following is a description of steps taken to determine the temperature differentials of the five case study buildings. Appendix A includes the FLIR report that contains the raw infrared data.

- The infrared software program, FLIR Tools was used
- General data required for each image (this data remained consistent across each of the five buildings)
  - Emissivity: 0.95 (all of the interiors of the buildings were painted with latex paint, which has an emissivity of approximately 0.95; materials that were in the images that had a significantly different emissivity (i.e. wood panels) were not included in the analysis
  - Atmospheric temperature: 68° F (building set points ranged between 68° F and 70° F, which does not significantly affect the infrared image data)
  - Relative Humidity: estimated to be about 45% (only a +/- 0.1°F difference if set to 40% or 50%) the relative humidity was chosen according to simulations from a Portland study conducted by Smegal and Straube – *High-R Walls for the Pacific Northwest – A Hygrothermal Analysis of various Exterior Wall Systems*[1]
  - Distance: 15'
- The approximate distance the image was taken from was determined and grouped into images taken from 10' and 15'
  - There were too few images to make a group for images that were taken from 20'+

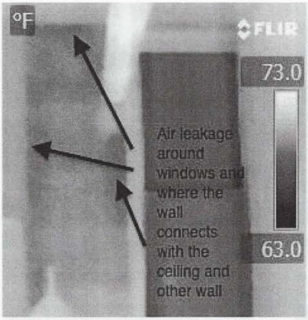
1 Jonathan Smegal and John Straube, *High-R Walls for the Pacific Northwest – A Hygrothermal Analysis of various Exterior Wall Systems* (Westford, MA: Building Science Press, 2010), 14.

- The images taken from approximately 15' were chosen to study because they included the most area and therefore more information to extract from
- Because the study only included images taken from approximately 15', not all of the rooms that were documented originally were part of the analysis
- In addition to the criteria that images had to be taken from about 15' away in order to be included, the following parameters were set:
    - The image must have included at least 2 visible stud bays (most of the images included more than 2 study bays, however some were covered by various objects and therefore could not be accurately read)
    - The image must also have included the part of the room where the wall and the floor met, where the wall and the ceiling met, where two walls met, or all of the above, in order to have a fairly consistent number of opportunities for hot and cold areas to occur across the case study buildings
- Images that fit my criteria
    - All of the buildings had four representative images analyzed covering three different rooms
    - One room in each building had two images included
- Analysis
    - **It did not work to black out parts of the image the author did not want to analyze (i.e. through Photoshop or Illustrator) because FLIR Tools could not read the altered images
    - Boxes, circles, spots and thick lines were used to cover as much of the wall space as possible in each image
    - Each box, circle and line includes a high and a low temperature point for the area of the wall the shape covers; each spot includes one temperature point that is an average of the area included in the spot
    - All of the IR images and photos of what the IR image displays were taken into Photoshop and corrected for perspective
    - From the plans and building sections, an estimate of the area covered in the IR image was produced; The plans/sections were brought into Illustrator and the measurement tool was used to find the area of the portion of each room displayed in the IR image
    - A consistent grid overlay (1" by 1") was used in Photoshop to estimate the number of grid cells that covered the IR image that was corrected for perspective (The ceilings and floors were not included because the ceiling and floor were not accounted for in estimating the area covered by the IR image)
    - An estimation was made for the number of grid cells that were included in each area box; for the area boxes that were difficult to read when corrected for perspective, the image prior to being corrected was used as a reference to come up with an estimated number of grid cells in each box
    - The number of grid cells in each area box was divided by the total number of grid cells covering the IR image to come up with a percentage of area the box covered in each image
    - The percentage of the area each box covered was multiplied by the total area of each IR image to get an estimate of how much area each box counted for
    - The area of each box was then used to produce a weighted average temperature for the portion of the room in each IR image
    - A mean, minimum and maximum temperature was then plotted for each building according to the weighted averages for each room (see Figure Eleven)

General Findings

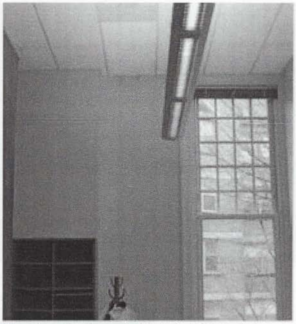
- All of the buildings experienced some air leakage and heat loss at the corners where two exterior walls, an exterior and interior wall, or an exterior wall and floor/ceiling met
- Areas surrounding windows were a source of air leakage and heat loss in a majority of the rooms imaged
- Thermal bridging was evident in the buildings with insulated stud walls (Anstett Hall and Peterson Hall), but not the building with un-insulated, ventilated stud walls (Fenton Hall)
- No conclusions could be made regarding moisture issues in any of the buildings

Figure One



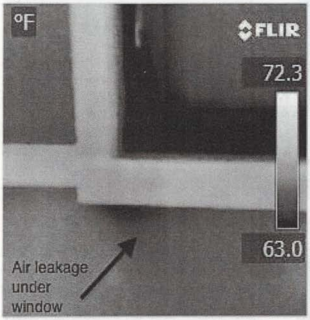
Lincoln 137. Image by Evanne St. Charles.

Figure Two



Lincoln 137. Photo by Evanne St. Charles.

Figure Three

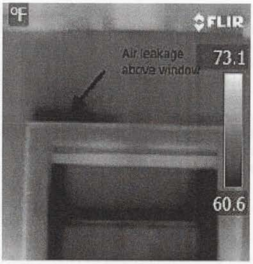


Shattuck C202. Image by Evanne St. Charles.

Figure Four

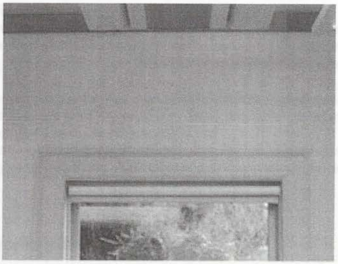
Shattuck C202. Photo by Evanne St. Charles.

Figure Five



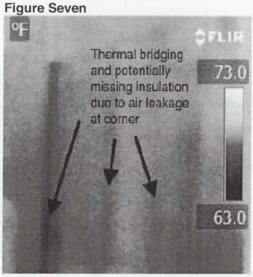
Fenton 119. Image by Evanne St. Charles.

Figure Six



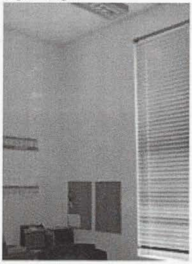
Fenton 119. Photo by Evanne St. Charles.

Figure Seven



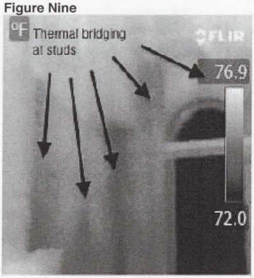
Peterson 302B. Image by Evanne St. Charles.

Figure Eight



Peterson 302B. Photo by Evanne St. Charles.

Figure Nine



Anstett 291C. Image by Evanne St. Charles.

Figure Ten

Anstett 291C. Photo by Evanne St. Charles.

Analysis Results

- Both insulated buildings (Peterson and Anstett) have higher overall temperatures than the three uninsulated case study buildings (see Figure Eleven)
- The range of wall assembly temperatures is smaller in Peterson, Anstett and Fenton. In Peterson and Anstett, this is likely due to the insulation, whereas in Fenton, it could possibly be due to the ventilated stud wall maintaing a more consistent temperature throughout the wall (both Lincoln and Shattuck do not have stud walls)
- The wall assemblies in Anstett maintain higher temperatures than in Peterson, even though they were retrofitted the same way. This could possibly due to the greater number of areas that seem to be missing insulation and/or experienced air leakage within the assembly (see Appendix A)
- Although Shattuck is not insulated (like Lincoln and Fenton), Shattuck maintains higher temperatures than Lincoln and Fenton, possibly because of the greater insulating value of concrete compared to brick

Figure Eleven

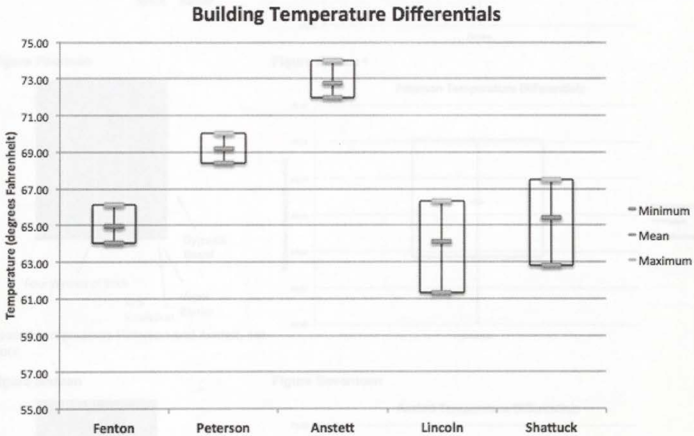


Figure Twelve

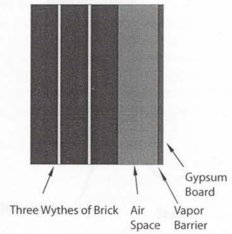


Figure Thirteen

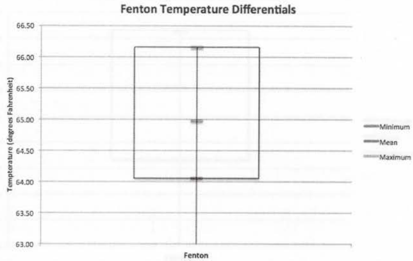
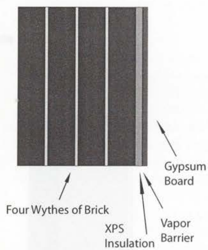


Figure Fourteen



Assembly represents Peterson and Anstett, 1st Floor

Figure Fifteen

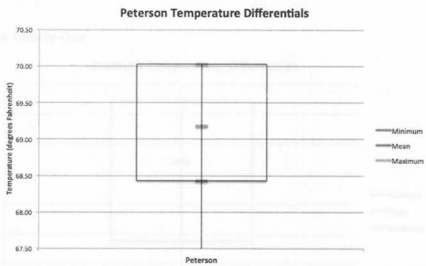
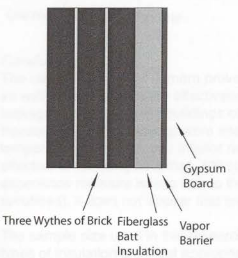


Figure Sixteen



Assembly represents Peterson and Anstett, 1st Floor

Figure Seventeen

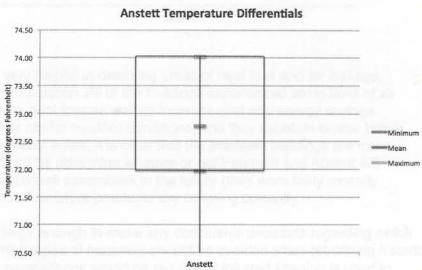


Figure Eighteen

Figure Nineteen

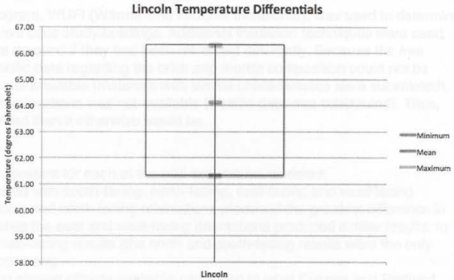


Figure Twenty

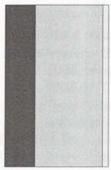
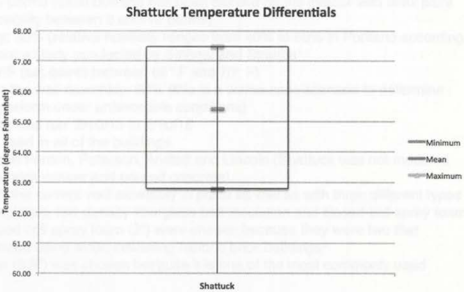


Figure Twenty-One



Conclusions

The use of the infrared camera proved to be very helpful at detecting areas of heat loss and air leakage, as well as determining the effectiveness of the insulation. All of the buildings experienced some level of air leakage. If alleviated, the buildings could reduce heat loss as well as increase cost and energy savings. Because all of the buildings were imaged under similar weather conditions, and they maintain similar indoor temperature set points and interior relative humidity levels, it is clear that the insulated buildings are more effective at reducing heat loss. Although it cannot be determine whether or not Peterson and Anstett will experience moisture issues due to their insulated wall assemblies in the future (they were fairly recently retrofitted), it does not appear that any significant moisture problems are occuring currently.

The sample size used in this research is not large enough to make any conclusive decisions regarding which types of insulation are most appropriate or which types of materials should be avoided when retrofitting historic brick walls. Thus, further research with more comparisons would be required if infrared imaging is used to make recommendations concerning the suitabilty of various retrofit methods.

HYGROTHERMAL MODELING

The hygrothermal modeling software program, WUFI (Wärme Und Feuchte Instationär), was used to determine the risk of moisture accumulation in the five case study buildings. Additional insulation techniques were used to model how each of the buildings might respond if they had been retrofitted differently. Because the free software version of WUFI was used, specific data regarding the brick and mortar composition could not be inputted, certain types of materials were not available (materials with similar characteristics were substituted), and weather data for the particular building locations was not available (Seattle data was substituted). Thus, the accuracy of the modeling is more limited than it otherwise would be.

Methodology

- The following features remained constant for each of the wall assemblies modeled:
  - Each assembly was modeled with south-facing, north-facing, east-facing and west-facing orientations; the south-facing and north-facing orientations produced the greatest difference in relative humidity levels, while the east and west-facing orientations produced similar results, in between the north and south-facing results (the north and south-facing results were the only graphs included in this document)
  - Climate: Seattle (this is the closest climate available compared to what Eugene and Portland have); each assembly was modeled with a cold year and a warm year, however the difference between the two years was insignificant (thus, only the cold year results were included in the analysis portion)
  - Indoor conditions
    - Interior finish: 10 perms (each building has been painted on the interior with latex paint that has a permeability between 8 and 10 perms)
    - Relative humidity: 50% (relative humidity ranges from 40% to 60% in Portland according to simulations from a study conducted by Smegal and Straube[1]
    - Temperature: 69°F (set points between 68° F and 70° F)
  - Initial relative humidity in the wall assembly: 80% (this is a worse case scenario to determine how the building would perform under unfavorable conditions)
  - Time period the modeling was run: 2/10/13 to 2/10/18
  - WUFI's "Old Brick" was used in all of the buildings
  - Type N mortar was used in Fenton, Peterson, Anstett and Lincoln (Shattuck was not modeled with mortar between the brick veneer and poured concrete)
- Each building was modeled with the current wall assembly in place as well as with three different types of insulation – cellulose fiber insulation, low density fiberglass batt insulation and closed cell spray foam
  - Cellulose (3.5") and closed cell spray foam (2") were chosen because they were two that professionals recommended using when insulating historic brick buildings[2]
  - Fiberglass batt insulation (3.5") was chosen because it is one of the most commonly used insulation types
  - The models with cellulose and fiberglass batt insulation were modeled with a 5 perm vapor retarder (Class III vapor retarder) a 1 perm vapor retarder (Class II) and a 0.07 perm vapor barrier (Class I); the 5 perm and 0.07 perm vapor retarders produced the greatest differences in relative humidity levels (thus, only the 5 perm and 0.07 perm vapor retarder results were included in this document)
- Peterson and Anstett have essentially the same wall assemblies – the wall is four wythes thick with extruded polystyrene insulation on the 1st floor, and the wall is three wythes thick with fiberglass batt insulation on the second and third floors; the modeling of a four-wythe brick wall applies to the 1st floor of Peterson and Anstett
- Anstett and Peterson (2nd and 3rd floors), and Fenton and Lincoln are all composed of a brick wall assembly that is three wythes thick with different interior treatments; the modeling for a three-wythe brick wall applies to all four of the buildings

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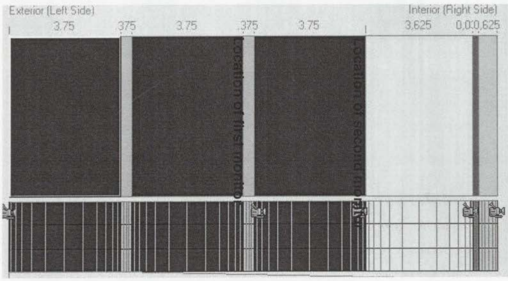
1 Jonathan Smegal and John Straube, *High-R Walls for the Pacific Northwest – A Hygrothermal Analysis of various Exterior Wall Systems* (Westford, MA: Building Science Press, 2010), 14.

2 Interviews with historic preservationists, architects, engineers and building science professionals, December 20, 2012 to March 21 2013.

- Shattuck was modeled with two different types of concrete (aerated concrete and concrete brick) because poured concrete was not an option in WUFI; it is assumed that the poured concrete at Shattuck has properties somewhere in between the aerated concrete and the concrete brick (the aerated concrete is very porous, permeable and less dense, while the concrete brick is dense and less permeable), due to the age of the concrete
- Gypsum-based stucco is not an option in WUFI (both Lincoln and Shattuck have stucco on the interior surface of the brick/concrete wall assembly), and the other stuccos available do not have comparable properties; thus, gypsum board and a 10 perm membrane were used to simulate similar conditions as what might be experienced with the gypsum-based stucco
- Each modeled section is paired with four different graphs representing two different locations in the wall (see Figure Twenty-Two) and two different orientations (north and south)
    - First monitor position: 7.5" to 8.5" into the assembly is the approximate location of where the wood joists are located in Fenton (and it is assumed that this is the approximate location for joists in Anstett and Peterson; Lincoln and Shattuck have concrete frames; the first monitor position in Shattuck is located around 4" to determine how the brick veneer reacts to the aerated concrete vs. the concrete brick)
    - Second monitor position: The location at the interior surface of the brick (between the brick and air space/insulation)

***A note on embedded framing members**: Although WUFI is not able to model framing, the moisture content at the approximate location of where the joist pocket would be is indicated in the analysis. The behavior of embedded beams and joists is not sufficiently understood.[3] In most cases, a relative humidity of up to 90% is accetable in wood, however it depends on a number of factors, including the availability of moisture, the temperature, etc.[4] The threshold for metal corrosion begins at approximately 80% relative humidity, however it can range between 70% and 99% relative humidity depending on the type of metal as well as external factors.[5] More information regarding the research currently being conducted on the susceptibility of wood and metal members in masonry walls can be found in Appendix B of "An Energy Reduction Strategy and Retrofit Guidebook for Owners of Historic Brick Buildings: Weighing the Values and Implications of Energy Efficiency and Historic Integrity".

Figure Twenty-Two



3 John Straube, Kohta Ueno, and Christopher Schumacher, *Internal Insulation of Masonry Walls: Final Measure Guideline* (Westford, MA: Building Science Press, 2007), iii.

4 Jasha Kistler (The Facade Group), interview by author, April 30, 2013.

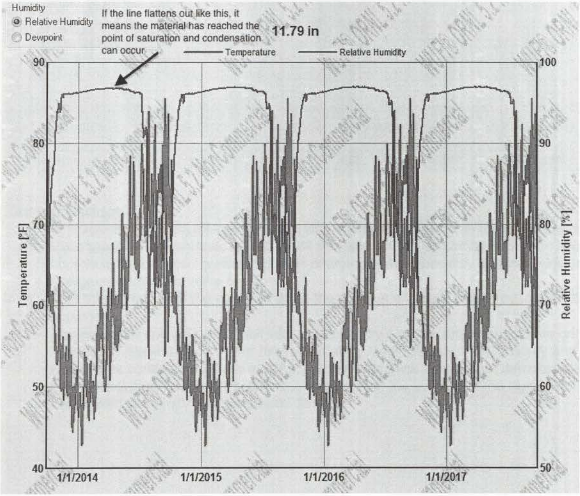
5 William B. Rose, *Water in Buildings: An Architect's Guide to Moisture and Mold* (New York: John, Wiley & Sons, 2005), 93.

Understanding the Graphs[6]

- In general, if the relative humidity is above 80% throughout most of the year, moisture accumulation is most likely occurring (this is not as much of a problem in walls that can dry to the interior and exterior, and are uninsulated/have mold-resistant insulation because there is no potential for mold growth)
- If the relative humidity is above 85% for most of the year in the wood/metal joist pockets, the joists could potentially rot or corrode
- The further in the moisture accumulation is occurring, the less likely the materials are able to dry (if insulation and/or impermeable membranes are in place)
- If the relative humidity line is fairly flat, this means the material has reached its point of saturation, and condensation can occur (see Figure Twenty-Three)
- If the relative humidity line is going up with time, the potential for moisture accumulation is also going up (thus, even if moisture is not a problem now, it could cause problems in the future) (see Figure Twenty-Four)

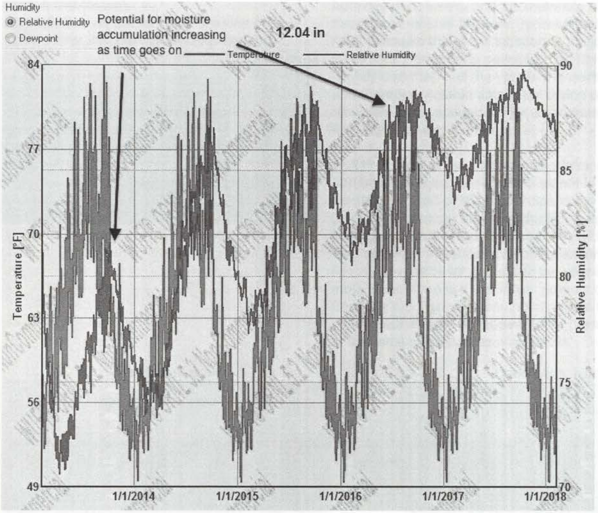
Although the graphs are helpful at discerning whether or not moisture accumulation might be an issue, there are a number of factors that come into play (that cannot be determined by this modeling - i.e. air tightness of the envelope, management of rain penetration, detailing of connections between wall and framing, etc.) that will affect whether moisture build up is/will become problematic.

Figure Twenty-Three



6 Jasha Kistler (The Façade Group), interview by author, April 30, 2013.

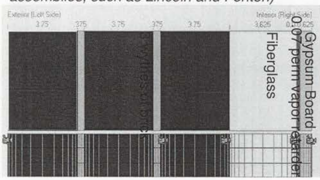
Figure Twenty-Four



General Findings

- In most instances, WUFI indicated that less drying is possible with the addition of insulation
- Even though both cellulose and fiberglas insulation indicated similar maximum humidity levels, the fiberglass experienced greater amounts of drying overall (possibly due to the lower density of the fibergalss compared to the cellulose)
- With the exception of the concrete brick, the addition of closed cell spray foam indicated less drying potential
- The assembly comprised of brick veneer backed by aerated concrete/concrete brick seemed to be less affected by the insulation (lower relative humidity levels between the masonry and insulation) than the assemblies comprimsed soley of brick; the concrete brick in particular demonstrated relative humidity levels consistently below 90% (with the exception of the addition of the closed cell spray foam, which had maximum humidity levels around 95%)

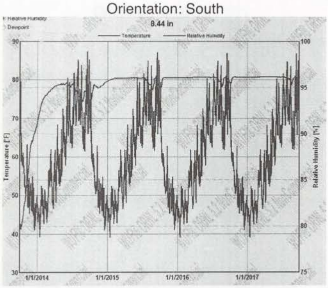
Anstett and Peterson Current Wall Assembly (2nd & 3rd floors)
(hypothetical retrofit for other 3-wythe brick assemblies, such as Lincoln and Fenton)

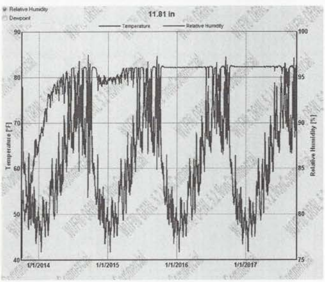


8.44": The **south-facing** model shows very high relative humidity (RH) levels, and the materials are saturated throughout most of the year (represented by the flat RH line). Because this is the location of the joist pocket, wood rot or steel corrosion is possible. The RH is above 80% for slightly less than half the year in the **north-facing** model, and there is a notable amount of drying occurring. The RH levels are likely acceptable for wood framing, but could be a little high for steel members.

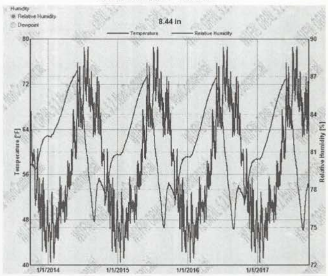
11.81": Although the surface of the brick (between insulation and brick) is drying out to some extent in the **south-facing** model (indicated by the sharp dips in the RH line during the spring and summer months), the RH is approximately 95% throughout most of the year, and the RH line flattens out. This indicates that moisture condensation is possible. The RH is above 80% for about half the year in the **north-facing** model, and there is a significant amount of drying occurring. Because mold growth does not occur on fiberglass and condensation does not appear to be present, the conditions at this location should be acceptable.

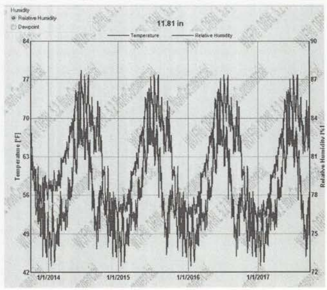
Orientation: South



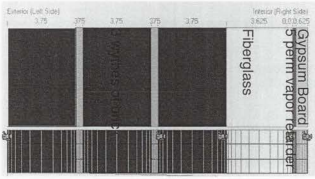


Orientation: North





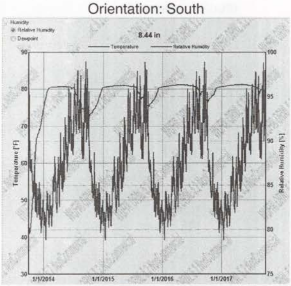
Hypothetical retrofit for 3-wythe brick assemblies, such as Anstett and Peterson (2nd & 3rd floors), Lincoln and Fenton

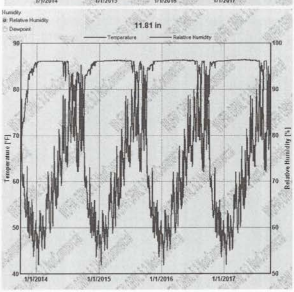


8.44": Although there is slightly more drying occurring than with the 0.07 vapor barrier, the **south-facing** model still shows very high RH levels, and the materials are saturated throughout most of the year. Because this is the location of the joist pocket, wood rot or steel corrosion is possible. The **north-facing** model shows higher RH levels than the same assembly with a 0.07 perm vapor barrier, however drying is still occurring, and the RH is never above 95%. Rot and corrosion is possible, but not as likely as the south-facing model.

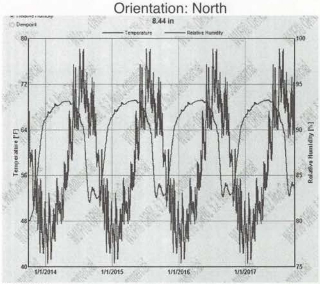
11.81": Although the surface of the brick (between insulation and brick) is drying out to some extent in the **south-facing** model (indicated by the sharp dips in the RH line during the spring and summer months), the relative humidity is approximately 95% throughout most of the year, and the line flattens out. This indicates that condensation is possible. The **north-facing** model shows higher RH levels than with the 0.07 perm vapor barrier, however drying is still occurring. Because mold growth does not occur on fiberglass and condensation does not appear to be present (no flat RH line), the conditions at this location should be acceptable.

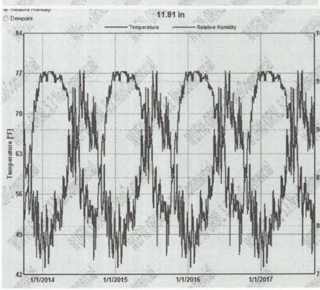
Orientation: South



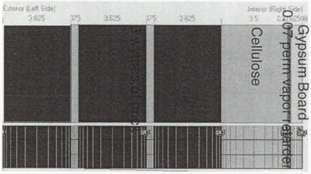


Orientation: North





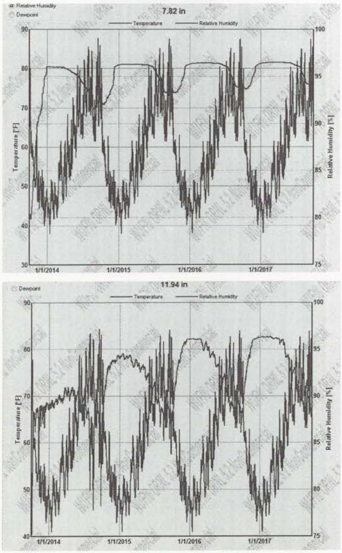
Hypothetical retrofit for 3-wythe brick assemblies, such as Anstett and Peterson (2nd & 3rd floors), Lincoln and Fenton



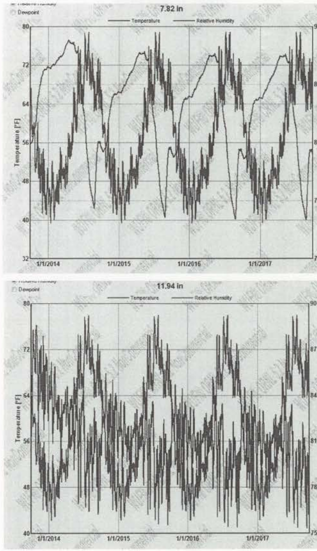
7.82": The **south-facing** model shows high RH levels, with little drying occurring and points of saturation. Because this is the location of the joist pocket, wood rot or steel corrosion is possible. The RH is above 80% for about half the year in the **north-facing** model, and there is a notable amount of drying occurring. The RH levels are likely acceptable for wood framing, but could be a little high for steel members.

11.94": Although the surface of the brick (between insulation and brick) is drying out to some extent in the **south-facing** model, the RH is between 90% and 95% throughout most of the year, and it is rising as time goes on. This indicates that even if moisture accumulation is not a problem now, it may be in the future. High RH levels are also more problematic with cellulose because of the potential for mold growth. The RH level in the **north-facing** model ranges between 75% and 85% for most of the year. Although mold growth could occur on the cellulose, the materials are drying out and the RH levels should be acceptable at this location.

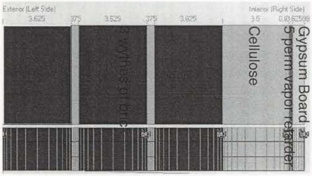
Orientation: South



Orientation: North



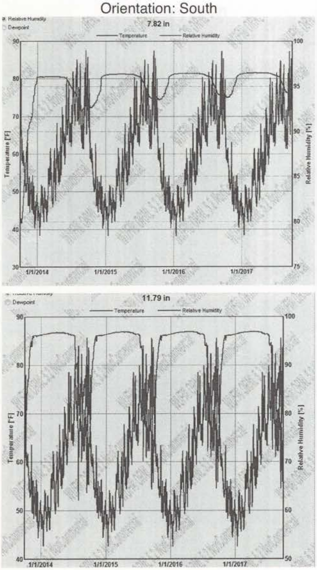
Hypothetical retrofit for 3-wythe brick assemblies, such as Anstett and Peterson (2nd & 3rd floors), Lincoln and Fenton



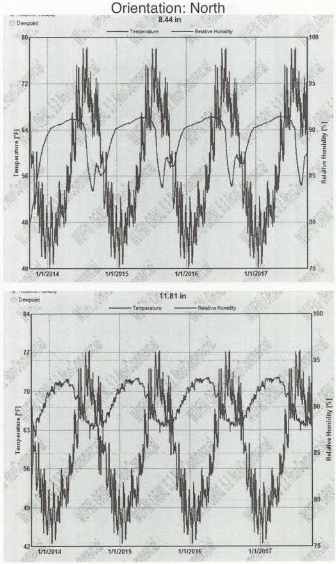
7.82"/8.44": The **south-facing** model shows high RH levels, with little drying taking place and some saturation occurring. Because this is the location of the joist pocket, wood rot or steel corrosion is possible. The **north-facing** model shows higher RH levels than the same assembly with a 0.07 perm vapor barrier, however drying is still occurring, and the RH is never above 95%. Rot and corrosion is possible, but not as likely as the south-facing model.

11.79"/11.81": Although the surface of the brick (between insulation and brick) is drying out for short periods in the **south-facing** model, the RH is approximately 95% throughout most of the year, and the line flattens out. This indicates that moisture accumulation and condensation is possible, which is more problematic with cellulose because it is not mold resistant. The RH is above 90% for about half the year in the **north-facing** model, and little drying is occurring. This could be problematic due to the potential for mold growth with cellulose.

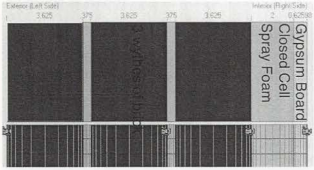
Orientation: South



Orientation: North



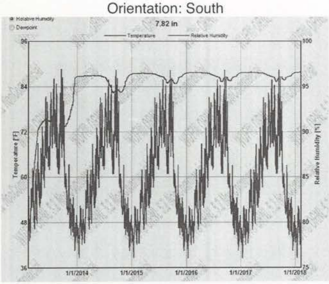
Hypothetical retrofit for 3-wythe brick assemblies, such as Anstett and Peterson (2nd & 3rd floors), Lincoln and Fenton



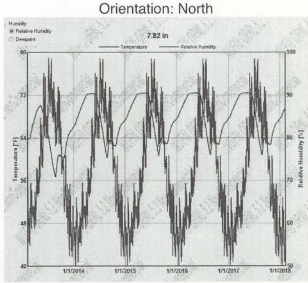
7.82": The **south-facing** model shows high relative humidity (RH) levels throughout the entire year with very little drying occurring. Because this is the location of the joist pocket, wood rot or steel corrosion is possible. The RH is above 80% for most of the year in the **north-facing** model, however there is a notable amount of drying occurring. The RH levels are likely acceptable for wood framing, but could be a little high for steel members.

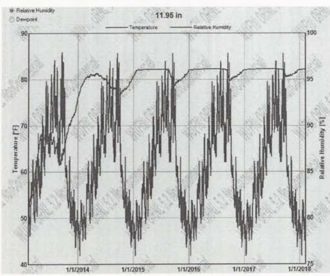
11.95": The surface of the brick (between insulation and brick) is experiencing very little drying in the **south-facing** model, the RH is approximately 96% throughout most of the year, and the line flattens out. This indicates that moisture accumulation and condensation is possible. The RH is above 80% for most of the year in the north-facing model, however there is a significant amount of drying occurring. Because mold growth does not occur on closed cell spray foam and condensation does not appear to be present, the conditions at this location should be acceptable.

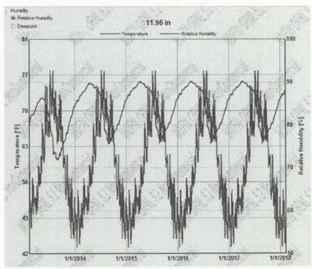
Orientation: South



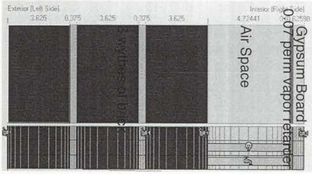
Orientation: North







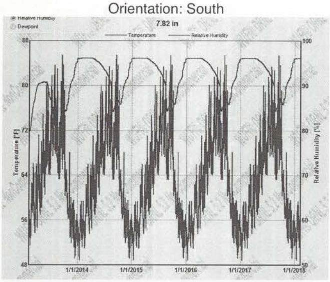
Fenton Current Wall Assembly *(the .07 perm vapor retarder is being used to simulate similar conditions as sheet metal - sheet metal was not an option in WUFI)*



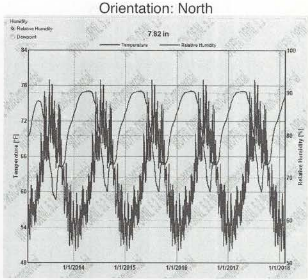
7.82": The **south-facing** model shows RH levels above 90% for more than half the year, however more drying is occurring than in the south-facing models with insulation. Because this is the location of the joist pocket, wood rot or steel corrosion is possible, but not as likely as with insulation. The RH is above 80% for about half the year in the **north-facing** model, and there is a notable amount of drying occurring. The RH levels are likely acceptable for wood framing, but could be a little high for steel members.

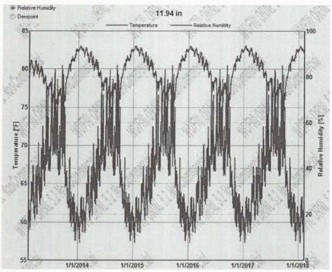
11.94": The RH levels at the surface of the brick (at the air space) in the **south-facing** model are above 80% for about half the year, and there is a significant amount of drying occurring. Moisture accumulation should not be a problem at this location. The RH is above 80% for about half the year in the **north-facing** model, and there is a significant amount of drying occurring. Because mold growth is not an issue and condensation does not appear to be present, the conditions at this location should be acceptable.

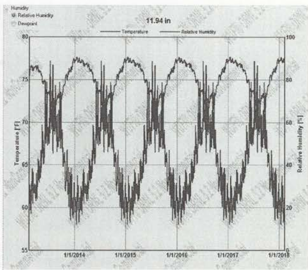
Orientation: South



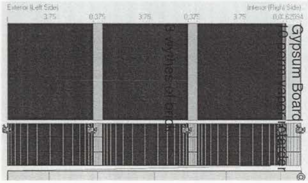
Orientation: North







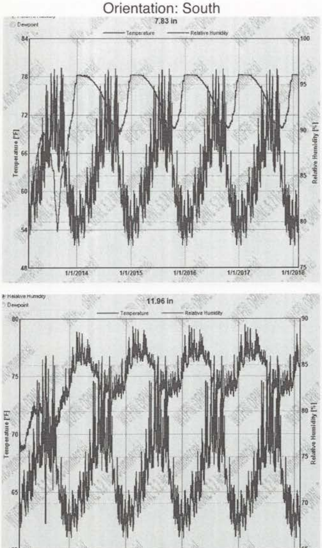
Lincoln Current Wall Assembly *(gypsum board and 10 perm vapor retarder used as substitute for gypsum-based stucco because no analagous stucco exists in WUFI)*



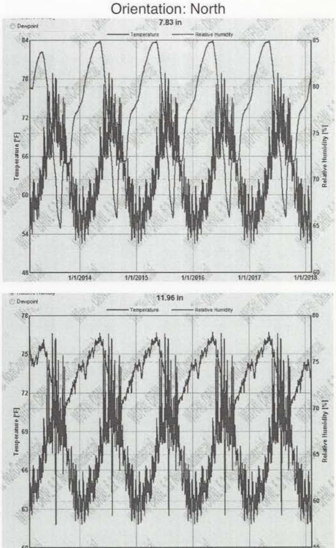
7.83": The **south-facing** model shows high relative humidity levels, ranging between 90% and 96% throughout the year. Because this is the location of the joist pocket, wood rot or steel corrosion is possible. The RH is above 80% for slightly less than half the year in the **north-facing** model, and there is a notable amount of drying occurring. The RH levels are likely acceptable for wood framing, but could be a little high for steel members.

11.96": The RH is above 80% for most of the year in the **south-facing** model, however drying is still occurring and condensation does not seem to be a problem. Because there is not potential for mold growth at this location, moisture should not be a problem. The RH is never above 80% in the **north-facing** model, and a significant amount of drying is occurring. Moisture accumulation should not be a problem at this location.

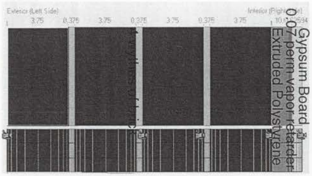
Orientation: South



Orientation: North



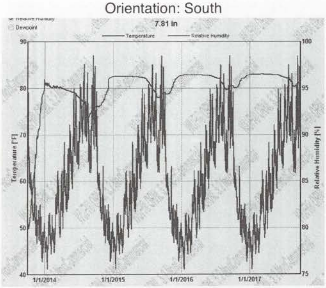
Peterson and Anstett Current Wall Assembly (1st floor)

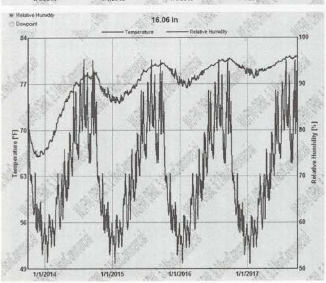


7.81": The **south-facing** model shows high relative humidity (RH) levels throughout the entire year with very little drying and some saturation occurring. Because this is the location of the joist pocket, wood rot or steel corrosion is possible. The RH is above 80% for more than half of the year in the **north-facing** model, however there is a notable amount of drying occurring. The RH levels are likely acceptable for wood framing, but could be a little high for steel members.

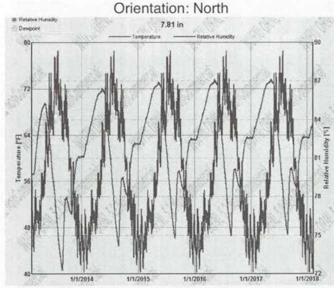
16.06": Although the surface of the brick (between insulation and brick) is drying out to some extent in the **south-facing** model, the RH is above 90% throughout most of the year, and the RH is rising over the time period. This indicates that even if moisture accumulation is not a problem now, it could be in the future. The RH remains below 80% most of the year, and a significant amount of drying is taking place in the **north-facing** model. Moisture accumulation should not be a problem at this location.

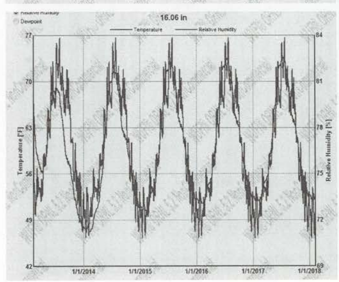
Orientation: South



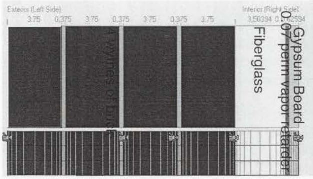


Orientation: North





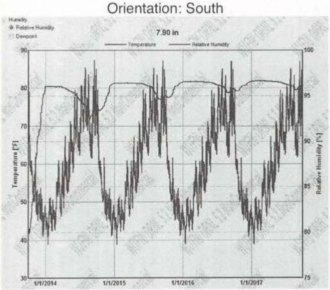
Hypothetical retrofit for 4-wythe brick assemblies, such as Peterson and Anstett (1st floor)



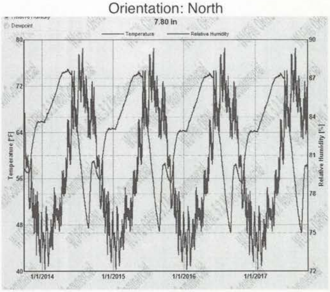
7.80": The **south-facing** model shows high RH levels throughout the entire year with very little drying and some saturation occurring. Because this is the location of the joist pocket, wood rot or steel corrosion is possible. The RH is above 80% for about half the year in the **north-facing** model, and there is a notable amount of drying occurring. The RH levels are likely acceptable for wood framing, but could be a little high for steel members.

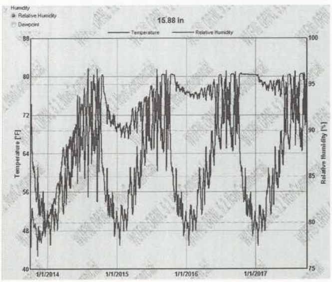
15.88"/16.05": Although the surface of the brick (between insulation and brick) is drying out to some extent in the **south-facing** model, the RH is above 90% throughout most of the year, and the RH is slightly rising over the time period. This indicates that even if moisture accumulation is not a problem now, it could be in the future.The RH never goes above 85% in the **north-facing** model, and there is a significant amount of drying occurring. Because mold growth does not occur on fiberglass and condensation does not appear to be present, the conditions at this location should be acceptable.

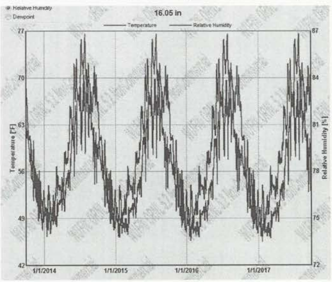
Orientation: South



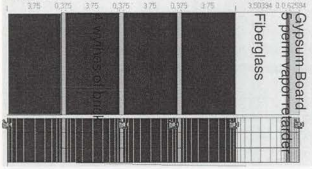
Orientation: North







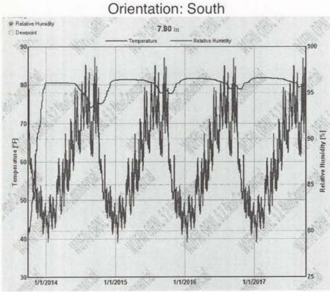
Hypothetical retrofit for 4-wythe brick assemblies, such as Peterson and Anstett (1st floor)

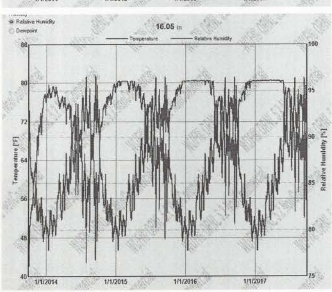


7.80": The **south-facing** model shows high relative humidity (RH) levels throughout the entire year with very little drying and some saturation occurring. Because this is the location of the joist pocket, wood rot or steel corrosion is possible. The RH is above 80% the entire year in the **north-facing** model, however the levels only slightly reach over 90%, and there is a notable amount of drying occurring. Rot and corrosion is possible, but not as likely as in the south-facing model.

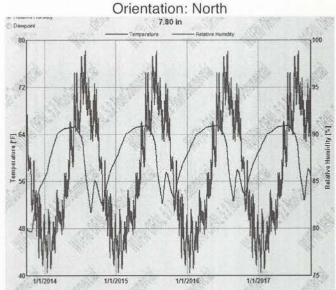
16.05": Although the surface of the brick (between insulation and brick) is drying out to some extent in the **south-facing** model (indicated by the sharp dips in the RH line during the spring and summer months), the RH is approximately 96% throughout most of the year, and the line flattens out. This indicates that moisture accumulation and condensation is possible. Although the RH is above 80% for most of the year in the **north-facing** model, there is a significant amount of drying occurring. Because mold growth does not occur on fiberglass and condensation does not appear to be present, the conditions at this location should be acceptable.

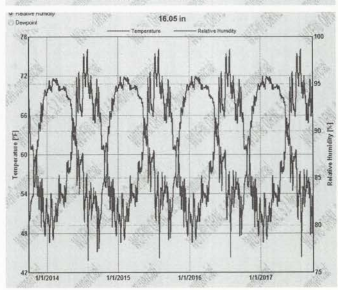
Orientation: South



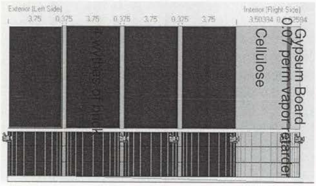


Orientation: North





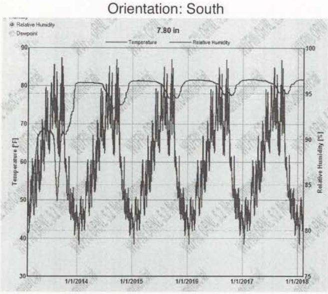
Hypothetical retrofit for 4-wythe brick assemblies, such as Peterson and Anstett (1st floor)

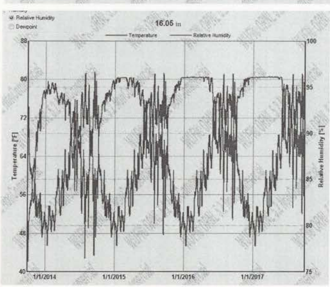


7.80": The **south-facing** model shows high RH levels throughout the entire year with very little drying and some saturation occurring. Because this is the location of the joist pocket, wood rot or steel corrosion is possible. The RH is above 80% for most of the year in the **north-facing** model, however the levels never reach over 90%, and there is a notable amount of drying occurring. The RH levels are likely acceptable for wood framing, but could be a little high for steel members.

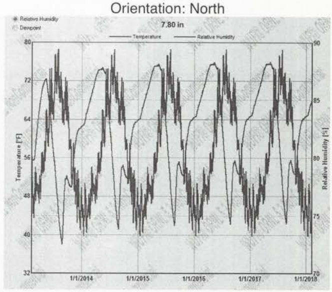
16.05": Although the surface of the brick (between insulation and brick) is drying out to some extent in the **south-facing** model, the RH is approximately 96% throughout most of the year, and the line flattens out. This indicates that moisture accumulation and condensation is possible. This is a more significant problem with cellulose because of the potential for mold growth. The RH is above 80% for slightly less than half the year in the **north-facing** model, and there is a significant amount of drying occurring. Although more of a problem with cellulose than fiberglass, the RH levels should still be low enough most of the year to prevent mold growth.

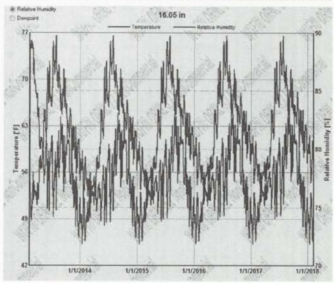
Orientation: South



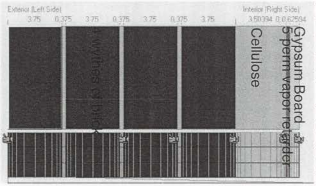


Orientation: North





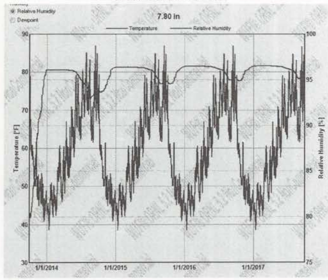
Hypothetical retrofit for 4-wythe brick assemblies, such as Peterson and Anstett (1st floor)

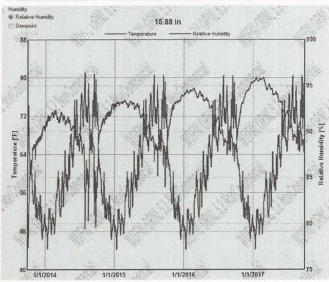


7.80": The **south-facing** model shows high relative humidity (RH) levels throughout the entire year with very little drying occurring. Because this is the location of the joist pocket, wood rot or steel corrosion is possible.The RH is above 80% for most of the year in the **north-facing** model, however the levels only slightly reach over 90%, and there is a notable amount of drying occurring. Rot and corrosion is possible, but not as likely as in the south-facing model.

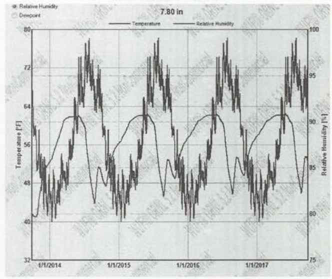
15.88"/16.05": Although the surface of the brick (between insulation and brick) is drying out to some extent in the **south-facing** model, the RH is above 90% throughout most of the year, and the RH is rising over the time period. This indicates that even if moisture accumulation is not a problem now, it could be in the future. Although there is drying occurring, the RH is above 80% for almost the entire year in the **north-facing** model. This could be an issue with cellulose insulation due to the potential for mold growth.

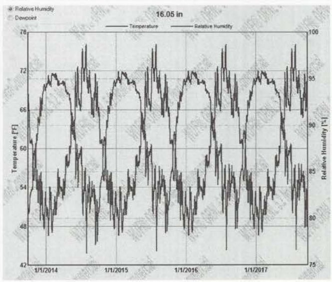
Orientation: South



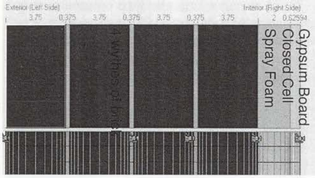


Orientation: North





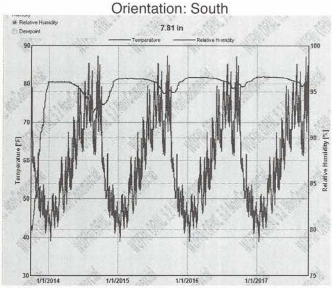
Hypothetical retrofit for 4-wythe brick assemblies, such as Peterson and Anstett (1st floor)

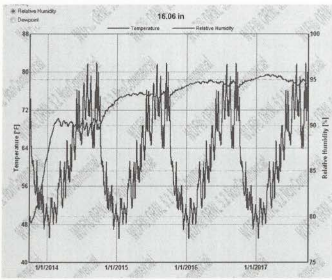


7.81": The **south-facing** model shows high relative humidity (RH) levels throughout the entire year with very little drying occurring. The RH line becomes flat, indicating the material has reached its saturation point. Because this is the location of the joist pocket, wood rot or steel corrosion is possible. The RH is above 80% for more than half of the year in the **north-facing** model, however there is a notable amount of drying occurring. The RH levels are likely acceptable for wood framing, but could be a little high for steel members.

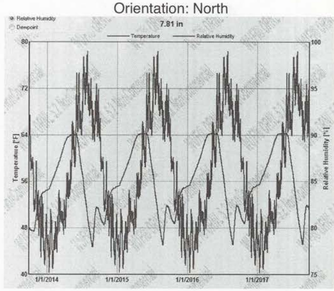
16.06": The RH level at the surface of the brick (between insulation and brick) is above 90% throughout the time period in the **south-facing** model, and the RH is rising over time. This indicates that even if moisture accumulation is not a problem now, it could be in the future. Although the RH is above 80% for almost the entire time period in the **north-facing** model, the RH never reaches 90%, and there is a significant amount of drying occurring. Because there is no potential for mold growth on closed cell spray foam, moisture should not be a problem at this location.

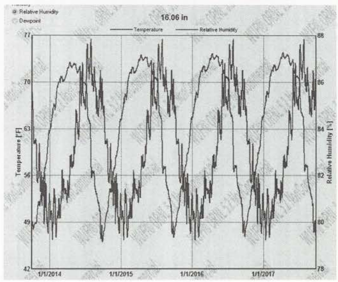
Orientation: South



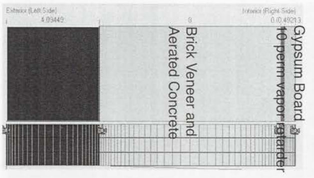


Orientation: North





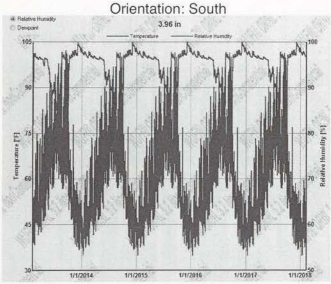
Shattuck Current Wall Assembly #1 *(modeled with two different types of concrete because actual concrete has characteristics that are likely between aerated concrete and concrete brick) (gypsum board and 10 perm vapor retarder used as substitute for gypsum-based stucco because no analagous stucco exists in WUFI)*

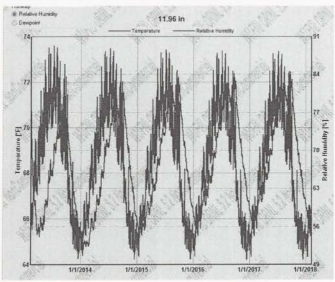


3.96": The relative humidity is above 95% for most of the year in the **south-facing** model, and some amount of drying is occurring. Because this location is close enough to the surface of the wall assembly, higher levels of relative humidity are more acceptable. The RH is less than 90% for most of the year in the **north-facing** model, and a significant amount of drying is taking place. As with the south-facing model, because this location is close enough to the surface of the wall assembly, higher levels of relative humidity are more acceptable.

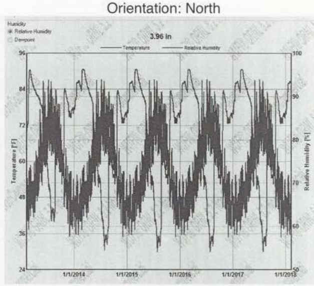
11.96": The RH never reaches above 85% in the **south-facing** model. Because there is no potential for growth, moisture should not be a problem at this location. The RH never reaches above 65% in the **north-facing** model. Moisture accumulation should not be a problem at this location.

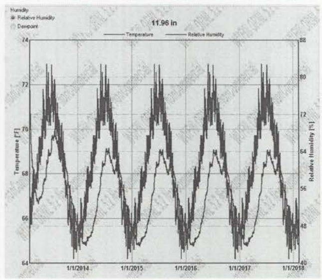
Orientation: South



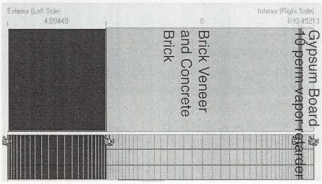


Orientation: North





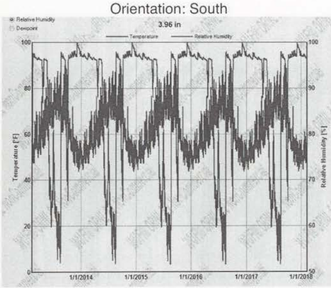
Shattuck Current Wall Assembly #2 *(modeled with two different types of concrete because actual concrete has characteristics that are likely between aerated concrete and concrete brick) (gypsum board and 10 perm vapor retarder used as substitute for gypsum-based stucco because no analagous stucco exists in WUFI)*

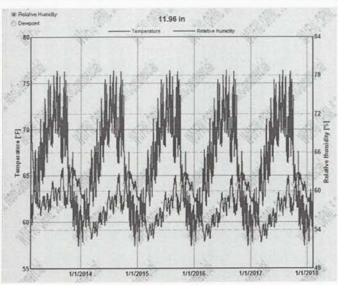


3.96": The relative humidity is above 95% for most of the year in the **south-facing** model, and some amount of drying is occurring. Because this location is close enough to the surface of the wall assembly, higher levels of relative humidity are more acceptable. The RH is less than 90% for most of the year in the **north-facing** model, and a significant amount of drying is taking place. As with the south-facing model, because this location is close enough to the surface of the wall assembly, higher levels of relative humidity are more acceptable.

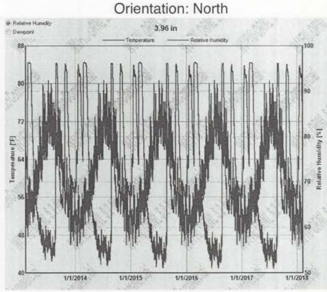
11.96": The RH never reaches above 65% in the **south-facing** and **north-facing** models. Moisture accumulation should not be a problem at this location.

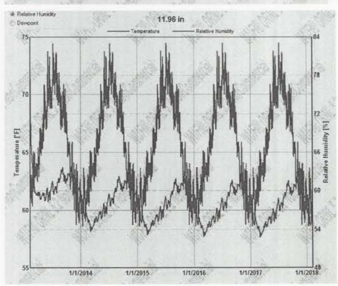
Orientation: South



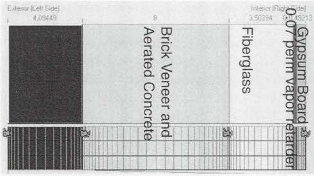


Orientation: North





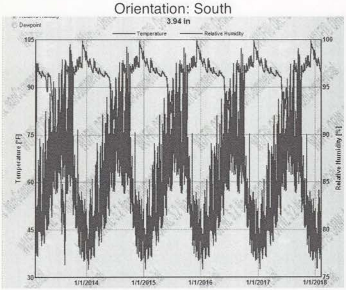
Hypothetical retrofit for brick veneer assemblies backed by load-bearing concrete, such as Shattuck

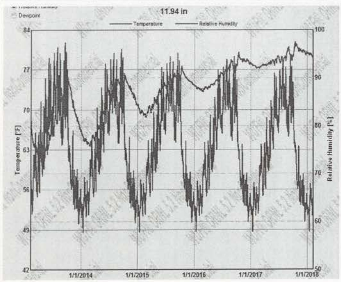


3.94": The relative humidity is above 95% for most of the year in the **south-facing** model, and some amount of drying is occurring. Because this location is close enough to the surface of the wall assembly, higher levels of relative humidity are more acceptable. The RH is less than 90% for most of the year in the **north-facing** model, and a significant amount of drying is taking place. As with the south-facing model, because this location is close enough to the surface of the wall assembly, higher levels of relative humidity are more acceptable.

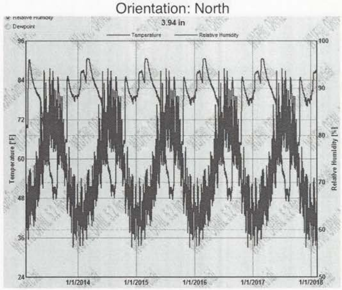
11.94": Although RH levels are between 80% and 90% in the **south-facing** model for about half the time period, the RH is rising over time. Thus, even if moisture accumulation is not an issue currently, it could be in the future. The RH is below 80% the entire time period in the **north-facing** model. Moisture accumulation should not be a problem.

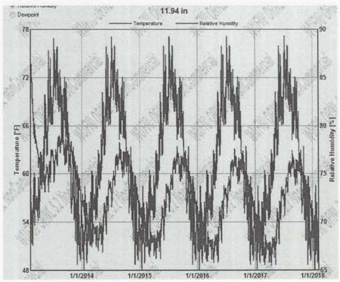
Orientation: South



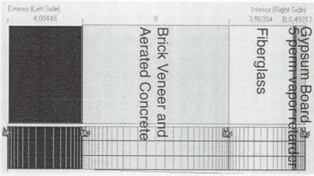


Orientation: North





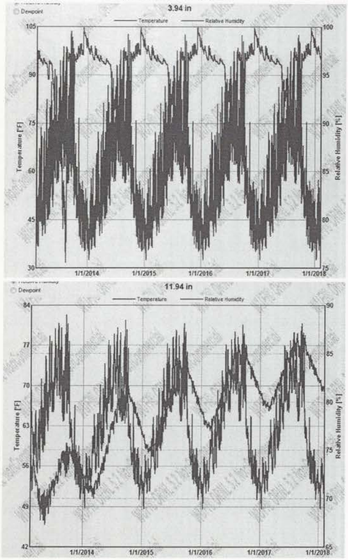
Hypothetical retrofit for brick veneer assemblies backed by load-bearing concrete, such as Shattuck



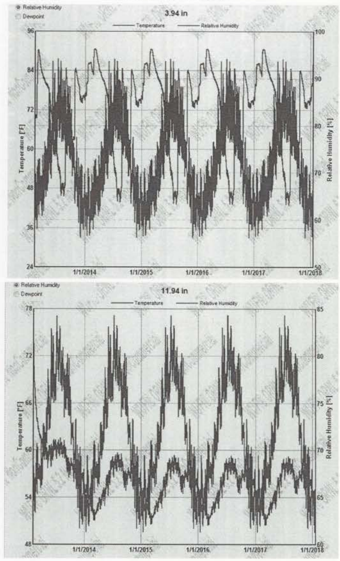
3.94": The relative humidity is above 95% for most of the year in the **south-facing** model, and some amount of drying is occurring. Because this location is close enough to the surface of the wall assembly, higher levels of relative humidity are more acceptable. The RH is less than 90% for more than half the year in the **north-facing** model, and a significant amount of drying is taking place. As with the south-facing model, because this location is close enough to the surface of the wall assembly, higher levels of relative humidity are more acceptable.

11.94": Although RH levels are between 75% and 85% in the **south-facing** model for about half the time period, the RH is rising over time. Thus, even if moisture accumulation is not an issue currently, it could be in the future. The RH is below 75% the entire time period, and drying is occurring in the **north-facing** model. Moisture accumulation should not be a problem at this location.

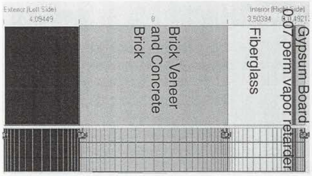
Orientation: South



Orientation: North



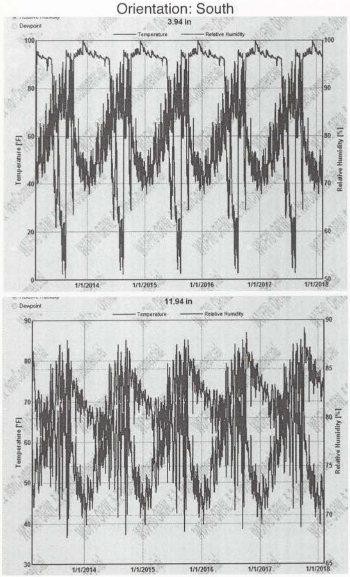
Hypothetical retrofit for brick veneer assemblies backed by load-bearing concrete, such as Shattuck



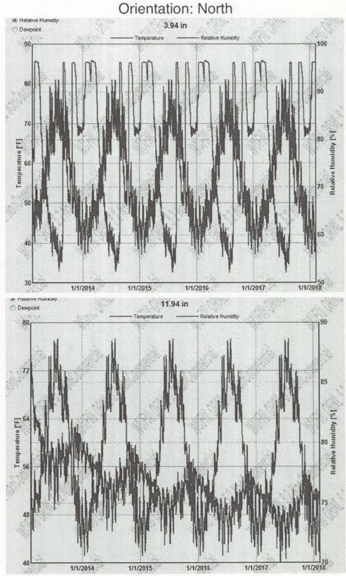
3.94": The relative humidity is above 95% for most of the year in the **south-facing** model, and some amount of drying is occurring. Because this location is close enough to the surface of the wall assembly, higher levels of relative humidity are more acceptable. The RH is less than 90% for about half the year in the **north-facing** model, and a significant amount of drying is taking place. As with the south-facing model, because this location is close enough to the surface of the wall assembly, higher levels of relative humidity are more acceptable.

11.94": Although RH levels never reach above 90% in the **south-facing** model, the RH is rising slightly over time. There is more drying occurring than with the aerated concrete and fiberglass, so the slight rise in the RH is probably not an issue. The RH is below 80% almost the entire time period in the **north-facing** model. Moisture accumulation should not be a problem.

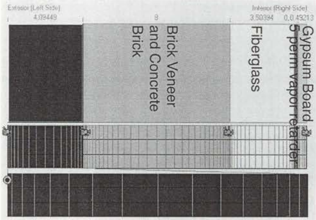
Orientation: South



Orientation: North



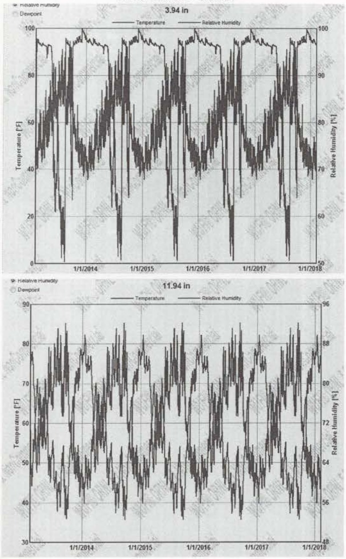
Hypothetical retrofit for brick veneer assemblies backed by load-bearing concrete, such as Shattuck



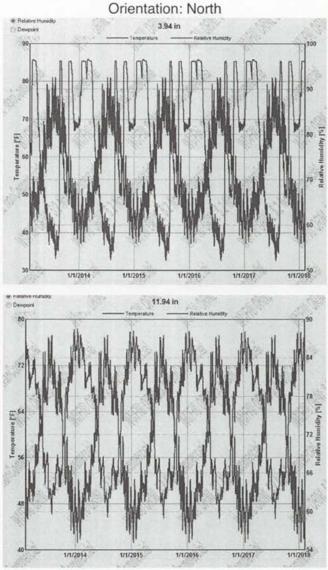
3.94": The relative humidity is above 95% for most of the year in the **south-facing** model, and some amount of drying is occurring. Because this location is close enough to the surface of the wall assembly, higher levels of relative humidity are more acceptable. The RH is less than 90% for about half the year in the **north-facing** model, and a significant amount of drying is taking place. As with the south-facing model, because this location is close enough to the surface of the wall assembly, higher levels of relative humidity are more acceptable.

11.94": RH levels never reach above 90% in the **south-facing** model, and a significant amount of drying is taking place. Because mold growth is not an issue with fiberglass insulation, the RH levels should not be a problem. The RH is below 90% almost the entire time period in the **north-facing** model. Moisture accumulation should not be a problem because there is no opportunity for mold growth on fiberglass.

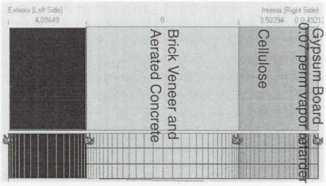
Orientation: South



Orientation: North



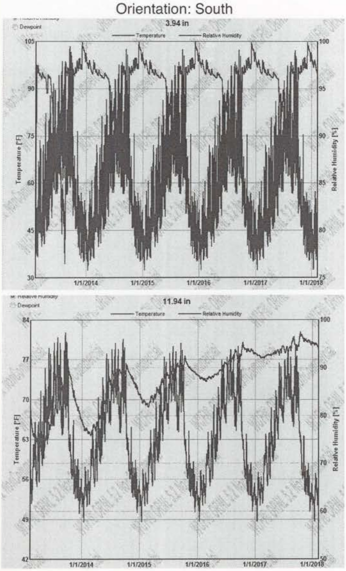
Hypothetical retrofit for brick veneer assemblies backed by load-bearing concrete, such as Shattuck



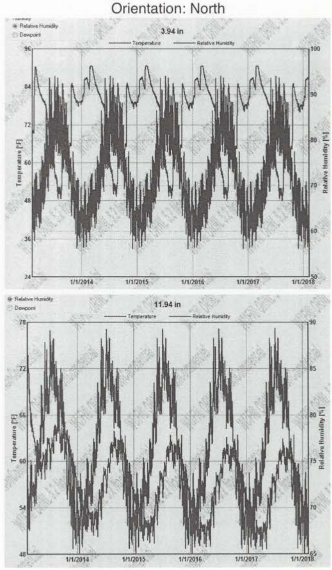
3.94": The relative humidity is above 95% for most of the year in the **south-facing** model, and some amount of drying is occurring. Because this location is close enough to the surface of the wall assembly, higher levels of relative humidity are more acceptable. The RH is less than 90% for about half the year in the **north-facing** model, and a significant amount of drying is taking place. As with the south-facing model, because this location is close enough to the surface of the wall assembly, higher levels of relative humidity are more acceptable.

11.94": Although RH levels are between 80% and 90% in the **south-facing** model for about half the time period, the RH is rising over time. Thus, even if moisture accumulation is not an issue currently, it could be in the future. Higher RH levels are also a more significant issue with cellulose because of the possibility of mold growth. The RH is below 80% the entire time period in the **north-facing** model. Moisture accumulation should not be a problem.

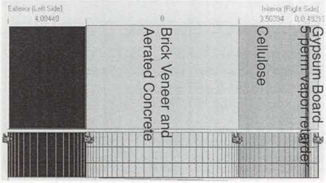
Orientation: South



Orientation: North



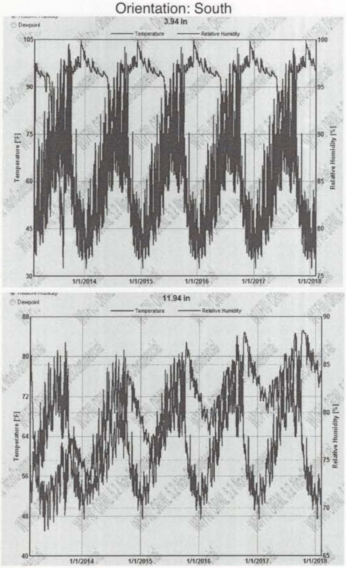
Hypothetical retrofit for brick veneer assemblies backed by load-bearing concrete, such as Shattuck



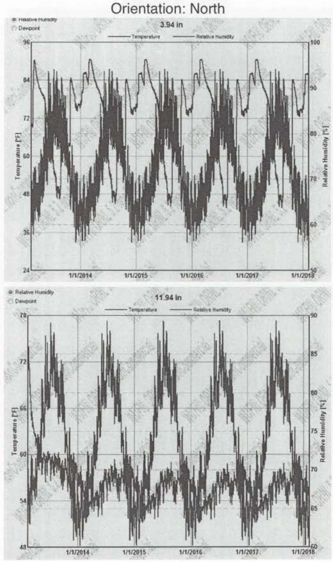
3.94": The relative humidity is above 95% for most of the year in the **south-facing** model, and some amount of drying is occurring. Because this location is close enough to the surface of the wall assembly, higher levels of relative humidity are more acceptable. The RH is less than 90% for more than half the year in the **north-facing** model, and a significant amount of drying is taking place. As with the south-facing model, because this location is close enough to the surface of the wall assembly, higher levels of relative humidity are more acceptable.

11.94": Although RH levels are never above 90% in the **south-facing** model, the RH is rising over time. Thus, even if moisture accumulation is not an issue currently, it could be in the future. Higher RH levels are more problematic due to the potential for mold growth on cellulose insulation. The RH is below 70% the entire time period, and drying is occurring in the **north-facing** model. Moisture accumulation should not be a problem at this location.

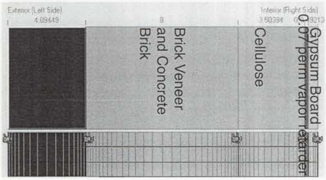
Orientation: South



Orientation: North



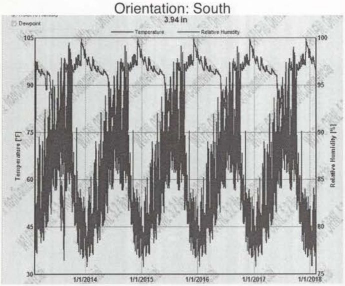
Hypothetical retrofit for brick veneer assemblies backed by load-bearing concrete, such as Shattuck

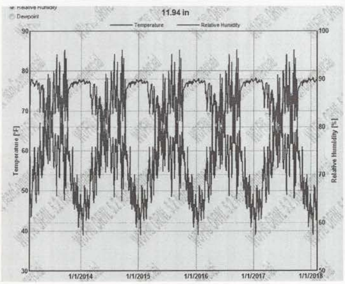


3.94": The relative humidity is above 95% for most of the year in the **south-facing** model, and some amount of drying is occurring. Because this location is close enough to the surface of the wall assembly, higher levels of relative humidity are more acceptable. The RH is less than 90% for about half the year in the **north-facing** model, and a significant amount of drying is taking place. As with the south-facing model, because this location is close enough to the surface of the wall assembly, higher levels of relative humidity are more acceptable.

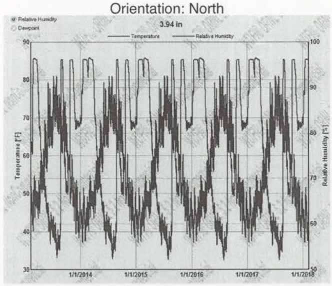
11.94": The RH levels are above 80% for about half the year in the **south-facing** model. Although the RH never goes above 90%, levels over 80% could be problematic with cellulose insulation because of the potential for mold growth. The RH is never above 90% in the **north-facing** model, and the RH is decreasing over time (meaning the assembly is drying out). Although higher RH levels could be an issue with cellulose, the fact that the assembly is drying and stays below 90% relative humidity means that moisture accumulation should be less of an issue.

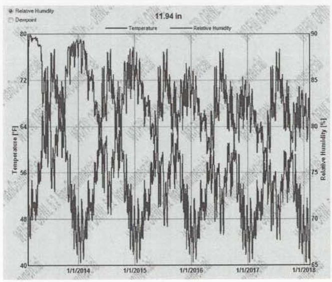
Orientation: South



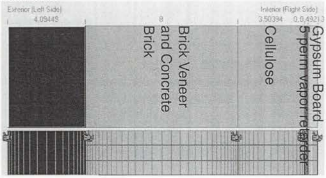


Orientation: North





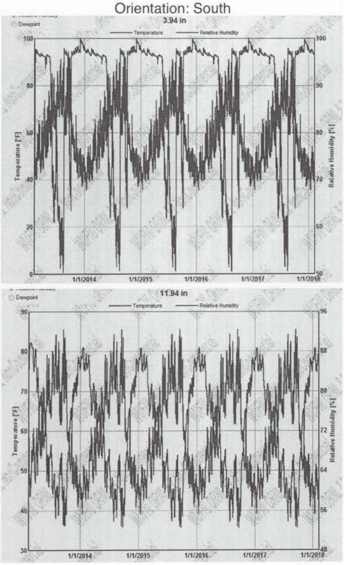
Hypothetical retrofit for brick veneer assemblies backed by load-bearing concrete, such as Shattuck



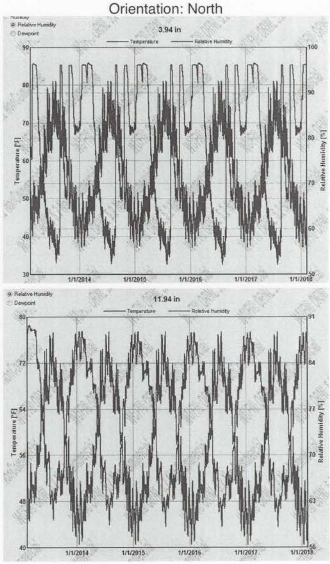
3.94": The relative humidity is above 95% for most of the year in the **south-facing** model, and some amount of drying is occurring. Because this location is close enough to the surface of the wall assembly, higher levels of relative humidity are more acceptable. The RH is less than 90% for about half the year in the **north-facing** model, and a significant amount of drying is taking place. As with the south-facing model, because this location is close enough to the surface of the wall assembly, higher levels of relative humidity are more acceptable.

11.94": RH levels never reach above 90% in the **south-facing** and **north-facing** models, and a significant amount of drying is taking place. Mold growth could potentially occur on the cellulose, however it is less likely since the RH is above 80% less than half the year.

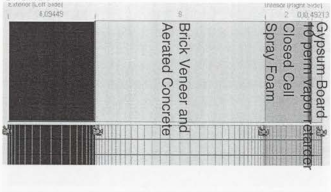
Orientation: South



Orientation: North



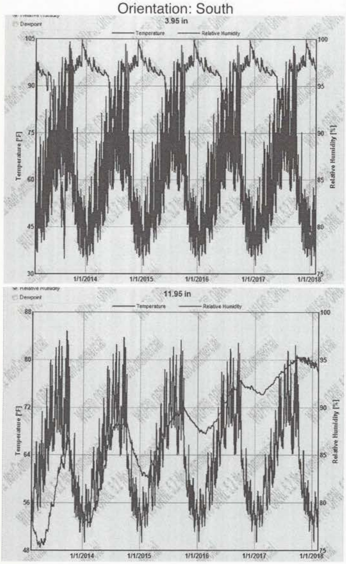
Hypothetical retrofit for brick veneer assemblies backed by load-bearing concrete, such as Shattuck



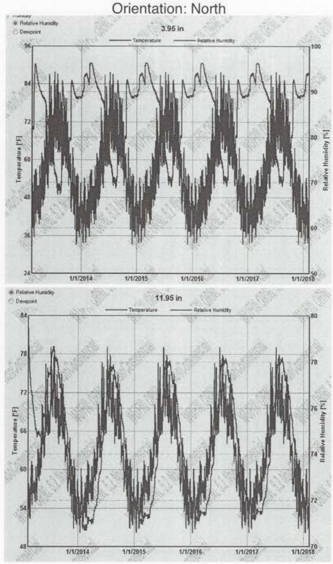
3.95": The relative humidity is above 95% for most of the year in the **south-facing** model, and some amount of drying is occurring. Because this location is close enough to the surface of the wall assembly, higher levels of relative humidity are more acceptable. The RH is less than 90% for about half the year in the **north-facing** model, and a significant amount of drying is taking place. As with the south-facing model, because this location is close enough to the surface of the wall assembly, higher levels of relative humidity are more acceptable.

11.95": Although some drying is occurring, the RH levels are rising significantly over time in the **south-facing** model. Thus, even if moisture accumulation is not an issue currently, it may be in the future. The RH is below 70% almost the entire time in the **north-facing** model. Moisture accumulation should not be a problem.

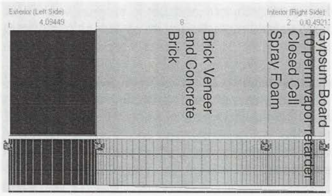
Orientation: South



Orientation: North



Hypothetical retrofit for brick veneer assemblies backed by load-bearing concrete, such as Shattuck

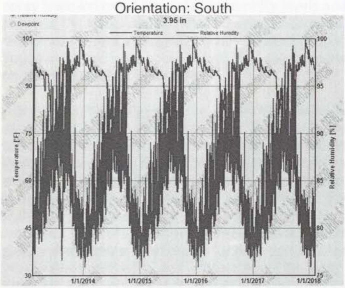


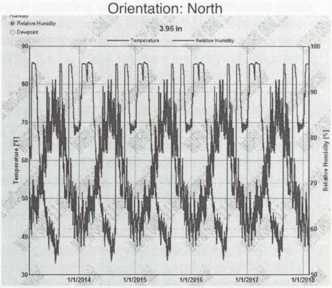
3.94": The relative humidity is above 95% for most of the year in the **south-facing** model, and some amount of drying is occurring. Because this location is close enough to the surface of the wall assembly, higher levels of relative humidity are more acceptable. The RH is less than 90% for about half the year in the **north-facing** model, and a significant amount of drying is taking place. As with the south-facing model, because this location is close enough to the surface of the wall assembly, higher levels of relative humidity are more acceptable.

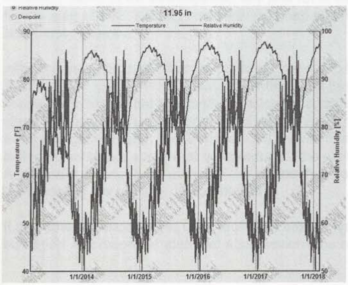
11.94": Although the RH is above 90% for about half the year in the **south-facing** and **north-facing** models, drying is still occurring, and the materials are not reaching saturation levels. Because closed cell spray foam does not grow mold, higher humidity levels at this location should be acceptable.

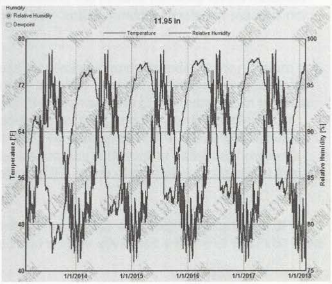
Orientation: South

Orientation: North









Conclusions
The hygrothermal modeling program, WUFI, was helpful for indicating how different types of materials could affect moisture levels in the wall assembly. The extent of the impact, however, is not fully understood through WUFI for a number of reasons, including the limitations regarding the accuracy of the program (discussed previously) as well as an imperfect understanding by the author with regard to some of the results of the modeling.

In most instances, the addition of insulation indicated less drying potential than the same assembly without insulation. It was also clear that the permeability of the insulation affected how much the wall could dry. The fiberglass batt and cellulose insulation had more drying potential than the closed cell spray foam. This intuitively makes sense - closed cell spray foam, with a perm rating of 1 to 2 per inch, does not hold much moisture, which means that more moisture is held in the brick and less drying can occur toward the interior of the building. Fiberglass and cellulose insulation are considered vapor permeable, which means the walls have more ability to dry to the interior.

Although the modeled drying patterns related to the permeability are explainable, some of the patterns indicated through WUFI are not as easily justified. Of all the different scenarios modeled (warm year vs. cold year, air space vs. no air space, etc.), the orientation of the wall assembly (whether it was north-facing or south-facing) had the most impact on the results of the modeling. In the assemblies modeled with a south-facing orientation, the 5 perm vapor retarder seemed to allow more drying than the 0.07 perm vapor barrier in general. However, the 0.07 perm vapor barrier kept the relative humidity levels lower than the 5 perm vapor retarder in the assemblies modeled with a north-facing orientation. Similarly, the less permeable, closed cell spray foam indicated high relative humidity levels and saturation occurring when the wall was oriented south, however the levels were for the most part acceptable when the wall was facing north. Although the extreme differences in relative humidity levels depending on the wall orientation is not fully understood, the results suggest that the walls could benefit from being treated differently (i.e. to allow more or less drying) depending on the orientation of each wall.

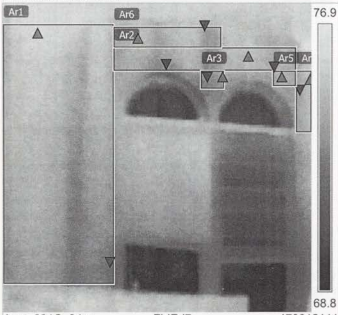
High relative humidity levels (i.e. above 90%) were indicated approximately 8" in all of the solid brick wall assemblies, with or without insulation. Because the accuracy of the hygrothermal modeling was somewhat compromised due to the reasons discussed above, the relative humidity levels WUFI indicated could be higher than the actual case. For instance, the model that represents Lincoln Hall's actual wall assembly (brick wall assembly, 3-wythes thick, uninsulated) demonstrated relative humidity levels above 95% approximately 8" in the wall (where the joists are located in Fenton, Peterson and Anstett) and above 85% for part of the year at the interior surface of the brick. These relative humidity levels seem high, particularly since Lincoln is not insulated. The humidity levels would also indicate that wood rot or steel corrosion in the joist is probable. The project managers and architects for Peterson and Anstett (which are also brick wall assemblies, 3-wythes thick) were consulted to see whether or not the joists in the buildings were rotted or corroded prior to being insulated. None of the buildings had any joist rot or corrosion, meaning the relative humidity levels modeled for the uninsulated, 3-wythe assembly (Lincoln) are likely higher than actual humidity levels, for reasons not completely grasped.

Although using the hygrothermal modeling proved to be a helpful exercise in understanding how moisture and heat transfer operate in brick wall assemblies, the free version of the WUFI hygrothermal modeling program seems to be too limited to provide significantly accurate results. Because several of the materials in the case study wall assemblies (gypsum-based stucco, sheet metal, poured concrete) and the particular climate of the buildings (Portland, OR, Eugene, OR) are not available in the free version of WUFI, the results indicated in this research are somewhat compromised (the extent of the inaccuracy is difficult to estimate, however). Additionally, because the author of this research is new to using WUFI, some of the patterns indicated through the modeling are not fully comprehended.

If hygrothermal modeling is used to predict how a historic brick wall assembly will react to the addition of insulation, it is recommended that a professional be consulted and a more advanced version of WUFI be used.

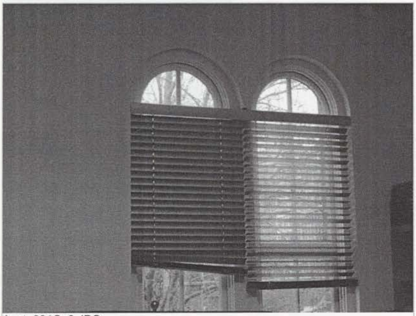
FLIR

2/19/2013 7:32:41 PM



Anst_291C_3.jpg FLIR i7 470012111

2/13/2013 2:35:35 PM



Anst_291C_3.JPG

Measurements		°F
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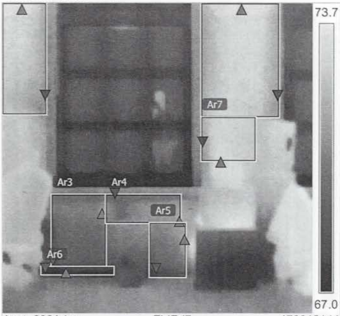
	Min	72.6
	Average	74.0
Ar2	Max	74.8
	Min	73.3
	Average	74.2
Ar3	Max	74.2
	Min	73.1
	Average	73.6
Ar4	Max	74.8
	Min	73.6
	Average	74.3
Ar5	Max	74.4
	Min	73.9
	Average	74.2
Ar6	Max	74.8
	Min	73.6
	Average	74.3

Parameters	
Emissivity	0.95
Refl. temp.	68 °F
Distance	15 ft
Atmospheric temp.	68 °F
Ext. optics temp.	68 °F
Ext. optics trans.	1
Relative humidity	45 %

Image Description

FLIR

2/19/2013 7:29:17 PM



Anst_292A.jpg FLIR i7 470012111

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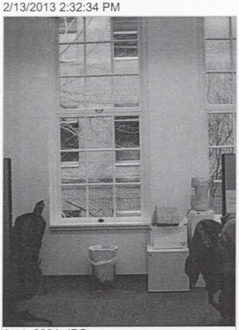


Anst_292A.JPG

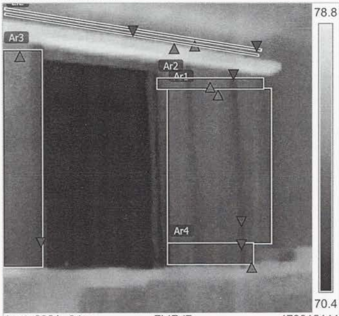
Measurements		°F
Ar1	Max	73.0
	Min	70.4
	Average	72.0
Ar2	Max	73.5
	Min	70.8
	Average	72.5
Ar3	Max	70.9
	Min	68.1
	Average	69.6
Ar4	Max	71.5
	Min	69.4
	Average	70.5
Ar5	Max	71.6
	Min	67.8
	Average	69.9
Ar6	Max	68.6
	Min	67.2
	Average	67.9
Ar7	Max	73.3
	Min	71.0
	Average	72.6

Parameters

Emissivity	0.95
Refl. temp.	68 °F
Distance	15 ft
Atmospheric temp.	68 °F
Ext. optics temp.	68 °F
Ext. optics trans.	1
Relative humidity	45 %

Image Description

2/19/2013 7:30:53 PM



Anst_292A_2.jpg FLIR i7 470012111

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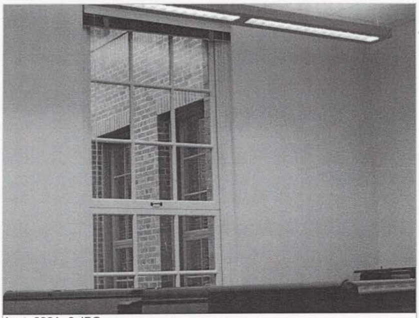


Anst_292A_2.JPG

Measurements °F

Ar1	Max	74.0
	Min	71.9
	Average	73.2
Ar2	Max	74.0
	Min	72.5
	Average	73.6
Ar3	Max	74.6
	Min	71.6
	Average	73.4
Ar4	Max	73.6
	Min	71.7
	Average	72.8
Li1	Max	74.6
	Min	73.5
	Average	74.1
Li2	Max	74.7
	Min	73.5
	Average	74.0

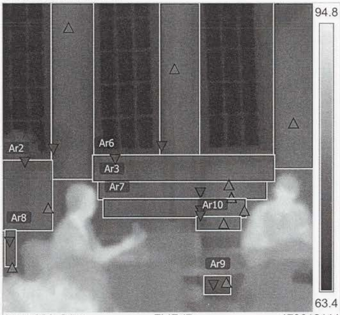
Parameters

Emissivity	0.95
Refl. temp.	68 °F
Distance	15 ft
Atmospheric temp.	68 °F
Ext. optics temp.	68 °F
Ext. optics trans.	1
Relative humidity	45 %

Image Description

FLIR

2/19/2013 7:41:09 PM



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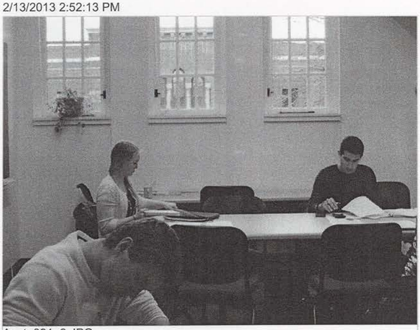


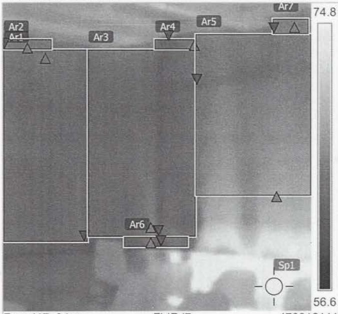
Anst_391_3.JPG

Measurements		°F
Ar1	Max	73.5
	Min	69.2
	Average	72.5
Ar2	Max	73.0
	Min	70.6
	Average	72.2
Ar3	Max	73.6
	Min	71.4
	Average	72.6
Ar4	Max	73.5
	Min	70.1
	Average	72.5
Ar5	Max	73.8
	Min	71.0
	Average	73.0
Ar6	Max	73.4
	Min	70.9
	Average	72.1
Ar7	Max	73.7
	Min	71.0
	Average	72.5
Ar8	Max	72.3
	Min	71.9
	Average	72.1
Ar9	Max	72.1
	Min	70.4
	Average	71.2
Ar10	Max	73.3
	Min	70.9
	Average	72.6

Parameters	
Emissivity	0.95
Refl. temp.	68 °F
Distance	15 ft
Atmospheric temp.	68 °F
Ext. optics temp.	68 °F
Ext. optics trans.	1
Relative humidity	45 %

FLIR

2/24/2013 7:59:36 PM



Fen_117_3.jpg FLIR i7 470012111

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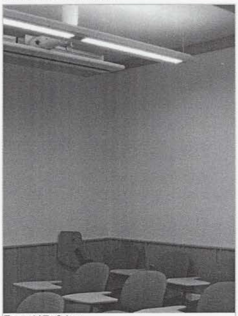


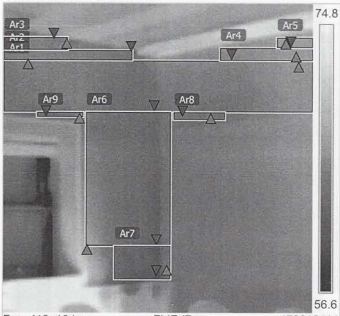
Fen_117_3.jpg

Measurements		°F
Ar1	Max	65.7
	Min	63.0
	Average	64.5
Ar2	Max	65.8
	Min	65.1
	Average	65.5
Ar3	Max	65.8
	Min	62.2
	Average	64.0
Ar4	Max	65.4
	Min	63.2
	Average	64.4
Ar5	Max	68.2
	Min	64.2
	Average	66.0
Ar6	Max	64.9
	Min	61.4
	Average	63.4
Ar7	Max	65.9
	Min	65.3
	Average	65.6
Sp1		80.7

Parameters	
Emissivity	0.95
Refl. temp.	68 °F
Distance	15 ft
Atmospheric temp.	68 °F
Ext. optics temp.	68 °F
Ext. optics trans.	1
Relative humidity	45 %

FLIR®

2/24/2013 7:57:47 PM



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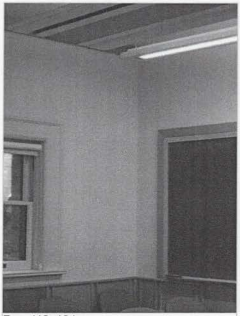
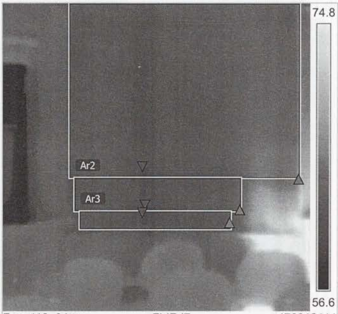


Fen_119_10.jpg

Measurements		°F
Ar1	Max	67.1
	Min	63.4
	Average	65.3
Ar2	Max	65.8
	Min	64.4
	Average	65.3
Ar3	Max	66.1
	Min	64.6
	Average	65.3
Ar4	Max	67.2
	Min	65.8
	Average	66.6
Ar5	Max	67.6
	Min	66.9
	Average	67.2
Ar6	Max	68.0
	Min	60.9
	Average	63.9
Ar7	Max	64.2
	Min	60.3
	Average	62.1
Ar8	Max	65.0
	Min	64.3
	Average	64.6
Ar9	Max	65.5
	Min	62.9
	Average	64.0

Parameters	
Emissivity	0.95
Refl. temp.	68 °F
Distance	15 ft
Atmospheric temp.	68 °F
Ext. optics temp.	68 °F
Ext. optics trans.	1
Relative humidity	45 %

2/24/2013 7:56:59 PM



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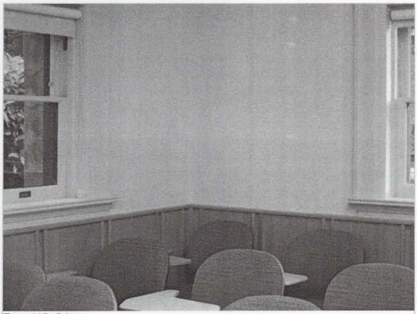

Fen_119_8.jpg

Measurements °F

Ar1	Max	67.6
	Min	60.3
	Average	62.9
Ar2	Max	63.9
	Min	59.8
	Average	61.7
Ar3	Max	62.5
	Min	59.5
	Average	61.3

Parameters

Emissivity	0.95
Refl. temp.	68 °F
Distance	15 ft
Atmospheric temp.	68 °F
Ext. optics temp.	68 °F
Ext. optics trans.	1
Relative humidity	45 %

Image Description

FLIR

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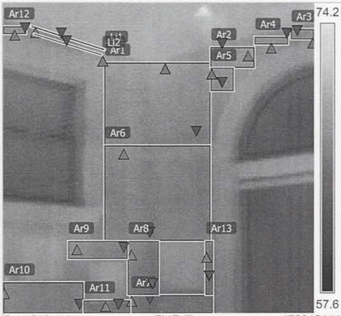

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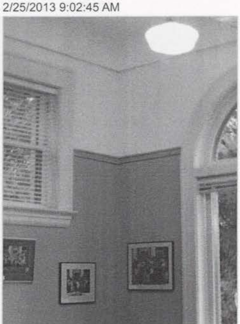
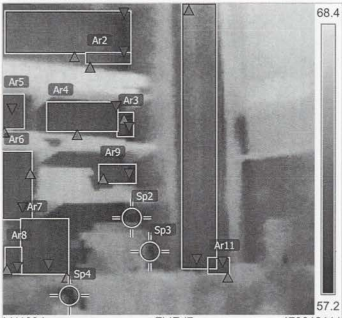


Fen_219_2.jpg

Measurements		°F
Ar1	Max	68.6
	Min	65.6
	Average	66.8
Ar2	Max	67.8
	Min	67.1
	Average	67.5
Ar3	Max	67.2
	Min	66.4
	Average	66.8
Ar4	Max	67.5
	Min	66.9
	Average	67.2
Ar5	Max	67.6
	Min	66.7
	Average	67.1
Ar6	Max	66.7
	Min	64.7
	Average	65.7
Ar7	Max	65.0
	Min	63.2
	Average	64.3
Ar8	Max	65.8
	Min	63.4
	Average	64.8
Ar9	Max	66.6
	Min	65.0
	Average	65.8
Ar10	Max	66.1
	Min	65.2
	Average	65.6
Ar11	Max	66.2
	Min	64.0
	Average	64.7
Ar12	Max	67.0
	Min	66.4
	Average	66.8
Ar13	Max	65.8
	Min	64.3
	Average	65.0
Li1	Max	68.2
	Min	66.4
	Average	67.4
Li2	Max	67.5
	Min	66.5
	Average	66.9

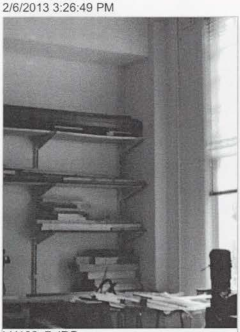
FLIR

2/18/2013 2:46:12 PM



LH103.jpg FLIR i7 470012111

2/6/2013 3:26:49 PM

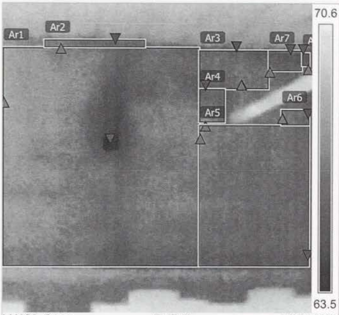


LH103_7.JPG

Measurements		°F
Ar1	Max	62.8
	Min	60.2
	Average	62.1
Ar2	Max	62.7
	Min	60.6
	Average	61.8
Ar3	Max	62.0
	Min	59.8
	Average	60.8
Ar4	Max	62.2
	Min	60.7
	Average	61.5
Ar5	Max	62.1
	Min	61.4
	Average	61.7
Ar6	Max	61.9
	Min	60.9
	Average	61.4
Ar7	Max	62.0
	Min	60.4
	Average	60.9
Ar8	Max	61.9
	Min	60.5
	Average	61.0
Ar9	Max	61.8
	Min	59.3
	Average	61.0
Ar10	Max	63.6
	Min	60.6
	Average	62.4
Ar11	Max	61.7
	Min	60.7
	Average	61.1
Sp4		59.7
Sp3		60.1
Sp2		59.3

FLIR

2/18/2013 3:17:12 PM



LH135_2.jpg FLIR i7 470012111

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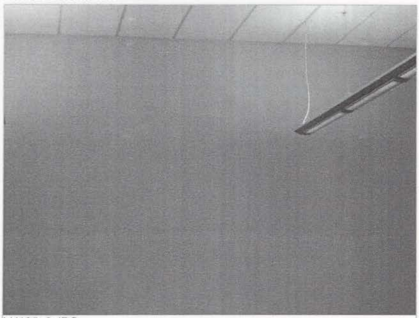


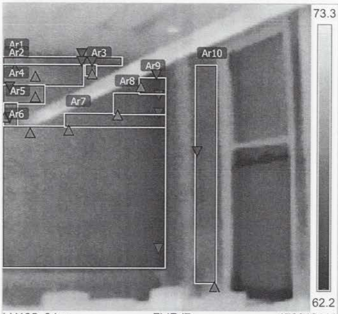
LH135_2.JPG

Measurements		°F
Ar1	Max	69.0
	Min	63.4
	Average	67.0
Ar2	Max	67.3
	Min	66.4
	Average	66.9
Ar3	Max	67.4
	Min	66.3
	Average	66.9
Ar4	Max	67.6
	Min	66.5
	Average	66.9
Ar5	Max	67.5
	Min	66.0
	Average	66.8
Ar6	Max	67.2
	Min	66.6
	Average	66.9
Ar7	Max	67.0
	Min	66.1
	Average	66.5
Ar8	Max	66.8
	Min	66.1
	Average	66.4

Parameters	
Emissivity	0.95
Refl. temp.	68 °F
Distance	15 ft
Atmospheric temp.	68 °F
Ext. optics temp.	68 °F
Ext. optics trans.	1
Relative humidity	45 %

FLIR

2/18/2013 3:17:23 PM



LH135_3.jpg FLIR i7 470012111

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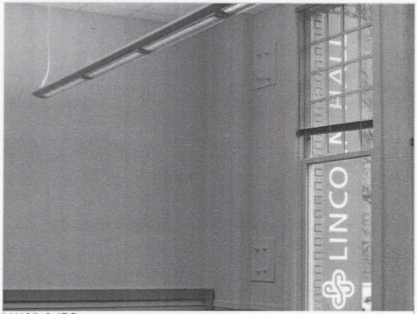


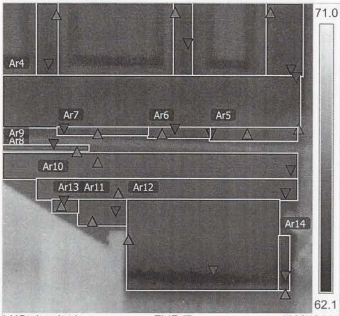
LH135_3.JPG

Measurements		°F
Ar1	Max	67.7
	Min	66.0
	Average	66.8
Ar2	Max	67.8
	Min	66.5
	Average	67.2
Ar3	Max	66.9
	Min	66.5
	Average	66.7
Ar4	Max	67.6
	Min	66.9
	Average	67.3
Ar5	Max	67.6
	Min	67.0
	Average	67.3
Ar6	Max	67.8
	Min	64.5
	Average	66.7
Ar7	Max	67.5
	Min	64.8
	Average	66.6
Ar8	Max	67.0
	Min	65.0
	Average	66.2
Ar9	Max	66.4
	Min	64.7
	Average	65.5
Ar10	Max	67.8
	Min	66.3
	Average	66.9

Parameters	
Emissivity	0.95
Refl. temp.	68 °F
Distance	15 ft
Atmospheric temp.	68 °F
Ext. optics temp.	68 °F
Ext. optics trans.	1
Relative humidity	45 %

FLIR

1/26/2013 2:43:28 AM



LHStairs_1st.jpg FLIR i7 470012111

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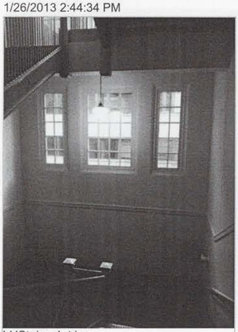


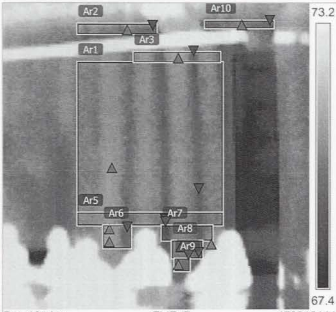
LHStairs_1st.jpg

Measurements °F

Ar1	Max	65.4
	Min	64.0
	Average	64.7
Ar2	Max	65.2
	Min	64.1
	Average	64.5
Ar3	Max	65.2
	Min	63.8
	Average	64.4
Ar4	Max	65.6
	Min	63.8
	Average	64.8
Ar5	Max	65.6
	Min	64.7
	Average	65.1
Ar6	Max	65.3
	Min	64.7
	Average	64.9
Ar7	Max	65.4
	Min	64.6
	Average	65.0
Ar8	Max	65.7
	Min	64.7
	Average	65.3
Ar9	Max	65.7
	Min	65.0
	Average	65.4
Ar10	Max	65.6
	Min	64.2
	Average	65.1
Ar11	Max	65.5
	Min	64.8
	Average	65.1
Ar12	Max	66.2
	Min	62.2
	Average	64.3
Ar13	Max	65.6
	Min	65.1
	Average	65.3
Ar14	Max	64.9
	Min	62.7
	Average	63.6

FLIR

2/19/2013 7:26:45 PM



Pet_101.jpg FLIR i7 470012111

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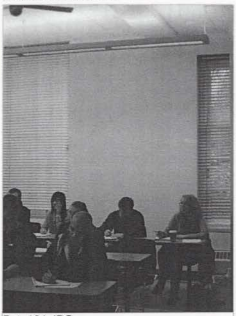


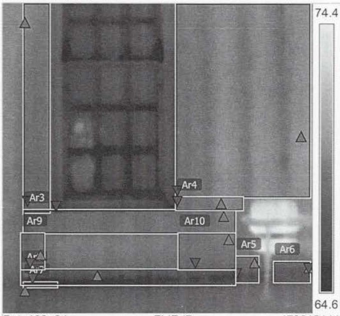
Pet_101.JPG

Measurements		°F
Ar1	Max	71.0
	Min	69.1
	Average	70.3
Ar2	Max	71.3
	Min	69.5
	Average	70.3
Ar3	Max	71.0
	Min	69.4
	Average	70.4
Ar5	Max	70.9
	Min	68.7
	Average	70.2
Ar6	Max	71.1
	Min	69.3
	Average	70.3
Ar7	Max	70.5
	Min	68.5
	Average	69.8
Ar8	Max	70.4
	Min	69.1
	Average	69.8
Ar9	Max	70.1
	Min	69.5
	Average	69.7
Ar10	Max	70.5
	Min	69.4
	Average	70.1

Parameters	
Emissivity	0.95
Refl. temp.	68 °F
Distance	15 ft
Atmospheric temp.	68 °F
Ext. optics temp.	68 °F
Ext. optics trans.	1
Relative humidity	45 %

FLIR

2/19/2013 7:27:27 PM



Pet_103_2.jpg FLIR i7 470012111

2/13/2013 2:29:24 PM

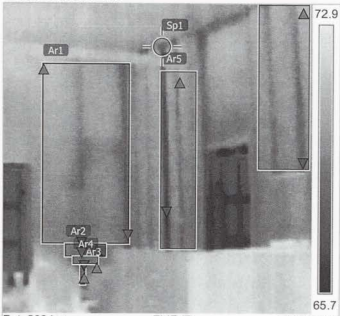
Pet_103_2.JPG

Measurements		°F
Ar1	Max	70.4
	Min	68.1
	Average	69.6
Ar2	Max	70.2
	Min	67.6
	Average	69.0
Ar3	Max	69.7
	Min	66.4
	Average	68.6
Ar4	Max	69.8
	Min	67.8
	Average	69.1
Ar5	Max	69.0
	Min	65.4
	Average	67.5
Ar6	Max	68.8
	Min	66.2
	Average	67.5
Ar7	Max	66.0
	Min	64.3
	Average	65.2
Ar8	Max	68.1
	Min	64.3
	Average	66.3
Ar9	Max	68.7
	Min	67.1
	Average	68.0
Ar10	Max	69.3
	Min	67.5
	Average	68.5

Parameters	
Emissivity	0.95
Refl. temp.	68 °F
Distance	15 ft
Atmospheric temp.	68 °F
Ext. optics temp.	68 °F
Ext. optics trans.	1
Relative humidity	45 %

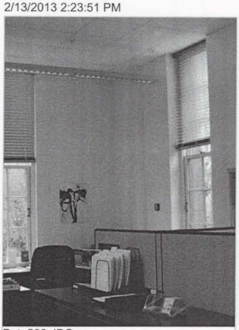
FLIR

2/19/2013 7:25:33 PM



Pet_203.jpg FLIR i7 470012111

2/13/2013 2:23:51 PM



Pet_203.JPG

Measurements °F

Ar1	Max	71.6
	Min	67.1
	Average	70.0
Ar2	Max	69.8
	Min	68.3
	Average	69.3
Ar3	Max	69.5
	Min	68.7
	Average	68.9
Ar4	Max	69.6
	Min	68.3
	Average	69.1
Ar5	Max	70.8
	Min	66.4
	Average	69.5
Ar6	Max	71.1
	Min	68.5
	Average	70.0
Sp1		68.6

Parameters

Emissivity	0.95
Refl. temp.	68 °F
Distance	3.3 ft
Atmospheric temp.	68 °F
Ext. optics temp.	68 °F
Ext. optics trans.	1
Relative humidity	50 %

Image Description

FLIR

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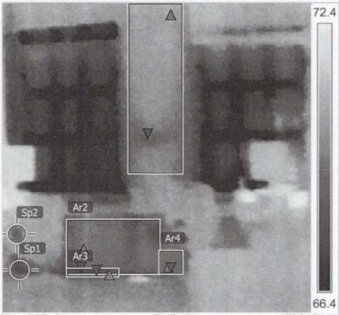
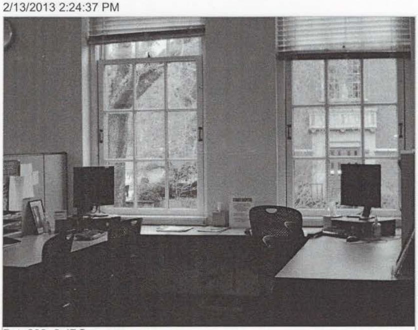


Pet_203_2.jpg FLIR i7 470012111

2/13/2013 2:24:37 PM



Pet_203_2.JPG

Measurements °F

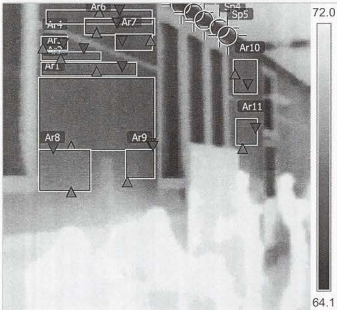
Ar1	Max	70.5
	Min	68.3
	Average	69.6
Ar2	Max	69.4
	Min	67.2
	Average	68.6
Ar3	Max	68.2
	Min	67.2
	Average	67.7
Ar4	Max	69.1
	Min	68.0
	Average	68.7
Sp1		67.7
Sp2		68.4

Parameters

Emissivity	0.95
Refl. temp.	68 °F
Distance	15 ft
Atmospheric temp.	68 °F
Ext. optics temp.	68 °F
Ext. optics trans.	1
Relative humidity	45 %

Image Description

2/18/2013 3:23:05 PM



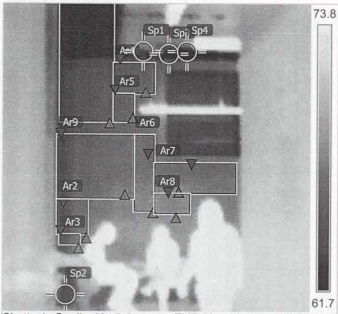
Shattuck_C302_5.jpg FLIR i7 470012111

2/6/2013 4:22:42 PM

Shattuck_C302_5.JPG

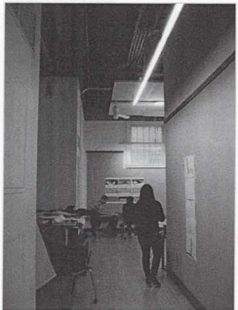
Measurements		°F
Ar1	Max	68.1
	Min	67.0
	Average	67.6
Ar2	Max	67.9
	Min	67.3
	Average	67.6
Ar3	Max	68.0
	Min	67.4
	Average	67.7
Ar4	Max	68.2
	Min	67.5
	Average	67.8
Ar5	Max	67.9
	Min	67.1
	Average	67.5
Ar6	Max	67.8
	Min	67.1
	Average	67.5
Ar7	Max	67.5
	Min	66.8
	Average	67.3
Ar8	Max	68.9
	Min	67.7
	Average	68.3
Ar9	Max	68.3
	Min	67.0
	Average	67.7
Ar10	Max	67.9
	Min	67.3
	Average	67.6
Ar11	Max	68.2
	Min	67.5
	Average	67.9
Sp1		65.8
Sp2		66.0
Sp3		66.3
Sp4		66.1
Sp5		66.4

2/18/2013 3:24:41 PM



Shattuck_Studio_North.jpg FLIR i7 470012111

2/6/2013 4:32:03 PM



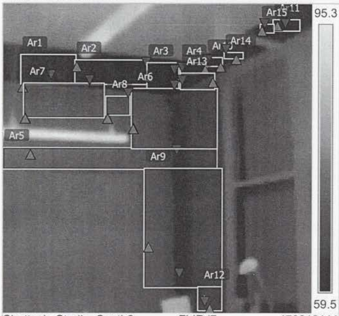
Shattuck_Studio_North.J...

Measurements		°F
Ar1	Max	67.2
	Min	60.6
	Average	64.3
Ar2	Max	68.2
	Min	64.6
	Average	66.6
Ar3	Max	68.0
	Min	65.4
	Average	66.6
Ar4	Max	67.9
	Min	66.0
	Average	67.0
Ar5	Max	67.8
	Min	66.8
	Average	67.3
Ar6	Max	69.1
	Min	67.3
	Average	68.1
Ar7	Max	68.8
	Min	67.4
	Average	68.0
Ar8	Max	69.0
	Min	68.3
	Average	68.6
Ar9	Max	68.7
	Min	64.1
	Average	67.0
Sp2		65.0
Sp1		64.8
Sp3		62.8
Sp4		62.8

Parameters	
Emissivity	0.95
Refl. temp.	68 °F
Distance	15 ft
Atmospheric temp.	68 °F
Ext. optics temp.	68 °F
Ext. optics trans.	1
Relative humidity	45 %

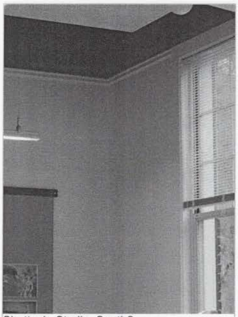
FLIR

2/18/2013 3:21:00 PM



Shattuck_Studio_South2.... FLIR i7 470012111

2/6/2013 4:13:32 PM

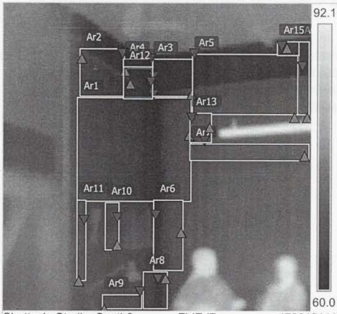


Shattuck_Studio_South2....

Measurements		°F
Ar1	Max	62.4
	Min	61.6
	Average	62.0
Ar2	Max	62.2
	Min	60.9
	Average	61.7
Ar3	Max	61.2
	Min	58.8
	Average	60.0
Ar4	Max	61.5
	Min	60.3
	Average	61.0
Ar5	Max	65.4
	Min	61.3
	Average	64.1
Ar6	Max	64.7
	Min	59.1
	Average	62.9
Ar7	Max	65.3
	Min	61.7
	Average	64.4
Ar8	Max	64.9
	Min	63.8
	Average	64.4
Ar9	Max	64.5
	Min	60.4
	Average	62.7
Ar10	Max	62.1
	Min	61.4
	Average	61.7
Ar11	Max	62.1
	Min	61.4
	Average	61.7
Ar12	Max	62.7
	Min	62.1
	Average	62.3
Ar13	Max	63.3
	Min	60.4
	Average	61.8
Ar14	Max	62.4
	Min	61.9
	Average	62.1
Ar15	Max	62.0
	Min	61.7
	Average	61.9

FLIR

2/18/2013 3:21:15 PM



Shattuck_Studio_South3.... FLIR i7 470012111

2/6/2013 4:14:01 PM

Shattuck_Studio_South3....

Measurements		°F
Ar1	Max	64.9
	Min	61.3
	Average	63.4
Ar2	Max	64.9
	Min	61.7
	Average	63.2
Ar3	Max	64.1
	Min	59.5
	Average	61.5
Ar4	Max	62.2
	Min	59.9
	Average	61.1
Ar5	Max	65.7
	Min	62.1
	Average	63.9
Ar6	Max	64.9
	Min	61.5
	Average	63.6
Ar7	Max	65.8
	Min	64.6
	Average	65.3
Ar8	Max	63.9
	Min	61.9
	Average	62.8
Ar9	Max	64.3
	Min	63.3
	Average	63.9
Ar10	Max	64.2
	Min	63.3
	Average	63.8
Ar11	Max	65.1
	Min	64.1
	Average	64.6
Ar12	Max	63.2
	Min	59.6
	Average	61.8
Ar13	Max	65.2
	Min	64.5
	Average	64.9
Ar14	Max	65.8
	Min	62.3
	Average	64.1
Ar15	Max	62.9
	Min	62.5
	Average	62.7

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