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The Evolving Philosophy of Climate Control for Historic House Museums in Subtropical Climates: Recommendations for the Aiken-Rhett House, Charleston, South Carolina

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THE EVOLVING PHILOSOPHY OF CLIMATE CONTROL FOR HISTORIC HOUSE MUSEUMS IN SUBTROPICAL CLIMATES: RECOMMENDATIONS FOR THE AIKEN-RHETT HOUSE, CHARLESTON, SOUTH CAROLINA

A Thesis
Presented to
the Graduate Schools of
Clemson University and College of Charleston

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
Historic Preservation

by
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May 2012

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Abstract

This study was designed to determine the most appropriate type of climate control system for the Aiken-Rhett House (1820-22), a historic house museum located in Charleston, South Carolina. The Aiken-Rhett property is unique in that it has never been restored and the current stewards of the museum have taken a conservation philosophy to the interpretation of the house. This house museum is rare because it is one of the few remaining unrestored antebellum structures in the South. Although grand mansions were never intended to exist in a state of decline, as the Aiken-Rhett does now, the preserved layers of time provide visitors with a sense of place and connect them to the past. Therefore, preserving this house museum and its original nineteenth-century finishes is of great importance to its interpretive value.

Because a majority of the house is not climate-controlled, the building and its finishes are subjected to the high heat and humidity of Charleston, accelerating the deterioration of the historic building fabric. The owners of the property, Historic Charleston Foundation, are seeking new ideas for a climate control system to better protect the building and the collections that are exhibited inside. The type of environment that is beneficial for museum collections is not always best for historic buildings. This study aims to find the most appropriate interior climate control system for the building and its finishes, while collections and visitor comfort are treated as secondary priorities. The final recommendations will respect the historic fabric of the
Aiken-Rhett House, while also providing economical and sustainable solutions for its continued care.
Dedication

I would like to dedicate this work to my family and friends who provided endless support throughout the whole process; especially my husband, Zack, and my favorite companion, Mulley. Without the two of you, I would have never made it through the year.
Acknowledgements

First and foremost, I would like to thank my primary advisor, James Ward, for all of his guidance and support during my thesis project. Second, I want to thank Historic Charleston Foundation for allowing me to conduct my research on the Aiken-Rhett House and for all of the help they provided me throughout my study. I would especially like to thank Karen Emmons who was always willing to help me hunt down whatever piece of information I needed in the HCF archives; Valerie Perry for coordinating all of my site visits and for crawling around the house with me to search for things like thermostats and evidence of radiators; April Wood for answering all of my miscellaneous questions about the house; Brandy Culp for providing me with information about the collections and finishes; and all of the docents at the Aiken-Rhett House for graciously allowing me to invade their spaces for a few months. Next, I want to thank Dennis Knight who provided tremendous guidance throughout my entire project, especially when it came to determining appropriate applications of HVAC systems in historic buildings. Thank you to Rebekah Wood for providing me with a plethora of information about current museum environmental standards and geothermal systems. I give much gratitude to Matthew Webster for answering a lot of my random questions about using different types of mechanical systems in historic structures. A big thank you to Cliff Parker for providing me with a copy of the 2007 ASHRAE Handbook and for helping me figure out what certain mystery pieces of HVAC
equipment were. I want to thank Melanie Wilson, Patricia Smith, Brandy Culp, and Marcella Hale for allowing me to use their historic houses as case study sites. I would also like to thank Adrienne Jacobsen, Glenn Keyes, Lenny Greene, Alan DeFrees, Shin Maekawa, and finally my thesis committee Ralph Muldrow, Kristopher King, Richard Marks, Ashley R. Wilson, and Frances Ford.
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Preface

Before I went back to school to pursue my Master’s degree, I was employed with a large construction management firm in their healthcare division. During this time, I worked on a central energy plant replacement project on a functioning hospital campus. Personally, I believe that this is when HVAC systems really started to interest me and became something I wanted to learn more about. When I got to Graduate School, I was very excited when I realized I could combine my past interests with my new passion, protecting historic structures. After the first year of my Master’s program, I obtained a summer internship with Historic Charleston Foundation, where I learned they were looking into new options of climate control for the Aiken-Rhett House. The Foundation has a growing concern about the effects of the hot and humid Charleston climate on the un-airconditioned building and its collections. The idea of being able to help Historic Charleston Foundation determine which type of climate control system would be most appropriate for their house museum really interested me.

After spending a lot of time in the Aiken-Rhett House this past summer, updating the interior plaster crack study and assessing the exterior shutters, I can definitely attest to the extreme environment inside the house during this time. The conditions on the third floor were miserable because the windows are kept closed in order to protect the museum collections stored in this location. When I was assessing the exterior shutters, I had to open windows to examine them, and when I did, the effect of opening just one
window in one room, made the space much more comfortable. I remember thinking at the time, if they would just utilize the windows and shutters on the third floor, it would lower the extreme heat and humidity on this level of the house and maybe even help with the lower levels. That thought, without knowing it at the time, would reappear on my final recommendations for the Aiken-Rhett House with considerably more documentation, research precedents and practice protocols.

It is no wonder that I gained an affinity for the house after spending so much time there this summer; and, always being interested in the use of mechanical systems in historic structures, I thought this thesis topic would be a great way for me to learn more on the subject matter. I have to admit that going into this study, I thought at the end of it all, I would be recommending some sort of high-tech HVAC system. This likely had to do with my background in hospital construction, where mechanical systems are extremely complex and are necessary to meet many health and safety codes. Very early in my research I began to realize my initial assumptions were way off-base...
Chapter 1 - Introduction

The installation of air-conditioning to increase visitor comfort in house museums throughout the South has become standard practice, but it has led to unintended consequences and is being questioned by building conservators. Despite the appeal of air-conditioning to tourists and benefits to museum collections, as well as a host of new technological options, the priorities of interpretation and the consequences to the building fabric have to be given careful review before proceeding. Furthermore, climate control has become one of the more important issues affecting the financial sustainability of small house museums. The stewards of the Aiken-Rhett House (1820-22), a historic house museum located in Charleston, South Carolina, are contemplating this very issue. Historic Charleston Foundation, which owns and operates the Aiken-Rhett property, has taken a conservation approach to the interpretation of the historic site. This means that the property is being preserved “as is” with minimal intervention since it was acquired by the Foundation in 1995. Although the same family lived in the house from the 1830s until the late 1960s, modern updates like air-conditioning were never installed and most of the house retains its nineteenth century finishes. Because the interior has never been restored, the building seems like a time capsule. Exposed layers of time and imprints of the people - owners and slaves alike – lend itself to a compelling interpretation. Essentially, the Aiken-Rhett House is one of the few genuine echoes of the antebellum South and helps tell the story of the recent past of Charleston, the region and the country.
For better or worse, the majority of the Aiken-Rhett property is not climate controlled and the historically important finishes are affected by the extremes of the exterior environment. The one-room Art Gallery and the staff-occupied areas of the basement level are the only spaces in the house that are heated and cooled throughout the year. A forced-air heating system was installed in 2004, for the first, second and third floors of the house, but no means exist for mechanically cooling or dehumidifying these spaces. Because Charleston winters are short and mild, the majority of the Aiken-Rhett house is un-airconditioned for most of the year.

In actuality, the building and its finishes are the main museum artifact and part of the museum story is how the building adapted to its climate. The high heat and humidity in Charleston lead to increased deterioration rates of the organic building materials and finishes in the Aiken-Rhett House. As a remedy, Historic Charleston Foundation is considering the installation of a mechanical heating, ventilation and air-conditioning (HVAC) system to slow the deterioration of the building fabric. In addition to the threat to the building and its finishes, the historic collections currently exhibited throughout the unconditioned spaces in the Aiken-Rhett House face the same danger. In fact, in hot and humid climates biological attacks (insects, fungi, and bacteria) pose a

---

1 The museum collections displayed in the Aiken-Rhett House include furniture, furnishings, books, and works of fine art (paintings on canvas and paper, sculptures, and similar items).
greater risk to collections than chemical or mechanical damage.\textsuperscript{2} In order to help protect the collections displayed inside the house, the Foundation’s Preservation Department feels that some sort of HVAC system needs to be installed. Many times, complex air-conditioning systems are installed to provide a stable interior climate for collections; however, this often results in damage to historic buildings because they were not constructed to withstand the operation of these systems. This is a very sensitive issue because what is best for the collections is not typically what is best for an historic building.

Lastly, when selecting a climate control system for the Aiken-Rhett House there is a responsibility to choose a system that respects not only the integrity of the workmanship and materials of the structure, but also the feeling and association of a place. The museum attempts to present a genuine interpretation of antebellum Southern culture; therefore, considerations for a new climate control system need to protect the historically significant elements of the building during the design and installation. The operation of the system should not cause deterioration of the essential building fabric in any way. The system also needs to be affordable and maintainable as most house museums are operated by non-profit organizations. Furthermore, selection of an appropriate climate control system means having realistic expectations for the resulting interior climate based on the capability of the building to sustain a modified

\textsuperscript{2} Shin Maekawa and Franciza Toledo, “Sustainable Climate Control for Historic Buildings in Hot and Humid Regions” (paper presented at PLEA 2001 – The 18\textsuperscript{th} Conference on Passive and Low Energy Architecture, Florianopolis, Brazil, November 7-9, 2001), 1.
interior environment without unintended consequences. Case studies clearly demonstrate that because of the construction methods used to build the Aiken-Rhett House and the current physical condition of the building, one should not expect it to be able to maintain a constant temperature of 70°F and 50% relative humidity throughout the entire year. This would result in significant damage to the building and increased costs for the building's maintenance. A more realistic approach would be to expect the building to respond in kind to the exterior environment, meaning the interior is warm in the summer and cool in the winter. The consequences for the collections and visitor comfort will need to be reconsidered based on this preference for building fabric.

Therefore, the question becomes what is the most appropriate type of climate control system to install at the Aiken-Rhett House, a nationally important landmark and a palpable reminder of a different way of life? As a part of a master plan for the Aiken-Rhett House property which includes the outbuildings and work yard, Historic Charleston Foundation will decide on a climate control strategy to implement in the main house. They have determined already that they want to add some new method of interior climate management to help conserve the finishes in the house. This study will help the Foundation make an informed decision about how to manage the interior environment of their historic property. The primary priority is considered the building,

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3 The Aiken-Rhett House was listed in the National Register of Historic Places on November 21, 1977 under NPS Reference Number 77001216. At the time of the nomination, the property was known as the Governor William Aiken House or the Robinson-Aiken House. The building was nominated for significance in architecture and politics/government for the period of 1800-1899.
while the collections and visitor comfort are considered secondary because they are not permanent or stationary. Moreover, the collections can be relocated to climate controlled storage facilities and visitors are at the house museum only for the duration of their tour.

To accomplish the task of determining the most appropriate climate control system for the Aiken-Rhett House, four research questions were developed:

1. What are the current physical conditions of the building, its finishes and HVAC systems?
2. What are the preferred interior environmental conditions desired for the Aiken-Rhett House? What are the current interior air properties and do they meet current museum environmental standards?\(^4\)
3. What type of current climate control systems are being employed in other similar historic house museums and what have been their outcomes?
4. Are there new technologies or trends in the heating, ventilation and air-conditioning (HVAC) industry that could be utilized at the Aiken-Rhett House to achieve the desired interior climate?

As a supplement to these research questions, the current best practices as outlined in the *Preservation Briefs* published by the National Park Service are carefully considered during this study. They will be examined before and after the final analysis of climate control for the house museum to reevaluate their usefulness and appropriateness based on newer, relevant research. Also, the study of the Aiken-Rhett House will include a review of the current operating procedures at the historic house museum.

Recommendations will be made at the end of the study for operational changes that

\(^4\) The “current museum environmental standards” refer to the ASHRAE standards for collections in different types of museums buildings. This information will be reviewed in detail in *Chapter 5*.  

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could help improve the interior climate. To establish an understanding for the final recommendations, background information for historic methods of climate control and those currently utilized at the Aiken-Rhett House are in Chapters 2 and 3. Next, a detailed methodology for this study is in Chapter 4. Lastly, the results from the study and final recommendations conclude the analysis in Chapters 5 and 6.

Several studies exist on historic structures in similar climate conditions that will prove useful in the development of a climate control plan for the Aiken-Rhett House. Likewise, there is research within the last twenty years that suggests the museum environmental standards inside historic buildings should allow for wider fluctuations in temperature and relative humidity levels. Considerable literature on climate control systems for historic buildings in hot, humid climates has been written recently by conservators and scientists and will be valuable reference materials for the final climate control recommendations. Even so, the Aiken-Rhett House is a special case, as this project involves many variables that make it unique. There are no known case studies of a historic house museum with a conservation philosophy, which displays collections in an un-airconditioned environment, and is located in the subtropical climate of the southeastern United States. This will be one of the first case studies of its kind, and a goal of the project is to contribute useful research to the existing body of literature on climate control for historic buildings in hot, humid climates. Stewart Brand, the renowned author of How Buildings Learn: What Happens After They’re Built, provides a suggestion in his chapter about vernacular buildings and how they learn from each
other. He states that vernacular builders “are content to accept well-proven old solutions to old problems.” Maybe the key to solving the Aiken-Rhett problem is looking into the methods used to historically manage the interior climate of the building.

Figure 1.1: View of the west and south elevations of the Aiken-Rhett House during the 1860s. There are very few places left in existence that are virtually untouched examples of antebellum Southern life. Source: Image from property file at the Margaretta Childs Archive, Historic Charleston Foundation, Charleston, SC.

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Chapter 2 - Climate Control Background

Historic Climate Control Methods & Systems

Early methods of climate control are passive in comparison to modern heating, ventilating, and air conditioning (HVAC) systems. Before the advent of more advanced technology, people manipulated the natural environment to enhance human comfort levels. Certainly, building design tended to reflect the climate, and people and their buildings had evolved an array of responses to weather. Building site orientation, window and door locations, and building materials were integral to managing the interior environment in historic buildings. Before the Industrial Revolution, heating was provided mainly from fireplaces or stoves. After the Revolution, advancement in technology allowed people to have better control of their interior environment, with the invention of central heating systems and forced air ventilation.

Why therefore is it important to investigate earlier methods of climate control if we are looking into a modern HVAC system for the Aiken-Rhett House? Most buildings today do not take into consideration the surrounding environment during the design process. Architects and engineers rely heavily on high-tech mechanical systems and the related building codes to manipulate the interior environment. Edward Jon Cazayoux, who wrote *A Manual for the Environmental & Climatic Responsive Restoration & Renovation of Older Houses in Louisiana* (Baton Rouge, LA: Department of Natural Resources, Technology Assessment Division, 2003), 7.

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Renovation of Older Houses in Louisiana, answers this question when he states “[i]n trying to understand and develop new ways to stay comfortable...it can be very beneficial to look back and study how those people who came before us used the natural environment to stay comfortable, especially before any mechanical systems were available.” The following subsections, therefore, discuss early methods of climate control for cooling and heating. Passive methods are discussed first, followed by early mechanical means of climate control.

**Early Passive Methods**

Building orientation on a site has a major impact on interior climate control, especially when it comes to sun exposure and air movement. Our predecessors took site orientation into account before constructing their homes to minimize solar radiation heat gain and to take advantage of prevailing breezes. Methods used to prevent solar heat gain include building orientation, shading (architectural and vegetation), shutters, and building materials. Likewise, methods employed for natural ventilation include building orientation, vegetation, building materials and location and types of openings.

In regards to solar heat gain, if the longer side of a building was oriented along an east-west axis, it would provide greater sun exposure on the south side of the building. In areas like Charleston, where summers are long and hot, the south side of a building could be shaded from the high summer sun with an overhang or porch. The

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shade created by the porch or overhang protected the south wall of the building from heat gain. Contrarily, the north side of the building received little sun, so an awning or porch would provide little protection. Because the sun is much lower in the sky when it hits the east and west sides of a structure, the best way to protect these elevations from heat gain is to use a vertical element to block the sun. Tall trees planted around the east and west sides of a house can provide excellent shade and prevent direct sun exposure in the summer.\footnote{Cazayoux, \textit{Environmental & Climatic Responsive Restoration}, 24 and 41.}

Since windows can be a large source of heat gain or loss, early residences used exterior and sometimes interior shutters to control the amount of exposure. Typically for security reasons, exterior shutters were solid on ground floor levels and louvered on the upper floors, while interior shutters were typically solid. The use of louvered

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{figure21.png}
\caption{Building site orientation and use of vegetation were passive methods used to control the interior climate of historic buildings. \textit{Source: Image from Edward Jon Cazayoux, A Manual for the Environmental & Climatic Responsive Restoration & Renovation of Older Houses in Louisiana} (Baton Rouge, LA: Department of Natural Resources, Technology Assessment Division, 2003), 41.}
\end{figure}
shutters was practical during hotter periods because the windows could be open while the shutters were closed, allowing for air to circulate through the house. Depending on the time of day and where the sun is located in the sky, shutters would be opened and closed to let in enough natural light to see, but to also help keep the interior climate at a comfortable temperature. Shutters were used to help block hot air from infiltrating the windows in the summer and cold air in the winter.

The selection of certain types of building materials also helped manage solar heat gain or loss. In order to understand how different building materials react to changes in temperature, the concept of “time lag” is explained. Time lag can be defined as the “time required for the heat to travel through a wall from the outer to the inner face.”¹⁰ A wood structure is comprised of relatively thin walls and lightweight materials when compared to a load bearing masonry structure. The wood materials require little heat to change their temperature and they have little capacity to store heat. This means that it takes very little time for hot exterior temperatures to raise the temperature of the wood building materials; thus it has a short time lag. Once the maximum wood temperature has been reached, the heat is then transferred to the interior space of the building. The heat will continue to flow through the wood materials and into the interior

space until the exterior conditions change.\textsuperscript{11} The thermal properties of masonry materials keep the interior climate of a structure fairly constant:

Heavy, thick walls have a large heat storage capacity. So the inner surface temperature will not vary for some hours after a change in outdoor temperature. The time lag of such a wall is considerable. In hot climates, old buildings with massive walls are often cool inside. The heat of the day never penetrates to the inner surface. The walls are so massive that it takes all day for heat to go any distance into the wall and increase its temperature. By the time that the temperature of the interior of the wall has been raised somewhat, night arrives. Then the relatively warm outer layers of the wall begin to lose heat to the cool night air. All night long heat flows from the hot outer layers of the wall to the cool night air. When morning arrives, the heat flow again reverses into the wall and the entire cycle is repeated. The wall acts as a buffer to the hot outdoor temperatures, storing the heat in the daytime and delivering it back to the outdoors at night.\textsuperscript{12}

Therefore, heavier building materials with greater thermal mass and larger time lags (brick or stone) were often preferred over lighter building materials (wood). The same can be said about the choice of roofing materials. Roofing materials with greater thermal mass, like clay tiles or slate, collect and store heat rather than letting it penetrate the roof like lighter roofing materials, such as wood shakes. The heat stored in the clay tiles or slate dissipates during the nighttime when temperatures are cooler. Of course, these heavier roofing materials would also need a more substantial structural system to support them.\textsuperscript{13} Historically, metal was a light roofing material that was used because of its reflective qualities and impermeability to moisture. Contrary to the heavy

\textsuperscript{11} Trane Company, \textit{Trane Air Conditioning Manual}, 39.
\textsuperscript{12} Ibid.
\textsuperscript{13} Cazayoux, \textit{Environmental & Climatic Responsive Restoration}, 51.
roofing materials, metal roofs can cool down as quickly as they heat up, making them a practical choice in hot, humid climates.\textsuperscript{14}

Building orientation can help maximize natural ventilation. A structure positioned so that prevailing winds can travel the shortest distance through the building will have better air movement.\textsuperscript{15} Air circulation helps to remove heat and creates a more comfortable interior climate for building occupants. Also, vegetation and trees can help lower the air temperature around a structure. An air movement technique used by plantation owners in the southern United States was the installation of an alley of trees that approaches a house. The trees were of the taller, broad canopy type (such as live oak) to help channel breezes towards the building.\textsuperscript{16} Moreover, the use of certain building materials and construction methods created a structure that “breathed.” For example, a breathable roof installation is comprised of wood shakes installed over horizontal purlins attached perpendicularly to roof rafters. The construction methods and wood materials created pathways for air to escape through and around the different roof components.\textsuperscript{17}

Early natural ventilation sources maximized air movement and included different types of architectural elements like double-hung sash windows, dormer windows, transoms, attic vents and high ceilings. Window and door openings were located directly

\textsuperscript{14} Franciza Toledo, “Museum Passive Buildings in Warm, Humid Climates” (paper presented at the Experts’ Roundtable on Sustainable Climate Management Strategies, Tenerife, Spain, April 2007), 12.
\textsuperscript{15} Cazayoux, \textit{Environmental & Climatic Responsive Restoration}, 43.
\textsuperscript{16} Ibid., 41.
\textsuperscript{17} Ibid., 52.
across a room from each other to increase air flow. Also, both sashes are operable in double-hung windows, allowing for cool air to enter the building through the bottom opening and hot air to escape through the top. High ceilings allowed hot air to rise while the cooler air settled at lower levels closer to the building occupants. The natural tendency for warmer air to rise and cooler air to fall helped create gravity ventilation in historic buildings. Open stairwells provided vertical shafts for air to move between different levels of the building. Once the warm air reached the attic level of the building, dormer windows and vents installed in the space would help draw this hot air up and out of the building at the roof level.18

Early heating methods included fireplaces and stoves. The main source of fuel was wood until the late 1700s, when coal began to replace wood as a cheaper fuel source. To burn coal, fireplaces were retrofitted, making the firebox smaller and installing metal grates that allowed air to burn the coal from underneath.19 Fireplaces served as the primary source of heat in homes until the early nineteenth century, when closed (airtight) stoves were first introduced.20 Unfortunately, fireplaces and stoves only provided small areas of comfortable heat, meaning that fire screens had to be used to

18 Cazayoux, Environmental & Climatic Responsive Restoration, 49-51.
19 Matthew Grubel, “Central Changes in Domestic Heating: Lingering Traditions and New Technology in Philadelphia, 1690-1890” (master’s thesis, University of Pennsylvania, 1998), 12. Though this thesis focuses on Philadelphia, it can be assumed that the ranges of dates provided for changes in heating methods can be applied to other large cities on the east coast of the United States at this time, like Charleston, SC.
shield a person from too much heat. Also, the heated rooms in a house tended to be
closed off from other areas to help prevent cold drafts. Another disadvantage of
fireplaces and stoves was the amount of smoke these heat sources produced, which
often made rooms uncomfortable and had a negative impact on clothes, furnishings and
the environment.21 By the 1830s, furnaces and central heating systems were being used
in modern, newer houses.22

**Early Mechanical Methods**

Central heating systems were first utilized in factories during the Industrial
Revolution. During a period of transition from 1840-70, central heating systems were
used in conjunction with fireplaces and stoves in residences; but, by the 1880s, furnaces
became the primary heat source in most middle-class houses.23

Early central heating systems included hot water, steam and warm air.24 The
early versions of these systems were fueled by burning wood or coal and were later
fueled by oil or gas as these resources became more widely available. Hot water heating
systems can be classified by high or low pressure. High pressure systems are closed and
sealed from the atmosphere, while low pressure systems are open to the atmosphere.
The increased pressure created by hot water systems increases the boiling point of the
water. This means that the water in a high pressure system can be heated to a higher

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22 Ibid., 188.
temperature without creating steam.\textsuperscript{25} The components of both types of hot water systems include a boiler (to heat the water), piping (to transport the water) and radiators (to distribute the heat). Advances in the hot water systems between the 1870s and 1900 made these types of central heating systems cost effective alternatives to warm air and steam systems.\textsuperscript{26}

Steam systems looked very similar to hot water heating systems except that they functioned differently. A boiler creates the steam that is piped to radiators that deliver the heat to the interior spaces. Once the steam condenses into water inside the radiator, the liquid is transported back to the boiler to be reheated by a dedicated return line or it dripped back through the same piping it was delivered in. The advantage of steam systems is that the physical properties of steam make it very effective in its ability to heat rooms uniformly in a short period of time. Disadvantages to using steam, however, are the lack of control and poor indoor air quality resulting from the high temperature of the metal radiator surfaces.\textsuperscript{27} Though steam was used effectively in factories after 1800, the systems were not considered safe enough or financially reasonable to use in houses until the second half of the nineteenth century.\textsuperscript{28}

\textsuperscript{26} Grubel, “Central Changes in Domestic Heating,” 65-66.
\textsuperscript{27} Graham and Emery, \textit{Audels Plumbers and Steam Fitters Guide #3}, 3,746.
\textsuperscript{28} Grubel, “Central Changes in Domestic Heating,” 67-69. Improper design and installation would cause boilers to explode and overheated pipes would burn and dry wood framing members. Also, there was concern that overheated metal components in a steam system damaged air quality and contributed to health problems.
Eventually advances in manufacturing made the components of a steam system more affordable and safer for the public, which in turn increased its use in residences.

Warm air systems were also first used in large public or commercial buildings before being utilized in homes. The earliest type of warm air systems used the gravity warm air furnace. The components of the system included a furnace to heat the air, ductwork to transport the heated air throughout a building, and supply grilles to deliver air to the interior spaces. Ventilation was an important factor to ensure there was a proper air supply for combustion in the furnace room. Also, a flue pipe needed to be installed on the furnace to exhaust the smoke from combustion to the outdoors. The earliest furnaces were built of brick and had to be constructed inside a building, but by the latter half of the nineteenth century, metal-cased “portable” furnaces were increasingly used.

The nineteenth century saw much improvement with central heating and ventilation systems, as well as improvements in cavity wall construction and fireproofing methods. Though buildings were constructed using insulation materials, such as mineral wool or cork, and masonry filler materials for fireproofing, they were not air-tight and there was still only a moderate difference between inside and outside temperatures in

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30 Grubel, “Central Changes in Domestic Heating,” 75-76. Similar to the steam central heating systems, complaints about the warm air systems included danger of damaging building components and poor indoor air quality due to overheating the metal and air.
unconditioned structures.\(^{31}\) With the use of electric power increasing in the late 1800s, mechanical systems transitioned from fuel sources like oil and gas to electricity. With the use of electricity, came the invention of the electric fan in 1882. The electric fan had the ability to circulate and cool air, but offered no control over humidity. Styles included ceiling fans and small table fans and they could be found in all types of buildings, including homes.\(^ {32}\)

Advances in heating systems and electricity also corresponded with advances in refrigeration methods and air conditioning systems. Even though experiments with refrigeration methods had begun in the mid-1700s, the U.S. Patent for mechanical refrigeration was not issued until 1851.\(^ {33}\) About fifty years later, the “world’s first scientific air conditioning system” that included humidity control was created by Willis Haviland Carrier on July 17, 1902.\(^ {34}\) Carrier defined air conditioning as the following:

> Air conditioning is the control of the humidity of air by either increasing or decreasing its moisture content. Added to the control of humidity are the control of temperature by either heating or cooling the air, the purification of the air by washing or filtering the air, and the control of air motion and ventilation.\(^ {35}\)

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\(^{33}\) Margaret Ingels, *Willis Haviland Carrier: Father of Air Conditioning* (Louisville, KY: Fetter Printing, 1991), 14. Dr. William Cullen (1710-1790) of Scotland conducted research on refrigeration by evaporative cooling during the mid-1700s, and Dr. John Gorrie (1803-1855) of Apalachicola, Florida, received the U.S. Patent for mechanical refrigeration in 1851.

\(^{34}\) Ibid., 17.

\(^{35}\) Ibid.
Further research and experimentation led to Carrier receiving the U.S. Patent for a dew point control system in 1914. By the 1920s the use of air conditioning shifted from industrial purposes to human comfort, with large auditoriums and theaters among the first buildings to use air conditioning systems to provide comfort cooling.\textsuperscript{36} After World War II, major advancements in mechanical system technology and building insulation materials increased their use and affordability. In spite of these advancements, air conditioning use in Southern residences was rare until the 1950s, and only since the 1970s has the South truly become “an air-conditioned culture.”\textsuperscript{37} Since the last part of the twentieth century, heating, ventilation and air-conditioning (HVAC) systems have become even more advanced with energy efficiency, indoor air quality (IAQ) and whole building integration as important factors for system design.

Today, historic house museums use a variety of mechanical climate control systems to maintain desired interior temperatures and relative humidity levels. Two of the most common types of HVAC systems used in house museums are direct refrigerant systems and chilled water systems. Direct refrigerant systems, also called direct expansion (DX), use a closed liquid refrigerant loop as a heat exchanger with air to provide heating or cooling to conditioned spaces. DX systems are factory-assembled and come in packaged (one piece of equipment) or split (two pieces of equipment) configurations. Split DX systems are commonly used in single-family residences and are


\textsuperscript{37} Ibid., 610-613.
suitable for smaller applications at historic house museums (for example, cooling only one room or part of the building). If a house museum is larger in size, typically a chilled water system is installed. These types of systems use chilled and hot water to provide cooling and heating to interior spaces. Chilled water systems are comprised of several pieces of HVAC equipment including chillers, boilers, remote condensers, and air handler units. Significant amounts of chilled and hot water piping are required to transport the water, but with less ductwork to distribute the conditioned air to the interior spaces.

A new HVAC trend developing for historic house museums is the use of geothermal systems. Geothermal is another name for ground source heat pump systems, which use the relatively constant temperature of the earth as a heat exchanger. Geothermal systems are beneficial because half of the system is installed underground and is not visible or audible; however, they have high initial and recurring costs and require significant site excavation for installation. Detailed explanations of all of these climate control systems and their corresponding HVAC equipment can be located in Appendix A.

**Issues with HVAC Systems in Historic Buildings**

When mechanical climate control systems are installed in historic structures, it is common for historic fabric in the building to be damaged during and after the installation. This section discusses some of the typical problems associated with climate
control systems in historic buildings. This study explains the issues related to the effects of installing the HVAC equipment and its distribution systems. It will also address the effects on the building and any collections that arise from operation of the climate control system.

During the installation of an HVAC system in a historic building, the historic space is typically modified to install the system. Usually, this means that some historic fabric is removed to fit the mechanical equipment and its distribution systems (ductwork or piping) into the building. Unfortunately, the process of removing historic building materials is non-reversible; however, the equipment is usually placed in relatively insignificant spaces. Another problem that occurs during installation of an HVAC system is structural overload. Sometimes, the system design team does not accurately calculate the structural strength of the areas of the historic building where the equipment is located or the weight of the equipment. Overloading the structure with too much weight can result in significant damage to historic building materials and sometimes even total failure. A common example of this type of problem is when HVAC equipment is installed in attic spaces. The structural members of the attic were not originally designed to handle the extra weight of heavy mechanical equipment, and without added structural support the historic materials will be damaged. In addition to weight, the HVAC equipment can create vibrations that put extra stress on the historic structure, which can also lead to material damage or failure.
After a climate control system has been installed, several different types of problems often occur. The majority of these problems result from the difference in air properties between the interior and exterior climates. For example, in the South a common problem is vapor diffusion, which is how water moves through a material when there is a difference in the pressure between two areas. The vapor will always move from areas of higher pressure and temperature to areas of lower pressure and temperature until a state of equilibrium is reached.\(^\text{38}\) Diffusion rates are affected by air pressure, temperature and relative humidity as well as permeability of the material the vapor is trying to pass through.\(^\text{39}\) Therefore, in hot and humid climates, the larger the difference between the inside and outside climate, the greater the amount of unwanted moisture will enter the building.

Because historic structures breathe by nature, these buildings typically allow for vapor diffusion to easily occur in and out of their exterior skin (walls, roofs, foundations). When a climate control system is installed in a historic structure in a hot, humid climate like Charleston, the mechanized conditioning of the interior air creates a greater differential in exterior and interior climates. In the summer time, the differential pressure between the cool, dry conditioned inside air and the hot, humid unconditioned exterior air will cause more moisture to move through building walls into the interior spaces. Contrarily, in the winter time, the warm humidified inside air moves through


\(^{39}\) Park, “Preservation Brief #39,” 492.
walls to the cool drier outside air.\textsuperscript{40} Vapor diffusion causes problems in historic structures when it changes physical state and turns into condensation on interior surfaces, such as walls, windows, and floors. It is also common for condensation to form inside exterior wall cavities as vapor moves through a wall and condenses on a cooler interior or exterior surface of the wall assembly. Condensation will speed up the deterioration process of building materials and rot, mildew, mold and fungus can occur when materials remain wet for long periods of time. Evidence of condensation problems inside a wall are lifting plaster or peeling paint finishes. In addition, undetected condensation inside wall cavities can lead to serious damage compromising the structural integrity of a building.\textsuperscript{41} The constantly wet environment invites insect attack and causes wood framing members to rot or masonry materials to effloresce or spall, reducing the ability of exterior walls to support the structure. The ability of historic structures to breathe can regulate wall cavity moisture by aiding in the drying process, while HVAC systems, however, cause excessive moisture.

In new construction, vapor barriers are installed in exterior walls to help protect the interior from vapor diffusion across the wall cavity. A vapor barrier is defined as “a membrane or system to retard the diffusion of moisture into building cavities.”\textsuperscript{42} In addition to vapor barriers, insulation materials are used in modern buildings to help prevent heat gain or loss. If vapor barriers and insulation are installed in walls of historic

\textsuperscript{40} Park, “Preservation Brief #39,” 490-491.
\textsuperscript{41} Ibid., 491.
buildings they can create moisture problems inside the cavity. In northern climates with long winters, vapor barriers are installed towards the inside of the wall on the interior side and tend to work well. Yet, in hot humid climates with long summers, there is much debate over which side of the wall a vapor barrier should be installed on or if they should even be used at all.\textsuperscript{43} Because air conditioned structures in the South have a large vapor pressure differential between the inside and outside, moisture will travel through the wall cavity, but will be blocked once it hits the vapor barrier. This excess amount of moisture in the wall cavity can lead to deterioration of historic materials. Applications in historic structures, however, where vapor barriers have been successful are in damp basements or crawl spaces. The vapor barrier is placed over the damp ground surface which helps stop the diffusion of moisture from the ground into the building.\textsuperscript{44}

Similarly, if insulation materials are installed in historic walls and they get wet, their thermal properties are reduced, moisture problems develop and the exterior building materials will suffer. The construction methods used on many historic structures, especially masonry buildings, made their exterior walls thicker and more robust than modern structures; therefore, adding insulation may not even help control interior humidity or temperature. In fact, recent research states that “the temperature and moisture effects of adding insulation are small; thus they have a minor effect on performance” and “actual energy savings from wall insulation, as from other retrofits, is

\textsuperscript{43} Cazayoux, \textit{Environmental & Climatic Responsive Restoration}, 79.
\textsuperscript{44} Park, “Preservation Brief #39,” 491.
often lower than the theoretical savings.” Adding insulation to attics in historic buildings can be beneficial in regards to minimizing heat gain and heat loss; however, the insulation should be installed in a way that is removable and if batt insulation is used, it should be unfaced to avoid the creation of a vapor barrier.

Another way for moisture to move through buildings is capillary action, which is often referred to as rising damp. Rising damp is very common in masonry structures where the porous masonry materials wick up water from the ground and carry it up the walls. The signs of rising damp are horizontal tide marks or white stains caused by efflorescing salts drawn into the walls with the ground water. When a climate control system is installed in a historic building, rising damp can become an even larger problem because of the dehumidification of the interior air. The dry interior air increases the vapor pressure differential between the inside of the building and the ground, creating a “greater wicking potential” in the masonry walls. Some try to resolve the rising damp issue by sealing the masonry walls with a waterproof coating, but this only draws the water higher up into the walls as they can no longer dry out. The best way to manage rising damp is to redirect as much water away from the building as possible through good site drainage.

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46 Cazayoux, *Environmental & Climatic Responsive Restoration*, 60 and 72.
49 Ibid., 63-64.
The last way for moisture to be transported in and out of a historic building is by air infiltration. Air infiltration is caused by wind, the stack effect and fan action. The amount of air infiltration also depends on the tightness of the exterior skin and interior skin of the building.\textsuperscript{50} Historic buildings inherently have “loose” exterior skins allowing the structures to breathe. If air conditioning systems are added to a historic building, the exterior envelope needs to be tight so that humidity is not introduced into the building by means of air infiltrating from the exterior. Properly designed HVAC systems in hot, humid climates should create positive pressure in the building with the use of fans and fresh air intake.\textsuperscript{51} Positive pressurization of the building will help prevent air from entering through any holes or cracks in the exterior skin of the structure.

Other problems may arise in an historic building as its finishes and collections acclimate to their new climate controlled environment. Dehumidification may cause drying and cracking in building materials, such as plaster walls, wood panels and floor boards. Improper humidity control may also cause mold or mildew to form on interior finishes. Furnishings are susceptible to changes in interior climate as well. If humidity levels inside a building are too high, the increased moisture content of the furniture can lead to swelling, warping, and softened veneer or glue joints. Contrarily, if the humidity levels are too low, furniture pieces can shrink and crack.\textsuperscript{52}

\textsuperscript{51} Michalski, “Quantified Risk Reduction in the Humidity Dilemma,” 27.
\textsuperscript{52} Ibid., 28.
The last issue with installation of HVAC systems in historic structures, especially historic house museums, is the impact they have on visitor experience. If components of climate control systems are visible to the public, it can detract from the sense of place a visitor has when in an historic building. Much the same, if an HVAC system produces a lot of noise and is audible to the public, it will take away from the visitor experience.

When visitors walk through a historic house museum, it may be unappealing or even distracting to see a modern piece of HVAC equipment. Usually HVAC equipment is located in spaces not accessible by the public, but the distribution systems related to these pieces of equipment are not so easy to hide. Chimney flues or small closets can be used to run ductwork and deliver conditioned air to the spaces; however, it is more typical for conditioned air to be delivered to the spaces through terminal outlets, such as diffusers, registers and grilles. Most times, terminal outlets are installed in inconspicuous locations like in a hidden corner of a room, behind a door, or concealed over a large door architrave. Care should be taken when installing these terminal outlets so they are unobtrusive and less visible to the public.
In historic house museums, it is common for HVAC equipment to be located on the building exterior to minimize its impact on the inside of the structure. Unfortunately, when this happens, these pieces of equipment can sometimes be seen or heard by house museum visitors, staff and neighbors. A common example of this is an air-cooled condenser like the ones typically used in DX systems for single-family residences. Air-cooled condensers need to be outside so that they can exchange heat with the air to complete the refrigeration cycle. Many times, condensers are placed on roofs or hidden in vegetation close to the building. When they are in operating mode, condensers are loud and easily heard. When a visitor hears a modern piece of equipment in operation, it takes away from the experience of an historic site that originally would not have had mechanical climate control systems. Furthermore, some historic house museums are large in size and require larger HVAC equipment to
maintain the indoor environment. The larger the piece of equipment, the louder and usually harder to conceal they become. Sometimes, even mechanical equipment on adjacent properties can detract from the visitor experience if it can be seen or heard at a house museum.

Figure 2.3: Condenser unit on the roof of an adjacent property, visible from a stair landing window in the Heyward-Washington House, a historic house museum in Charleston, South Carolina. Photograph by author.

Today, when historic house museums are being restored, it is important to discuss how a new HVAC system can be incorporated into the interpretation philosophy of the museum. Some may argue that no elements of an HVAC system should be visible to visitors; however, others may argue that evolution of historic houses should allow for some components of mechanical systems to be seen. While the philosophical argument about interpretation of a house museum is not intended to be a part of this study, the issue inevitably arises during discussions about these systems. Ultimately, the decision about how interpretation and HVAC systems work together is up to the stewards of the house museum.
Preservation Briefs

The current best practices of climate control in historic buildings were established by the Department of the Interior and the National Park Service (NPS). The Department of the Interior has published *Preservation Briefs* which are considered the “U.S. Government’s Official Guidelines for Preserving Historic Homes.”\(^{53}\) Two of these *Preservation Briefs* are relevant to the climate control case study of the Aiken-Rhett House and have been reviewed to determine their suggested best practices. “Brief 24 – Heating, Ventilating, and Cooling Historic Buildings: Problems and Recommended Approaches (1991)” will be discussed first followed by a review of “Brief 39 – Holding the Line: Controlling Unwanted Moisture in Historic Buildings (1996).” While these articles outline the current best practices from the NPS, both of these Briefs are fifteen to twenty years old and the technology in the conservation and HVAC industries has changed substantially since these were first written.

*Preservation Brief 24*

The first Brief entitled “Heating, Ventilating, and Cooling Historic Buildings: Problems and Recommended Approaches,” was authored by Sharon C. Park, FAIA. This Brief mainly deals with typical problems associated with installing HVAC systems in historic structures and recommends ways to minimize the visual and physical damage to their historic fabric. Also included in the article is a short history about HVAC systems

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and an overview of the different types of systems that are available today. Perhaps the most useful portions of *Preservation Brief 24* are sections about the planning and design phases before a new HVAC system is chosen. It provides six planning steps and four design guidelines as well as “HVAC Do’s and Don’ts,” a list of best practices regarding what to do and what not to do when installing HVAC systems in historic structures.

The section of the article titled “Planning the New System,” discusses six recommended steps before an HVAC system is chosen for a historic building. The six planning steps are as follows:

1. *Determine the use of the building.*
2. *Assemble a qualified team.*
3. *Undertake a condition assessment of the existing building and its systems.*
4. *Prioritize architecturally significant spaces, finishes, and features to be preserved.*
5. *Become familiar with the local building and fire codes.*
6. *Evaluate options for the type and size of systems.*

This study will apply the recommendations that pertain to the four research questions. It will also explain the recommendations for planning a new HVAC system by summarizing each step and highlighting the best practices.

Step one establishes how often the building will be used and the number of building occupants to help determine the type of climate control system.\(^{55}\) The second


\(^{55}\) Ibid., 263.
planning step basically states that a qualified design team of architects, engineers and preservation consultants should be selected to address issues such as initial costs, heating and cooling loads, local building codes, future maintenance, aesthetics and conservation requirements.\textsuperscript{56} The third planning step discusses the need to conduct a conditions assessment of the building and its current mechanical systems. The assessment should be completed in order to understand what the current building materials are, their current physical condition, and how they may be affected by installation of a new mechanical system. The current HVAC systems should be evaluated to determine their functionality and if they are reusable. Also, any issues with the building envelope, like sources of air infiltration or water leaks, need to be addressed before a mechanical system is installed. Finally, the third step recommends monitoring interior temperature and relative humidity for at least a year before an HVAC system is selected.\textsuperscript{57} These procedures set forth in step three are employed during the Aiken-Rhett study and are discussed further in \textit{Chapter 4: Methodology}.

The goal of the fourth planning step in this Brief is to identify important historic components of the building that need to be preserved during the installation of a new mechanical system.\textsuperscript{58} Secondary spaces that are not significant will need to be identified as potential locations for HVAC equipment and distribution systems. For example, in the Aiken-Rhett House, some of these secondary locations are likely where mechanical

\textsuperscript{56} Park, “Preservation Brief #24,” 263.
\textsuperscript{57} Ibid.
\textsuperscript{58} Ibid., 266.
equipment already exists. The next step highlights the importance of knowing health, safety, fire and energy codes. These building codes will have an impact on the HVAC system that is chosen and will dictate certain design requirements; therefore, it is imperative to understand them before the planning process begins.\(^5^9\) For this study, the priority is conservation of building fabric; but when a new climate control system is designed for the Aiken-Rhett House, a team of architects and engineers will ensure that building codes are followed. The sixth and final planning step suggests conducting a feasibility study to examine the advantages and disadvantages of different types of mechanical systems considered for the historic building.\(^6^0\) In regards to the Aiken-Rhett House, a design team of architects, engineers and preservationists will compare different climate control systems to select the one that is most appropriate for the historic building.

The next section of the article, titled “Designing the New System,” suggests four activities for the design phase of a new mechanical system for a historic building. These four activities are listed below:

1. Establish specific criteria for the new or upgraded mechanical system.
2. Prioritize the requirements for the new climate control system.
3. Minimize the impact of the new HVAC on the existing architecture.
4. Balance quantitative requirements and preservation objectives.\(^6^1\)

\(^{5^9}\) Park, “Preservation Brief #24,” 266.
\(^{6^0}\) Ibid.
\(^{6^1}\) Ibid., 267.
The suggested first activity in the design phase is the establishment of specific criteria that the new mechanical systems must meet in order to be selected. The set of criteria can include items like the new HVAC system must not produce excessive vibration, noise, dust or moisture. Another suggestion states that the equipment and system components should be easily accessible for maintenance and future upgrades. The last criterion suggests that any equipment located outside of the historic structure should not impact archaeological resources or the visual appearance of the historic building and site.62

During the second design phase activity proposed in the Brief, it should be determined if different areas in the building require different levels of climate control. The different zone requirements, desired control system, and operational times will have an effect on the type of climate control system that is selected for the historic building.63 The third design activity states that decisions need to be made about what areas inside the historic building it is appropriate to see HVAC system components, what components are appropriate to be seen, and those that should be hidden. The third activity also states that a combination of different HVAC systems may need to be used with the purpose of protecting the historic fabric.64

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63 Ibid.
64 Ibid.
The last design phase activity states that sometimes “ideal” HVAC systems may not be able to be achieved because of reasons like cost, code requirements, or space limits. Even with limitations on these climate control systems, creative solutions can usually satisfy both the preservation and system requirements. Lastly, as with any historic preservation project, the HVAC system and all of its components should be installed so that they are reversible and can be removed in the future without causing damage to the building and its finishes.65

*Preservation Brief 24* also provides a list of “HVAC Do’s and Don’ts” which can be considered a generic list of best practices when designing an HVAC system for a historic building. The list of “HVAC Do’s” includes items that were suggested in the six planning steps and four design activities. Some of these items are as follows: upgrading existing mechanical systems if possible, retaining decorative elements of older climate control systems, use secondary spaces (closets, chases) for new distribution systems, and designing the system for easy maintenance access and future upgrades.66 Other best practices include adequate ventilation, maintaining appropriate temperature and humidity levels, and installation of safety monitors and backup devices like moisture detectors, double drain pans and battery packs.67 Perhaps the three most important best practices for house museums are training staff members to monitor the operation

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66 Ibid., 270.
67 Ibid., 270.
of the HVAC system, having a regular temperature and humidity monitoring schedule and having an emergency plan for system malfunctions.

The twelve “HVAC Don’ts” start simply with the statement if you do not need a new climate control system, then do not install one. The list moves on to some of the “don’ts” relating to design: do not over-design a system, do not overload the structure with the weight of new equipment, do not put exterior pieces of equipment in highly visible locations, and do not put undue stress on the building with equipment vibrations. The remaining “HVAC Don’ts” state that historic windows and finishes should not be removed or damaged during installation of a new climate control system. The list also states that operable historic windows should not be sealed unless they are in a part of a building where air pollutants need to be controlled. Lastly, it is important to prevent condensation from forming on windows or inside wall cavities because this will lead to rotting or spalling of historic building materials.68

Preservation Brief 24 is a resource that every historic house museum should utilize before the decision is made to install a new climate control system. If a house museum does not have the time or resources to go through every step suggested by the Brief, then the “HVAC Do’s and Don’ts” can be consulted as a simple, straightforward list of best practices. As stated previously, three of the most important best practices are training the staff members to monitor the operation of the system, having a regular

68 Park, “Preservation Brief #24,” 270.
environmental monitoring schedule and having an emergency plan for system breakdowns. These three items are usually the ones that are overlooked, yet they can help solve many problems that can occur with an HVAC system. If staff members understand how their climate control system should operate properly, they will be able to spot problems more easily when something starts to go wrong. Along this same note, if staff members have a regular schedule setup for monitoring temperature and humidity levels, then they will be able to detect incorrect or harmful levels for the house or collections much earlier. Lastly, if there is a major HVAC system malfunction, the staff members should have an emergency plan to follow in order to protect the house museum and the collections from any potential damage.

**Preservation Brief 39**

The second Brief, “Holding the Line: Controlling Unwanted Moisture in Historic Buildings,” was also written by Sharon C. Park, five years later in 1996. This article provides information about controlling sources of unwanted moisture and recommendations based on the *Secretary of Interior’s Standards for the Treatment of Historic Properties*. Discussions included in the article are common sources of moisture, how moisture transports through structures, and factors that contribute to moisture problems. Also, the Brief provides guidelines for how to survey and diagnose moisture problems in historic buildings and how to select an appropriate treatment.

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plan. Because it is not possible to control humidity in buildings with any leaks and water intrusion problems, these issues must be addressed before any HVAC system recommendations can be made.\textsuperscript{70}

The first section of the article, titled “Remedial Actions within a Historic Preservation Context,” lists six guidelines for moisture problem treatment decisions. These guidelines recommend careful diagnosis of remedial treatments, protection of historic and archeological resources, addressing rain run-off and ground-related moisture problems, continual maintenance and monitoring of moisture problems, and resolving any moisture problems before mechanical systems are installed.\textsuperscript{71} The second section of the article is “How and Where to Look for Damaging Moisture” is very short and merely provides a list of “Factors Contributing to Moisture Problems.”\textsuperscript{72} The list of factors contributing to moisture problems in historic buildings includes items like types of building materials, type of soil, building use and occupancy, mechanical and plumbing systems, daily and seasonal climate changes, air infiltration and conditions in exterior wall cavities. The third section of the Brief provides a list of signs that one should look for when trying to diagnose a moisture problem. Signs for visible moisture problems include: standing water, mold, mildew, fungus, water stains, condensation, surface erosion or efflorescence. Hidden moisture problems may be diagnosed by looking for

\textsuperscript{71} Park, “Preservation Brief #39,” 485.
\textsuperscript{72} Ibid., 486.
signs of flaking paint, peeling wallpaper, damaged wood, spalled or cracked masonry, metal corrosion or musty smells in unventilated spaces.73 The fourth section titled “Uncovering and Analyzing Moisture Problems” discusses the five most common sources of moisture problems in historic buildings. These sources are as follows: above grade exterior moisture, below grade ground moisture, leaky mechanical and plumbing systems, interior moisture related to climate control systems and occupant use, and lastly, water used during construction and or any maintenance projects.74

The next section of the Brief discusses how moisture is transported throughout a building. Moisture movement occurs when water is in its liquid or vapor state and when there is a pressure differential between two spaces. Moisture will always move from higher pressure areas to lower pressure areas to try to balance out the difference in these pressures. The permeability of building materials will decide the rate of moisture movement when it is in a gaseous state, while the absorption rate of the building materials will determine the rate of movement when moisture is in a liquid state.75 The three types of moisture intrusion in historic buildings are capillary action, infiltration and vapor diffusion. Capillary action is defined as “the force that moves moisture through the pore structure of materials” and it is commonly referred to as rising damp and typically occurs in masonry materials that are in contact with ground moisture.76

73 Park, “Preservation Brief #39,” 486.
74 Ibid., 487.
75 Ibid., 489.
76 Ibid., 492.
Second, air infiltration is “the movement that carries moist air into and through materials” and “is created by wind, temperature gradients (hot air rising), ventilation fan action, and the stack or chimney effect.” Lastly, vapor diffusion is “the natural movement of pressurized moisture vapor through porous materials.” When vapor diffusion occurs in hot, humid climates the warm, moist exterior air moves through the building envelope towards the cool, dry interior air. This form of moisture transportation becomes a problem if condensation starts forming on interior surfaces or inside wall cavities. Condensation is defined as “the physical process by which water vapor is transformed into a liquid” and occurs when the air reaches it dew point temperature. Signs that condensation may be forming inside wall cavities are peeling paint or plaster lifting off its substrate. The Brief goes on to state that condensation is a major problem in historic buildings that have improperly designed climate control systems, causing significant structural damage and creating an unhealthy interior environment.

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77 Park, “Preservation Brief #39,” 492 and 490.
78 Ibid., 490.
79 Ibid., 492.
80 Ibid., 490-491.
The last three sections of the article discuss the surveying methods for diagnosing moisture problems, selecting appropriate treatments and ongoing care for moisture issues. The section concerning surveying methods provides guidelines for the “systematic approach” to take while looking for moisture problems, as well as recommended tools to use during your investigation and questions to answer to help prevent erroneous conclusions. In fact, some of these tools (building plans, flashlight, camera) and investigation tips were used during a conditions assessment of the Aiken-Rhett House during this study. The next section titled “Selecting an Appropriate Level of

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“Treatment” discusses treatment options for moisture related problems in historic buildings. The Brief gives three different levels of treatments with corresponding charts to use as guidelines for varying degrees of moisture remediation projects. Indeed, some of these same treatment options were used as recommendations after interpreting the results from the Aiken-Rhett House building condition assessment. The last section of *Preservation Brief 39* advises that ongoing maintenance and continual monitoring of historic properties is of paramount importance in preventing future moisture problems. The article also states that in case of a mechanical or plumbing system failure, warning systems and back-up devices should be employed, as well as having an emergency plan in place and trained staff members. For example, staff members could be trained to know what to do in a situation where a plumbing pipe leaks or if the condensate pan for an air-conditioning unit overflows. These types of emergency preparedness plans could be incorporated into the operating procedures of a house museum.

Water is the worst enemy of all buildings. Not only is it difficult to manage, but it also leads to biological attacks from insects, fungus, and bacteria. All of these things combined with its ability to “dissolve buildings” make it that much more important to control. Like *Preservation Brief 24*, this article highlights the importance of continual monitoring for water intrusion, having a plan in place for water-related emergencies and

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83 Ibid., 494.
having trained staff members at historic house museums. Whether it is in regards to HVAC systems or unwanted moisture, these three components can help spot small problems before they develop into larger more expensive problems. In fact, climate control and moisture problems in historic buildings are very closely related. The indoor environment cannot be controlled while there are sources of unwanted moisture and the sources of unwanted moisture cannot be controlled with an improperly designed climate control system. The main points to take away from both of these Preservation Briefs are that after the installation of an HVAC system, it is important to train staff members to be able to recognize problems with the equipment, as well as problems relating to inadequate climate control (for example: condensation, mildew or peeling finishes). The staff also needs to be trained in how to monitor the interior environment of the museum and how to diagnose problems and take corrective actions with the data they collect. Lastly, historic house museums need to incorporate emergency plans into their operational policies. If staff members are prepared to take action during a HVAC system or moisture related emergency, then greater catastrophes may be averted and historic fabric saved. As an illustration, the staff members at Kenmore Plantation were trained to monitor their HVAC equipment and had the knowledge to be able to recognize a problem when it occurred in their geothermal system. The staff members brought attention to the issue, suggesting to the system designer that there was a water
leak, and a crisis was averted before it has a chance to become a larger, more costly problem.\textsuperscript{85}

\textbf{Air Properties & Psychrometry}

Along the same note, trained and engaged house museum staff members should understand how buildings respond to changes in the exterior and interior climate. These staff members should include the building managers, the directors of the museum and even senior-level docents. It would also be beneficial to provide the staff members with a basic understanding of the different properties of air and how they can be manipulated by simple air-conditioning processes. Mechanical engineers use a tool called the psychrometric chart to help them design HVAC systems and solve air-conditioning related problems. This chart, which is essentially a multi-axis graph, displays the properties of air and how they can change through different air-conditioning processes (figure 2.5). In fact, the word psychrometry is defined as “the science dealing with the physical laws of air-water mixtures.”\textsuperscript{86} Since the air-conditioning processes of cooling, dehumidifying, heating, and humidifying involve changes in air and water mixtures, the analysis of these air properties can be done using the psychrometric chart. At first glance, the chart is very complicated and difficult to interpret; but, with

\textsuperscript{85} Rebekah Wood, e-mail message to author, February 23, 2012. In the spring of 2008, Kenmore Plantation, a historic house museum located in Fredericksburg, VA, developed a leak in the underground water loop field of their geothermal system. Because the staff members were trained to monitor the system daily, when the issue developed they reported the problem and had the leak repaired before it became an even larger problem. This event is described in more detail in Chapter 5: Results.

\textsuperscript{86} Trane, \textit{Air Conditioning Clinic: Psychrometry} (La Crosse, WI: American Standard, 1999), 64.
simple explanations that break down each component on the chart, the concept of psychrometrics becomes easier to understand.
Figure 2.5: Standard format of a psychrometric chart that shows all of the air properties that can be found on the chart. Source: Image from Trane.
There are several air properties displayed on the psychrometric chart; however, only the five fundamental properties are discussed -- dry-bulb temperature, wet-bulb temperature, dew-point temperature, relative humidity and humidity ratio. The psychrometric chart is a great tool for determining unknown air properties because if any two of these five basic air properties are known, then the other properties can be determined by using the chart.\footnote{Trane, \textit{Psychrometry}, 6.} The first basic air property is dry-bulb temperature (DB), which is the measurement of the ambient air temperature taken with a common thermometer that has a dry bulb.\footnote{Ibid., 3.} The second basic air property is wet-bulb temperature (WB), which is taken by a thermometer with a wet bulb (created by covering the thermometer bulb with a wet wick) and it measures the dryness of the air. Because the bulb is wet, when the water evaporates from the wick it will create a cooling effect on the thermometer bulb (like when sweat evaporates to cool a body down); thus making the temperature reading of the thermometer lower than the dry-bulb temperature. The difference between the two readings is equal to the dryness of the air. The drier the air is, the more moisture evaporates off the wet bulb and the temperature reading is much lower than it would be if the air contained more moisture. Contrarily, if there is more moisture in the air, then less moisture evaporates from the wet wick and the wet-bulb temperature readings are higher. Therefore, large
differences between the dry-bulb and wet-bulb temperature signify drier air; while smaller differences signify humid air.\textsuperscript{89}

The dew-point temperature (DP) of the air is the “temperature at which moisture leaves the air and condenses on surfaces.”\textsuperscript{90} If the dry-bulb, wet-bulb and dew-point temperatures are all the same, then the air is saturated and fog can occur.

Relative humidity is expressed as a percentage that is the “comparison of the amount of moisture that a given amount of air is holding, to the amount of moisture that the same amount of air can hold, at the same dry-bulb temperature.” If the relative humidity is 100-percent, then the dry-bulb, wet-bulb and dew-point temperatures are all the same. On the other hand, if the relative humidity is anywhere between zero and 100-percent, then the different air properties (DB, WB, DP) and their location on the psychrometric chart will vary. The fifth property of air is the humidity ratio and it is a quantity that describes “the actual weight of water in an air-water vapor mixture.”\textsuperscript{91} The humidity ratio is expressed as grains of moisture (or pounds of moisture) per pound of dry air, with 7000 grains of water in one pound. This ratio can be used to calculate the relative humidity percentage by dividing the humidity ratio of the air by the humidity ratio of the air if it were saturated.\textsuperscript{92}

\textsuperscript{89} Trane, Psychrometry, 3.
\textsuperscript{90} Ibid., 64.
\textsuperscript{91} Ibid., 6.
\textsuperscript{92} Trane, Trane Air Conditioning Manual, 60.
The next aspects of psychrometrics are sensible heat and latent heat. Sensible heat “causes a change in the air’s dry-bulb temperature with no change in moisture content,” while latent heat “causes a change in the air’s moisture content with no change in dry-bulb temperature.”\textsuperscript{93} If only sensible heat is added to the air, the air is heated and the condition moves horizontally to the right perpendicular to the dry-bulb temperature lines on the psychrometric chart. Likewise, if sensible heat is removed from the air, it is cooled and moves horizontally to the left on the chart. If only latent heat is added to the air, the air is humidified and the condition moves vertically up the psychrometric chart along a dry-bulb temperature line, resulting in a higher relative humidity. When only latent heat is removed from the air, the air is dehumidified and the

\textsuperscript{93}Trane, \textit{Psychrometry}, 64-65.
condition moves down a dry-bulb temperature line, resulting in lower relative humidity. During the air conditioning process, air is usually simultaneously cooled and dehumidified or heated and humidified, resulting in the conditions of air moving at diagonal lines across the psychrometric chart representing changes in dry-bulb temperature and moisture content at the same time (figure 2.7).

![Psychrometric Chart](image)

Figure 2.7: Psychrometric chart showing the diagonal lines that represent the changing air conditions as it is cooled, dehumidified, heated or humidified. Source: Image from Trane, *Psychrometry*, Figure 30.

**How to Use a Psychrometric Chart**

The Aiken-Rhett House is used as an example to help show how air properties are related on the psychrometric chart in a real life application. Information recorded from the interior environmental data logger in the first floor West Parlor will be used in the following example (these records will be examined in much more detail in later chapters). For the purposes of this exercise, the *ASHRAE 2007 Handbook* “Class C” standards for museum buildings are used for the acceptable interior temperature and
relative humidity levels. The “Class C” level of control states that allowable temperature ranges are between 59-86°F and the allowable relative humidity ranges are between 25-75% RH.\textsuperscript{94}

**Situation:**

On August 4\textsuperscript{th} and 5\textsuperscript{th}, 2011, the data logger in the first floor West Parlor recorded dry-bulb temperatures above 86°F from 11:00AM to 4:00AM, with the highest being 90.96°F recorded at 4:00PM on August 4\textsuperscript{th}. These temperatures are too high and out of the allowable range. The relative humidity at this time is 61.9% and is within the allowable range and the dew point temperature is 76.04°F.

![Aiken-Rhett House Air Properties: 1st Floor West Parlor 8/4/11 to 8/5/11](image)

*Figure 2.8: Temperature and relative humidity levels plotted on a graph to visually show measurements outside of the allowable ranges.*

**Problem:**
The air temperature needs to be reduced below 86°F to fall within the “Class C” allowable temperature range.

**Solution:**
By plotting the three known air properties that are recorded by the data logger (dry-bulb temperature, dew point temperature, relative humidity) on the psychrometric chart, we have an index point (A) on the chart at 90.96°F DB, 61.9% RH and 76.1°F DP.

(Note: Only the dry-bulb temperature and relative humidity need to be plotted on the chart as the index point will naturally fall on the accurate dew point temperature because of the relationship between the five basic air properties. Just the same, any two of these three known air properties could be plotted on the chart and will be located at the same point that also corresponds to the third air property.)
Because the air conditions are in the allowable relative humidity range, only the dry-bulb temperature needs to be reduced. In order to reduce the dry-bulb temperature in the West Parlor, sensible heat needs to be removed from the air to cool it down below 86°F. In this example we will use 80°F as the target dry-bulb temperature. If only sensible heat is removed from the air (sensible cooling), this is represented on the chart by drawing a horizontal line from the index point over to the 80°F dry-bulb temperature line (B). By only removing enough sensible heat to drop the temperature from 90.96°F...
to 80°F, one can see on the chart that the relative humidity level has increased to approximately 87.9% RH, which is significantly higher than the allowable upper limit of 75% RH. Therefore, the air also needs to be dehumidified to bring it back into an acceptable relative humidity and temperature range.

Dehumidification is done by removing latent heat from the air. For this example, the goal is to remove enough latent heat (moisture) from the air to reduce the relative humidity to 60%. The dehumidification process is represented by drawing a vertical line

Figure 2.10: Point B plotted on the psychrometric chart at 80°F DB, 87.9% RH and 76.1°F DP. Source: Image from Trane.
from the second point (B), down along the 80°F dry-bulb temperature line to the 60% relative humidity curve, to a new point (C) that represents the desired air conditions for the West Parlor. The new desired conditions are 80°F DB, 60% RH and the DP is approximately 65°F. To achieve these desired air properties, the air must be simultaneously cooled and dehumidified by mechanical means or by passive methods.

Figure 2.11: Point C plotted on the psychrometric chart at 80°F DB, 60% RH and 64.9°F DP. The blue arrow represents the final result of cooling and dehumidifying the air. Source: Image from Trane.
The psychrometric chart is a valuable tool used by many people in the HVAC industry as well as the historic preservation field. In preservation and conservation applications, the psychrometric chart has been used to plot local climate data and to show the relationship between building materials or collections to the air around them. Before designing HVAC systems for historic structures, historical temperature and relative humidity data can be plotted on a psychrometric chart to help determine the characteristics of the local climate. Also, the chart can be used to determine the difference between the inside and outside air properties to help determine when certain air-conditioning processes should be used. Next, the chart can be used to show the moisture contents of organic building materials and collections compared to the properties of air that surrounds them. By overlaying the properties of building materials that comprise an exterior wall cavity onto a psychrometric chart, the temperature and humidity of each component in the assembly can be determined. Furthermore, the chart can be used to show the effects of fluctuations in temperature and relative humidity levels on different building materials like wood. Lastly, the chart is used to help solve different HVAC system problems. Currently, there are modern software applications that can produce psychrometric calculations without having to plot

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95 Shin Maekawa and Franciza Toledo, “Controlled Ventilation and Heating to Preserve Collections in Historic Buildings in Hot and Humid Regions” (paper presented at the ICOM-CC 13th Triennial Meeting in Rio de Janeiro, Brazil, September 22-27, 2002), 4-5.
conditions on an actual graph. Still, having a basic understanding of air properties and how they are related on is important when using these new computerized tools.\(^97\)

When dealing with air properties in historic buildings, it is important to remember that there are factors that can affect temperature and relative humidity levels even if climate control systems are utilized. Temperature and humidity levels can range broadly in different areas of older structures because of vertical and horizontal gradients.\(^98\) Vertical temperature gradients form when air stratifies into different thermal layers. Because warm air rises and cool air sinks, the temperature of air in an interior space usually increases from lower levels to higher levels (floor to ceiling or bottom floor to top floor).\(^99\) Both vertical and horizontal temperature and relative humidity gradients can be caused by heat gains from lighting and equipment, and heat gains or losses through windows, doors, exterior walls, floors and roofs.\(^100\) Air flow patterns also have an effect on temperature and humidity levels inside historic structures. Patterns of air flow are affected by room shape, room size, any vertical or horizontal obstructions, and air buoyancy -- all of which can create pockets of air that have different temperature and humidity levels.\(^101\) All of these factors affecting air properties inside climate controlled spaces mean that it is not reasonable to expect

\(^97\) Rose, “Effects of Climate Control on the Museum Building Envelope,” 51.
\(^101\) Brown, “Alternatives to Modern Air Conditioning,” 49.
HVAC systems to be able to maintain homogenous temperature and humidity levels throughout an entire building, much less throughout the entire year. Therefore, the preservation and conservation industries need to change their expectations about the interior environment that mechanical systems in historic buildings can actually achieve.

![Cooling Load Components](image)

Figure 2.12: The image of this room shows all of the different types of heat gain that can affect the cooling requirements for an interior space. The red arrows represent the heat moving into the conditioned space. In the winter, the directions of the arrows are reversed as heat moves out of the building. Source: Image from Trane, *Cooling and Heating Load Estimation*, Figure 12.

Modern buildings are constructed with inorganic materials that create a sealed interior environment that can perform in ways that older buildings cannot. Even so, these structures have difficulty maintaining consistent interior environments.

Homogenous temperature and humidity levels are even more difficult to achieve in historic structures because they are built with organic materials that breathe. This ability to “breathe” and coexist with the environment has allowed historic buildings to adapt over time and to learn with the people who use them. Prior to mechanical

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cooling, methods of passive interior climate control went through trials and errors to find what works best in different environments. Vernacular buildings like the Aiken-Rhett House evolve as they “become finely attuned” to their local climate. Today, building occupants have distanced themselves from the functionality of buildings and how they perform to control their interior climates. Perhaps part of the solution to modern means of climate control in historic structures lies with the people who use these historic buildings. If the operators of house museums can reconnect with the structures and understand how all of the building systems work together, then the options for climate control management increase considerably.

103 Brand, How Buildings Learn, 132.
Chapter 3 - Aiken-Rhett House Background

Charleston's Climate

![Map of Charleston Peninsula](image)

Figure 3.1: Map of the downtown peninsula of Charleston in the center. The Ashley River borders its west side and the Cooper River borders the east, with the Charleston Harbor to the southeast. The Aiken-Rhett House is located at the yellow marker. Source: Image from Google Earth.

The Aiken-Rhett House is located on the eastern side of the downtown peninsula of Charleston, in the state of South Carolina. The peninsula is surrounded by two rivers, the Ashley to the west and the Cooper to the east, and the Charleston Harbor to the southeast. Charleston is a coastal city and its weather is greatly affected by its close proximity to large bodies of water. The downtown peninsula of Charleston is prone to milder temperatures than other areas of the city because it is closer to the water;
however, it also tends to be more humid than the inland areas. The prevailing winds of Charleston also have an effect on humidity and temperature levels. In the summer, winds typically come from the south and in the winter months the winds blow from the north and west directions.\textsuperscript{104} Charleston’s location in a coastal zone makes it susceptible to tropical storms during hurricane season, which can bring battering winds and rain to the area. Because the elevation of the peninsula is close to sea level, the downtown area is subject to flooding, especially during heavy summer rain storms.

According to the Köppen-Geiger climate classification, Charleston is located in the “Cfa” climate type, which is described as a humid subtropical climate with hot, muggy summers and mild winters.\textsuperscript{105} The short and mild winter period usually lasts from December through February with temperatures warming up in March. The hot summer temperatures arrive in May, with the hottest months typically being July and August. Charleston receives most of its rain during the summer time, with annual averages a little over 51 inches. Snowfall is a very rare occurrence in Charleston, with temperatures reaching below 32°F on average about 28 times a year.\textsuperscript{106} In regards to climate control,
the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) has classified South Carolina as climate zone type 3A, which is described as “Warm-Humid” requiring significant amounts of cooling versus heating.¹⁰⁷

The Aiken-Rhett House

The Aiken-Rhett House, located at 48 Elizabeth Street, is situated on the northeast corner of Elizabeth and Judith streets in today’s Mazyck-Wraggborough neighborhood. The property was nominated to the National Register of Historic Places in 1977 and is known as one of the best preserved antebellum townhouse complexes in America. Though the neighborhood was laid out in 1796, no site improvements were constructed upon the present-day Aiken-Rhett property until 1820, when John Robinson, a Charleston merchant, constructed the building known today as the Aiken-Rhett House.¹⁰⁸

different from the building’s original appearance. The original building was exposed brick with a wood shingle roof, but now the brick is covered with yellow ochre-colored stucco and the roof is constructed of standing seam metal. The structure underwent several transformations during the fifty year period from 1820-70, with most changes after this time to the interior finishes and furnishings.  

Figure 3.2: Current basement level (cellar) floor plan showing room names and numbers. Source: Image from Willie Graham, Carl Lounsbury, and Orlando Ridout V, Architectural Investigations of the Aiken-Rhett House, 48 Elizabeth Street, Charleston, South Carolina (Charleston: Historic Charleston Foundation, 2005).

Figure 3.3: Current first floor plan showing room names and numbers. Source: Image from Willie Graham, Carl Lounsbury, and Orlando Ridout V, *Architectural Investigations of the Aiken-Rhett House, 48 Elizabeth Street, Charleston, South Carolina* (Charleston: Historic Charleston Foundation, 2005).
Figure 3.4: Current second floor plan, showing room names and numbers. Source: Image from Willie Graham, Carl Lounsbury, and Orlando Ridout V, Architectural Investigations of the Aiken-Rhett House, 48 Elizabeth Street, Charleston, South Carolina (Charleston: Historic Charleston Foundation, 2005).
Though the entire Aiken-Rhett property includes several intact outbuildings, such as the stables, kitchen building and slave quarters, the focus of this study is the main house. The Historic Structures Report (HSR) for the Aiken-Rhett House discusses several different periods of architectural change for the building, but the first four occur during the fifty year period (1820-70) of the most significant structural change. The first period
comprises the time of the initial construction of the house from 1820-22. The original plan for the house was a Federal style, double-pile variation of the Charleston single house. The first and second floors were two rooms deep and the third floor was only one room deep (figure 3.6). The original main entrance to the house was via grand stairs on the south elevation, which led into a central passage that offered access to all four rooms on the first floor.

Figure 3.6: Period I (1820-22) architectural floor plans of the Aiken-Rhett House. Source: Image from Willie Graham, Carl Lounsbury, and Orlando Ridout V, Architectural Investigations of the Aiken-Rhett House, 48 Elizabeth Street, Charleston, South Carolina (Charleston: Historic Charleston Foundation, 2005).

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Though the Aiken family acquired the property in 1827, they did not make any changes to the house until six years later in 1833. This time reflects the second period of significant architectural change in the house. During Period II (1833-35), a two-story wing was added to the northeast side of the main house to increase entertaining space (figure 3.7). At this same time a back stair hall was added between the new East Wing and the existing structure, the main entrance was moved to the west elevation, and double parlors were created on the south side of the first floor. Also, interior finishes were upgraded at this time, the exterior brick was covered in stucco and a metal roof replaced the original wood shingles.\textsuperscript{111}

\textsuperscript{111} Graham, Lounsbury, and Ridout V, \textit{Architectural Investigations of the Aiken-Rhett House}, II-3 and III-7.
The third period of architectural significance occurred from 1857-58, when the Aikens were on their grand tour of Europe. To display the artwork they purchased on their trip, the Aikens built a one story Art Gallery on the northwest side of the house that was accessed through the main Entry Foyer (figure 3.8). Other structural changes during Period III include the addition of two dressing rooms on the north side of the third floor and expansion of the East Wing to include a third level. While decorative finishes were upgraded to a more elaborate style during Period III, practical modern...
conveniences were also installed at this time like gas lighting, indoor plumbing and a service bell system.\textsuperscript{112}

Figure 3.8: Period III (1857-58) architectural floor plans of the Aiken-Rhett House. Source: Image from Willie Graham, Carl Lounsbury, and Orlando Ridout V, \textit{Architectural Investigations of the Aiken-Rhett House, 48 Elizabeth Street, Charleston, South Carolina} (Charleston: Historic Charleston Foundation, 2005).

The last significant phase of architectural change as determined by the Historic Structures Reports is Period IV, which is referred to as 1870s Improvements.\textsuperscript{113} During this period, access to the third floor Northwest Dressing Room was created from the

\begin{footnotesize}
\begin{itemize}
  \item \textsuperscript{112} Graham, Lounsbury, and Ridout V, \textit{Architectural Investigations of the Aiken-Rhett House}, II-4.
  \item \textsuperscript{113} Ibid., II-5.
\end{itemize}
\end{footnotesize}
central hall. It is believed the use of this room changed from private to service because a stove was installed and a flue was cut into the back of the chimney.\textsuperscript{114} Period IV also brought about the conversion of the Northeast Dressing Room on the third floor into a bathroom and the south end of the back passage was turned into a water closet (figure 3.9). Similar to the previous periods, some of the interior finishes were upgraded at this time.

![Third Floor Plan](image)

**Figure 3.9:** Period IV (1870s) architectural floor plan of the third floor where changes occurred during this time. 

**Site Orientation**

The Aiken-Rhett property sits on the northeast corner of Elizabeth and Judith Streets on the downtown peninsula of Charleston, South Carolina. Elizabeth Street runs at a slight angle through the Mazyck-Wraggborough neighborhood in the direction of

northwest to the southeast. Judith Street dead ends into the east side of Elizabeth to form a right angle; it also runs at a slight angle, going from southwest to the northeast direction. The Aiken-Rhett property is about 283 feet in length, running the entire block of Elizabeth Street from Judith north to Mary Street and about eighty feet wide, extending to the east on Judith Street.  

Because of the slight angles of the streets, the “south” elevation of the Aiken-Rhett House actually faces the southeast direction. This southeast face of the building receives the most amount of exposure to the sun as it moves across the sky. Fortunately, the piazza along the south elevation protects the building from direct exposure when the sun is high in the summer sky. The “west” (southwest) elevation of the house also receives a large amount of exposure to the sun, especially during the summer when the sun is lower in the sky.\textsuperscript{116} The west side of the building does not have a piazza or any other type of overhang that would help protect it from sun exposure. However, because of the lower position of the sun in the sky, a more vertical type of

protection is needed, rather than a porch or awning. The west façade of the Aiken-Rhett House does have palm trees planted on the Elizabeth Street sidewalk, but these do very little to help shade the west side of the building. Most of the east side of the structure is blocked by a neighboring house that abuts right up to the property line and the piazza covers the remaining exposed portion. Therefore, the east elevation receives little sun exposure. As one might guess, the north façade of the building receives very little direct sunlight, especially on the lower levels of the house. The height of house and the rear additions and outbuildings prevent direct sun exposure to the lower floors of the north elevation throughout most of the year.

Figure 3.12: The north elevation of the Aiken-Rhett House receives little direct sunlight, especially on the lower levels. Photograph by author.
Architectural Features Related to Climate Control

As discussed in Chapter 2, historic houses used site orientation, vegetation and architectural features to naturally and passively cool or heat the building. Long before the Aiken-Rhett House had mechanical climate control systems, the building occupants utilized its architectural features to control the interior environment. In the subsections below, the original architectural features of the Aiken-Rhett House that contribute to maintaining a comfortable indoor environment are briefly explained.

Full Basement

The first level of the Aiken-Rhett House finished as a living space is raised one full story above ground level. This full basement below the first floor allowed for the living spaces to take advantage of breezes and to also be a further distance away from the noise and dust of the streets. Most of the floors in the basement level are herringbone brick pattern laid directed onto the ground surface. The brick floor helps to keep the basement level of the house cooler, but it is also a source for moisture intrusion as it is in direct contact with the ground, which has a high water table.

Thermal Mass

The thick exterior masonry walls of the Aiken-Rhett House help maintain a more constant interior environment because of their thermal mass. The concept of thermal mass was explained in Chapter 2 as “time lag,” or the amount of time it takes for heat to be transmitted through a wall. The thicker the wall and heavier the material, the longer

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117 Garrett, At Home, 31.
it takes for heat to travel through the wall. At the Aiken-Rhett House the brick walls in
the basement range from 2’-4” thick on the original section of the building to about 1’-8” thick on the newer additions. As the brick walls increase in height, they are stepped
back and are thinner at the upper levels of the house, ranging from 1’-1” to 1-9” thick
depending on the location.118 These solid brick walls of the Aiken-Rhett help to keep
heat out in the summer maintaining a cooler interior temperature.

**Exterior Stucco & Limewash Finish**

Though the Aiken-Rhett House was originally an exposed brick structure, the
exterior was covered in stucco and a limewash finish during the 1830s addition of the
East Wing. The application of the stucco and limewash provides additional protection
from moisture intrusion into the interior of the building. Also, limewash coatings have
reflective properties which help reduce heat gain through the exterior walls.119

**Roof Materials**

Originally the Aiken-Rhett House had a wood shingle roof, but during the 1830s,
the wood shingles were replaced with a metal roof. As stated in *Chapter 2*, metal roofs
that are lighter in color have a more reflective finish and will allow less heat to
penetrate the interior of the building. The current metal roof was installed in the last
quarter of the twentieth century, and is constructed of modern standing seam metal

118 "Historic American Buildings Survey, Drawings & Photographs of Robinson-Aiken House, 48 Elizabeth
119 Franciza Toledo, “Museum Passive Buildings in Warm, Humid Climates” (paper presented at the
Experts’ Roundtable on Sustainable Climate Management Strategies, Tenerife, Spain, April 2007), 10.
over tongue-and-groove sheathing that was installed over the original roof lathing.\textsuperscript{120}

Though the roof could not be accessed during this study to determine the original color or thickness of the metal, it can be assumed that the existing metal roof on the Aiken-Rhett still possesses some reflective qualities even though it has darkened over time. Also, metal roofs are impermeable which is important for reducing moisture transportation into the building through the roof. Lastly, the physical properties of the metal roof at the Aiken-Rhett allow it to cool down almost as quickly as it heats up.\textsuperscript{121}

\textbf{Attic}

Originally the Aiken-Rhett House attic spaces were ventilated naturally by the wood shingle materials which were breathable. The shingles were laid a specific distance apart, thus allowing hot air to escape the attic spaces. Unfortunately, the modern metal roof has taken away the attic’s natural ability to breathe. Visual

\footnotesize{\textsuperscript{120} Graham, Lounsbury, and Ridout V, \textit{Architectural Investigations of the Aiken-Rhett House}, III-2 and III-8. Review of the HSR provided no definitive metal type, but observations and interviews have indicated that the material is copper and some parts may be terne metal.}
\footnotesize{\textsuperscript{121} Toledo, “Museum Passive Buildings in Warm, Humid Climates,” 12.}
inspection in the attic over the main block of the house did not yield any eave vents or ridge vents and the attic over the East Wing was not accessible during the study. The attic over the main block appeared to be a very tightly sealed space, so this study assumes that the other attic spaces are the same. Because attics are the areas of a building with the highest temperatures, historically eave vents were necessary. Even though the Aiken-Rhett does not have any attic vents, perhaps the lunette window in the pedimented gable once was utilized for ventilation purposes. There is no insulation in the attics at the Aiken-Rhett House, but the floor joists are covered in the original wood floorboards, providing a barrier between the attic and the third floor below.

Figure 3.14: South façade of the Aiken-Rhett House with the two-story piazza over a one-story arcade. Photograph by author.
Piazza

The south elevation of the Aiken-Rhett House has a two-story piazza supported by a one-story arcade at the ground floor (figure 3.14). The piazza runs the entire length of the south elevation and wraps around the east corner of the original house to run across the south side of the East Wing. Piazzas were typically constructed on the south or west sides of houses in Charleston to shield the exterior wall from direct exposure to the sun and to catch the prevailing breezes during the summer. Because the piazzas were positioned to catch breezes, they were used as an extension of the interior living spaces during hot, humid periods of the year. In fact, Charlestonians, the Aikens included, would often dine and sleep on their piazzas because it was more comfortable than being indoors.\textsuperscript{122}

Windows & Shutters

Most of the windows in the Aiken-Rhett House are double-hung wood sash with six-over-six light, single paned glass. Some exceptions are the large tripartite triple-hung windows, double-hung sidelights and nine-over-nine double-hung windows on the north façade. The tripartite windows are located in the first floor entertaining spaces (Double Parlors and Dining Room) to serve as doorways to the piazza. These large windows are flanked by triple hung, two-light sidelights. All of the windows in the Aiken-Rhett House are operable except the lunette in the pedimented gable on the south elevation and the semicircular transom over the front door. The double and triple-hung windows allow

\textsuperscript{122} Garrett, \textit{At Home}, 199.
each sash to move so that the bottom sash can open to allow cool air inside and the top sash can be open to allow warm air exit the building. The basement level and first floor openings have solid paneled shutters and the top two floors of the house have louvered shutters. While the shutters are used for security and light control, when closed they also allow for the windows to be open and air to circulate through the building. Shutters are also used to regulate heat gain or loss in the building. During the summer, shutters are closed when exposed to direct sunlight to help prevent heat gain and in the winter shutters can be kept closed to prevent heat loss to the exterior. In the Aiken-Rhett, windows are located across from each other on opposite walls to increase natural ventilation.

Figure 3.15: Example of a tripartite triple-hung window in the Dining Room that is used as a doorway to the piazza. Photograph by author.
Doors

Much like the window openings, doors are also used to increase natural ventilation throughout the Aiken-Rhett House. Doors can be left open to let cool air into the building and let warm air escape. Additionally, doors are located across from other doors or windows to increase the air movement through the building. An example of a door historically used for ventilation at the Aiken-Rhett is the back door in the main stair hall. Hooks installed in the door lintel secured some type of curtain that created privacy from the service yard while also allowing cross ventilation when the door was opened.\textsuperscript{123}

Stairwells

The three sets of staircases in the Aiken-Rhett House allow air to circulate passively to different levels of the building. Through gravity ventilation, warmer air will rise to the upper levels of the building, allowing for cooler air to move to the lower levels. The Entry Foyer provides means for air to move between the basement level and the first floor on the west side of the house. The main staircase is located due east from the Entry Foyer and north of the Double Parlors and provides access to the second and third floors. This staircase serves as a large ventilation shaft allowing air to pass freely between the first through third floors. Similarly, the back staircase in the East Wing addition allows for air to circulate from the first to third floors on the east side of the building.

Ceiling Heights

The interior spaces of the Aiken-Rhett House have high ceilings to help move the warm air away from the building occupants. As the warm air rises naturally to the ceilings the cooler air falls lower in the room, closer to the occupants keeping them cooler. Also, throughout the house the tops of window openings reach near the ceilings so the warm air is able to escape to the exterior. Some of the ceiling heights in the Aiken-Rhett House are: 13’-1” in the first floor West Parlor, 12’-5 ¾” in the second floor
Southwest Bedroom, 10’-1” in the second floor Northwest Dressing Room, 12’-4 ½” in the second floor Withdrawing Room, 10’-6” in the third floor Southwest Bedroom, and 8’-8 ½” in the third floor Northwest Dressing Room.124 The ceilings heights show the hierarchy of spaces with the first and second floors having higher ceilings that the third floor and the entertaining spaces and bedrooms have higher ceilings than the ancillary dressing rooms. Also, people spent more time in these entertaining spaces and bedrooms; therefore, they needed to be more comfortable and have higher ceilings.

**Chimneys & Fireboxes**

Historically, the main source of heat in the Aiken-Rhett House was the fireboxes and chimneys. There is a firebox in every room inside the house, except the two third floor dressing rooms and the stair halls. The chimneys in the original block of the main house are interior and the chimneys on Art Gallery and East Wing additions on located on exterior walls. Originally, the fireboxes used wood as their fuel source; however, most of the boxes were retrofitted to burn coal in the late-nineteenth century. The two rooms in the house that still retain their original wood-burning fireboxes are the second floor Northeast Dressing Room and the third floor North Bedroom in the East Wing. No definitive evidence was found that implies the use of radiators or a furnace at the Aiken-

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Rhett House; however, there is evidence of a stove being installed in the Northwest Dressing Room on the third floor to provide heat to this space.  

Aiken-Rhett House Climate Control Systems

Timeline of Modern Heating and Cooling Systems in the Aiken-Rhett House

Prior to the installation of any HVAC equipment, heating and cooling at the Aiken-Rhett House were provided by traditional passive methods. The multiple fireboxes on each floor supplied heat to the house during cooler periods and window and door openings provided cross ventilation to cool the house during warmer periods. The first “modern” climate control equipment to be installed at the Aiken-Rhett property was the electric heaters in the Dining Room and Art Gallery. An invoice from the family papers states that these electric heaters were installed during July 1950. The Charleston Museum removed the heaters from the Art Gallery when they restored the space during the 1980s, but six heaters still exist in the first floor Dining Room even though they are no longer in use.

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125 The Historic Structures Report cites a family letter that mentions repairs to a grate and boiler in 1901 (see end note 75 on I:26), but there is no mention if the boiler was located in the main house or outbuildings or what it was used for.
127 Ibid., I:21.
When Historic Charleston Foundation acquired the Aiken-Rhett property in 1995, they renovated the basement level to provide functional space for the staff. In the 1996 renovation project, a gas packaged system was installed under the piazza at the south wall of the East Wing. This system provided heating and cooling to the staff-occupied areas of the basement level. During this project, dirt was excavated under the existing flooring in the basement to run ductwork in the space. Supply air registers and return air grilles were installed in the floor to deliver the heated and cooled air to the conditioned spaces.

Though an exact date is unknown, the Charleston Museum installed an air conditioning system in the Art Gallery during their ownership period (1975-95). In the

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128 Glenn Keyes Architects, “Restoration of Aiken-Rhett House” (February 2, 1996), Basement Mechanical Plan, Sheet No. M1, Preservation and Museums Department Files, Historic Charleston Foundation, Charleston, SC.
Aiken-Rhett House Conservation Status Report of December 2002, the Historic Charleston Foundation discusses the residential air conditioning system that the Charleston Museum installed in the Art Gallery. The outdated Gallery system failed in early 2002, creating a poor environment for the artworks on display inside the space. In fact, during September of that year, the Foundation hired a consultant to conduct mold testing in the Art Gallery because of issues found during the demolition phase of the restoration project. The results from the report state there was a presence of active mold growth on the walls that were tested. There were already plans to update the defunct air conditioning system in the Art Gallery, but the recurring moisture problems inside the wall cavities created a new problem that needed to be addressed. This is when the design decision was made to condition the wall cavities and pressurize the Art Gallery. By the end of 2002, the restoration project for the Gallery was in progress and the final HVAC system design from the mechanical engineers was forthcoming.

At the same time that the Art Gallery restoration project was occurring, the rest of the main house was experiencing condensation problems during cooler periods. Charleston is prone to inconsistent fluctuations in temperature during the winter time when there will be a cold night followed by a warm day. When this happens, the outside air temperature heats up rapidly and the building material temperatures adjust more.

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slowly. The thermal mass of a large masonry structure, like the Aiken-Rhett House, takes more time to change temperature than the surrounding air. After a cold night the rapidly heated air would come in contact with the cooler interior surfaces and condense on the walls and floors. This excessive moisture on the interior surfaces caused harm to the historic finishes throughout the house. Clearly, the Foundation needed a solution to this problem. The idea to install a mechanical system to prevent the condensation from occurring during the winter time had been discussed for at least a couple of years. In February 2002, the Historic Charleston Foundation applied for the Cynthia Woods Mitchell Fund for Historic Interiors in hopes of gaining funding for an engineering study to examine the possibility of installing a forced-air heating system in the house. In May, the grant was approved and the Foundation moved forward with the engineering study setting out to find the most appropriate solution that was still cost-effective for the museum.

Epic Engineering, the mechanical engineers who conducted the study, determined that a forced-air heating system was the best solution for the condensation problem. If the air inside the house was kept above 60°F, then the dew point would never be reached, thus preventing condensation. The final engineered design consisted of a two-phase heating system implementation. First, heated air was

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131 Cynthia Woods Mitchell Fund for Historic Interiors Grant Application, February 2002, file National Trust Proposal, Preservation and Museums Department Files, Historic Charleston Foundation, Charleston, SC.
132 Jim Crow, e-mail message to Historic Charleston Foundation staff, December 27, 2000, Preservation and Museums Department Files, Historic Charleston Foundation, Charleston, SC.
133 Jim Crow to Jon Poston and Museum Staff, interoffice memorandum, March 15, 2004, Preservation and Museums Department Files, Historic Charleston Foundation, Charleston, SC.
introduced into the main house at the first floor, letting it heat the rest of the house through natural convection. The engineers were concerned that the heat would not reach the third floor as it may leave the building too quickly because of the leaky nature of the Aiken-Rhett House. Therefore, the system was to be operated through one cooling season to see if it functioned effectively. If not, the second phase of implementation would include installation of two furnaces in the attic to introduce more heated air at the third floor.\textsuperscript{134} Both phases of the heating system were eventually installed and this low-tech solution seems to have solved the condensation problem to this date.\textsuperscript{135}

The main house heating system was in operation by March 2004 and the startup of the Art Gallery system was not far behind.\textsuperscript{136} In May, the Foundation applied for the Save America’s Treasures grant in hopes of gaining funding for the weatherization of the main house and the outbuildings. The funding was received and the Aiken-Rhett property went through a weatherization campaign that included exterior openings restoration (doors, windows, shutters), piazza stabilization, stucco repair and a new limewash finish coating.\textsuperscript{137}

\textsuperscript{134} Glenn Keyes to Willie Graham, Orlando Ridout and Carl Lounsbury, memo, July 26, 2002, Preservation and Museums Department Files, Historic Charleston Foundation, Charleston, SC.
\textsuperscript{135} Valerie Perry, interview by author, Charleston, SC, February 6, 2012.
\textsuperscript{136} Jim Crow to Jon Poston and Museum Staff, interoffice memorandum, March 15, 2004, Preservation and Museums Department Files, Historic Charleston Foundation, Charleston, SC.
\textsuperscript{137} Save America’s Treasures Grant Application, May 18, 2004, Preservation and Museums Department Files, Historic Charleston Foundation, Charleston, SC.
Though the HVAC systems at the Aiken-Rhett House were thoughtfully designed, they began to have operational issues within a couple years. Some sort of design or equipment failure must have occurred with the Art Gallery system, because in March 2006, the original dehumidifier was replaced. The original Drykor unit was removed and a Therma-Stor Ultra-Aire 150H dehumidifier was installed and still remains in use today. The Art Gallery’s outside condenser unit (heat pump) failed in April 2009, and the fan motor and capacitor had to be replaced. A couple months later in June, the fan coil unit failed and the motor and capacitor had to be replaced in it as well. Less than a year after the Art Gallery system issues were resolved, the packaged system that provided heating and cooling to the basement level failed. Quarterly maintenance reports show that the evaporator coil had corroded beyond repair and needed to be replaced. Ultimately, the Foundation decided to replace the old Goodman gas package unit with a new Trane packaged gas/electric system in May 2010. Most likely, these failures and corrosion problems are due to the installation of the HVAC equipment in damp confined spaces that do not receive much ventilation. This type of environment lends itself to materials deteriorating rapidly until they ultimately fail.

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138 Morelli Heating & Air Conditioning, price quotation, February 16, 2006, Preservation and Museums Department Files, Historic Charleston Foundation, Charleston, SC. The proposal was accepted and approved by HCF on March 6, 2006.
139 Elizabeth Schreiner, e-mail message to Hastie, Perry and Wood, June 23, 2009, Preservation and Museums Department Files, Historic Charleston Foundation, Charleston, SC.
140 Morelli Heating & Air Conditioning, service order invoice, March 11, 2010, Preservation and Museums Department Files, Historic Charleston Foundation, Charleston, SC.
141 Minutes of Properties Committee for the Aiken-Rhett House, May 17, 2010, Preservation and Museums Department Files, Historic Charleston Foundation, Charleston, SC.
In April 2011, the Aiken-Rhett House Properties Committee approved monies for a dehumidification system study. Through the property architect, a consultant was asked to provide an analysis of the current climate control systems at the Aiken-Rhett House and to make system upgrade recommendations to improve the interior environment. On September 1, 2011, the final evaluation and recommendations report was received from the consultant. The report suggested installing a dehumidification system with the goal of controlling the interior dew point temperature. The recommendations were based on less than one month of interior air monitoring (May, 2011), historical climate data, and description of conditions inside the Aiken-Rhett by the building occupants. Currently, there are no plans to move forward with the dehumidification, but the option is still on the table.

The report references work done by the Getty Conservation Institute about climate control for museum buildings in hot, humid climates. This work stresses the importance of maintaining the interior climate close to exterior conditions to create small vapor pressure differential and less movement of moisture into the building. The consultant’s report recommends controlling the interior dew point temperature slightly lower than the exterior dew point to prevent condensation. The report also states the interior dew point needs to rise and fall with the exterior conditions and

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142 Minutes of Properties Committee for the Aiken-Rhett House, June 11, 2010, Preservation and Museums Department Files, Historic Charleston Foundation, Charleston, SC.
interior relative humidity levels need to be maintained below 60% RH to prevent mold growth. The consultant chose to limit the interior dew point temperature to a maximum of 4°F less than the exterior dew point to keep the vapor pressure differential small. Based on Charleston design data provided by ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) and the design parameters set by the consultant (4°F dew point difference, 60% RH maximum), the report states the interior temperatures in the Aiken-Rhett House will be no lower than 84-90°F during periods of high exterior dew point temperatures. The report goes on to state that if lower interior temperatures are desired during these times, then “it will be necessary to consider substantial modifications to the exterior walls and create some type of vapor barrier to resist increased vapor pressure differential created by the lower indoor dew points.”

The report provides two options to create this indoor environment. The first is to seal all of the exterior openings and air condition the building; but as discussed in Chapter 2, this is not a valid option. The report states this as well, noting the increased difference in vapor pressure between the interior and exterior would result in significant damage to the historic building materials. The second and more viable option provided is to install four dehumidification units using a combination of desiccant dehumidification and DX cooling. The supply air would have lower moisture levels, but would also be warm enough to prevent the interior dew point temperature from falling too low. Moreover, the dehumidification units would utilize the existing ductwork for

forced-air heating system, but all of the existing furnaces would be replaced. Because two of the units would utilize 100-percent outside air to positively pressurize the building, all of the exterior openings will have to be closed while this dehumidification system is operating. It appears the ultimate result from the report would create an interior environment that is warmer and less humid, but also more stagnant and uncomfortable for visitors and staff. The existing ductwork system in the Aiken-Rhett House delivers air to very few interior spaces; therefore, there would not be much air circulation if all exterior openings were closed. Small fans might be used to circulate air to provide increased levels of comfort for the building occupants.

**Current Systems**

Currently, the majority of the Aiken-Rhett House does not have any type of cooling system; however, heating is supplied to the entire main house. The two areas of the main house that are both heated and cooled are the Art Gallery and the staff-occupied areas of the ground level (figure 3.18 and 3.19). The staff-occupied areas of the basement include the office, staff lounge, gift shop, ticket office, and the room where house tours begin. The original main house climate control systems will be discussed first and the Art Gallery systems will be discussed last.
Figure 3.18: Current basement floor plan showing the areas that are heated and cooled. Source: Floor plan from Willie Graham, Carl Lounsbury, and Orlando Ridout V, *Architectural Investigations of the Aiken-Rhett House, 48 Elizabeth Street, Charleston, South Carolina* (Charleston: Historic Charleston Foundation, 2005).

Figure 3.19: Current first floor plan showing the area (Art Gallery) that is heated and cooled. Source: Floor plan from Willie Graham, Carl Lounsbury, and Orlando Ridout V, *Architectural Investigations of the Aiken-Rhett House, 48 Elizabeth Street, Charleston, South Carolina* (Charleston: Historic Charleston Foundation, 2005).
Main House

The forced air heating system for the main house was completed in 2004. This system was installed because there were problems with condensation forming on the interior walls and ceilings when exterior temperatures would warm up rapidly during the winter. Historic Charleston Foundation was able to install the heating system because they were awarded a grant in 2002, which provided funding for an engineering study that was discussed in the previous section. This heating system serves all three floors of the main house and the basement level, with equipment installed in four different locations.

The first equipment location is underneath the piazza on the south elevation of the East Wing at the basement level (figure 3.20). In this location there is an indirect gas-fired furnace that provides heat to a portion of the first floor and a gas packaged system that provides heating and cooling to the staff-occupied areas of the basement level. The gas-fired furnace uses 100-percent outside air to provide heating to the house; so, there is no return air ductwork for this unit. The supply ductwork from the furnace runs west a short distance along the exterior brick wall and cuts north into a small closet at the south end of the back stair hall. From here the duct turns to continue straight up to the first floor water closet, which is also located at the south end of the back stair hall. From the first floor water closet, the heated air is delivered to the adjacent Dining Room and the back stair hall. A decorative cast iron floor grille is installed in the southwest corner of the Dining Room. The duct supplying heated air to
the back stair hall terminates open-ended above the screen wall to the water closet and points toward the north wall. It appears the location of the terminal outlets were chosen because they offered the shortest distance to run ductwork and the least amount of historic fabric removal. The gas packaged system for the basement supplies conditioned air to the spaces through ductwork concealed under the existing flooring. Supply air registers and return air grilles are installed in the floor at inconspicuous locations so they are not easily seen by visitors.

Figure 3.20: Basement floor plan showing the location of the furnace (labeled SF-2 and circled in red) under the piazza and the associated ductwork running into the closet on the south end of the back stair hall. The ductwork runs up to the first floor through this closet and delivers heated air to the Dining Room and the back stair hall. The blue square represents the location of the packaged system that provides heating and cooling to the staff-occupied areas of the basement. Source: Image from Glenn Keyes Architects, “Restoration of Aiken-Rhett House” (July 15, 2002), Sheet No. M2, Preservation and Museums Department Files, Historic Charleston Foundation, Charleston, SC.

The second heating system equipment location is in the basement under the Art Gallery (figure3.21). Here, a second indirect gas-fired furnace provides heat for another
portion of the first floor of the main house. The furnace is located at the southeast corner of the Art Gallery basement which is adjacent to the bottom level of the Entry Foyer. A short branch of ductwork runs directly south from the furnace to provide heated air to the Foyer. Another short branch of ductwork runs up to the main stair hall on the first floor. Similar to the Dining Room, a decorative cast iron supply grille is installed in the floor in the northwest corner of the stair hall to deliver the heated air to this space.

![Figure 3.21: Basement floor plan showing location of furnace (labeled SF-1, circled in red) under the Art Gallery. Source: Image from Glenn Keyes Architects, “Restoration of Aiken-Rhett House” (July 15, 2002), Sheet No. M2, Preservation and Museums Department Files, Historic Charleston Foundation, Charleston, SC.](image)

The third and fourth locations for heating system equipment are both located in the attic. The third set of equipment provides heat for the southern portion of the original main house on the third level (figure 3.22). Here, a smaller gas furnace is
installed in the main attic above the third floor Southeast Bedroom. This furnace
delivers heated air to the Southwest and Southeast Bedrooms on the third floor. Two
arms of ductwork extend out from the furnace, running parallel to the south wall, to
deliver heated air to a diffuser installed in the ceiling of each room. The supply air for
this furnace is delivered to the equipment through a large return air grille in the ceiling
of the central passage on the third floor.

Figure 3.22: Third floor plan showing the locations of the two furnaces above in the main attic (labeled FU-1) and East Wing attic (labeled FU-2). Source: Image from Glenn Keyes Architects, “Restoration of Aiken-Rhett House” (July 15, 2002), Sheet No. M3, Preservation and Museums Department Files, Historic Charleston Foundation, Charleston, SC.
Additional heat is supplied to northeast area of the third floor by another small gas furnace located in the attic above the East Wing (figure 3.22). At this fourth and final location of heating equipment, the furnace is installed above the ceiling of East Wing’s North Bedroom at the south wall. Ductwork runs west from the furnace to deliver heated air to the back stair hall through a diffuser in the ceiling. Another branch of ductwork runs southwest from the furnace to the water closet at the south end of the back stair hall. Here, the duct runs straight down to the water closet on the second floor and then turns east to run under the flooring into the Withdrawing room. A decorative cast iron supply grille is installed in the floor at the southwest corner of the Withdrawing Room, to mimic the Dining Room below. The supply air for this furnace is delivered to the equipment through a return air grille in the ceiling of the North Bedroom in the East Wing.

The control system for the forced air heating system is very simple and is comprised of thermostats. Controls for the two indirect gas-fired furnaces that provide heating for the first floor include a wall mounted thermostat and a duct-mounted temperature sensor for each piece of equipment. Construction documents state that “a thermostat located in the building shall cycle on the make-up air and heater when temperatures inside the building drop below 68°F (adjustable). A duct-mounted temperature sensor shall modulate gas supply to provide a leaving air temperature of
100-110°F (adjustable)." The “make-up air and heater” is the packaged indirect gas-fired furnace. The thermostat for the furnace under the piazza is located on the east wall of the first floor water closet and the thermostat for the furnace under the art gallery is located on the west wall of the main stair hall. The duct mounted temperature sensors are installed inside the supply air ductwork that is connected directly to the furnace. The controls for the two furnaces in the attic are simple wall mounted thermostats set at 67°F. The thermostat for the furnace in the main attic is located on the east wall of the third floor central passage. Lastly, the thermostat for the furnace in the East Wing attic is located on the west wall of the north room in this same wing.

Placed in both these locations, the thermostats measure the temperature of the supply air (recirculated air) and not the temperature of the spaces where the heated air is delivered. The temperatures in the heated spaces may be warmer than the thermostat reading; however, the goal of this system is to have the heated air naturally circulate throughout the house. Therefore, placement of the thermostats in areas farthest away from the heated supply air ensures that even these spaces remain above the heating set point.

**Art Gallery**

The climate control system for the Art Gallery provides heating, cooling and dehumidification to the space. The equipment for this system is located under the

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146 Glenn Keyes Architects, “Restoration of Aiken-Rhett House” (July 15, 2002), Sheet No. M1, Preservation and Museums Department Files, Historic Charleston Foundation, Charleston, SC.

147 Ibid.
Gallery in its basement and in the small exterior space between the Gallery and the stable building to the north (figure 3.23). A split DX system with a heat pump provides the general heating and cooling for the art gallery. The air handler, in this case a fan coil unit (labeled AHU-1), is installed horizontally in the northern part of the basement. The corresponding heat pump (labeled HP-1) is located on the exterior north wall of the art gallery and the refrigerant piping runs between the two pieces of equipment. The dehumidifier (labeled MAU-1) is the make-up air unit for the system, bringing in outside air whenever it is needed to maintain temperature and humidity set points. Also, the dehumidifier is installed upstream of the fan coil unit so that it dehumidifies the outside air before it enters the fan coil unit to be heated or cooled. There is also an electric reheat coil (labeled EDH) installed downstream from the fan coil unit to maintain the Gallery’s heating set point. The conditioned air is supplied to the Art Gallery through ductwork run under the floor in the basement. Supply registers and return air grilles are installed in the floor near the north, east and west walls.
During the design phase of this mechanical system, there was an existing mold problem that led to concern about moisture problems developing inside the exterior wall cavity because there is no vapor barrier installed in the historic walls. The walls are comprised of load bearing masonry with plaster over lath installed on furring strips on the interior space. These furring strips are what create the 1” air space (or wall cavity) between the brick and the finished plaster. Having a conditioned space without a vapor
barrier draws the humid outside air in through the porous exterior masonry walls, where it would condense on the backside of the plaster and lath. This causes moisture damage to the interior plaster walls and would likely result in mildew and mold issues, as well as lifting plaster and peeling paint. An innovative solution from the design team was created to help prevent this damage. It was decided to pressurize and condition the 1” furred space between the exterior masonry and interior plaster walls. This solution was accomplished in four steps described below.

First, the bottom of the Art Gallery flooring was insulated and sealed so that unconditioned air from the basement did not infiltrate the space above. Second, the Art Gallery was positively pressurized to prevent the outside air from infiltrating. This was done by using the make-up air unit to draw in outside air and dehumidify it before it was delivered to the gallery. Next, the pressurized conditioned air was directed to enter the wall cavity by creating ¼” slots in the baseboard all around the room. Lastly, an exhaust fan was installed on the Gallery roof to draw the conditioned air up through the walls and out at the roof.\textsuperscript{148} Without the exhaust fan, the dry conditioned air would not move upward in the furred space to prevent moisture from entering the higher sections of the exterior walls.

The control sequence for the Art Gallery is comprised of three processes: cooling/heating, dehumidification, and pressurization. A diagram of the control

\textsuperscript{148} Glenn Keyes to Willie Graham, Orlando Ridout and Carl Lounsbury, memo, July 26, 2002, Preservation and Museums Department Files, Historic Charleston Foundation, Charleston, SC.
sequence is located in figure 3.24. For the cooling and heating controls, an automatic changeover thermostat is wall-mounted inside the Art Gallery. “Automatic changeover” means that the thermostat can change automatically from the cooling to the heating mode to maintain temperature setpoints, without having to be manually changed. This thermostat controls the heat pump operation to maintain cooling and heating setpoints that are programmed at 75°F and 72°F, respectively. The electric reheat coil provides emergency heat to the supply air if the art gallery temperature drops more than two degrees below the heating setpoint.

Figure 3.24: Diagram of the control sequence for the Art Gallery HVAC system. Source: Image from Glenn Keyes Architects, “Aiken-Rhett House” (November 12, 2003), Mechanical Plans, Sheet No. M2, Preservation and Museums Department Files, Historic Charleston Foundation, Charleston, SC.

149 Glenn Keyes Architects, “Aiken-Rhett House” (November 12, 2003), Mechanical Plans, Sheet No. M2, Preservation and Museums Department Files, Historic Charleston Foundation, Charleston, SC.
The dehumidification process is controlled by a wall-mounted humidistat inside the Art Gallery. The humidistat signals the fan coil unit and heat pump to start the cooling mode if the relative humidity inside the gallery rises above 60-percent. To help maintain the heating setpoint, the reheat coil will operate as needed. After the relative humidity inside the Art Gallery drops back down to 55-percent, the humidistat will signal the equipment to shut down if all of the setpoint conditions are satisfied.\(^{150}\)

Construction documents for the Art Gallery restoration project state that all of the temperature and humidity setpoints are adjustable.

The last control sequence for the Art Gallery is the pressurization process. If outside air temperatures rise above the adjustable setpoint (listed as 67°F on the mechanical plans), then the make-up air unit and the roof exhaust fan cycle on. As stated previously, the make-up air unit provides dehumidification for the outside air and also creates the positive pressure within the Art Gallery. The exhaust fan helps to ventilate the wall cavities by drawing the conditioned air into the cavities and out through the roof.\(^{151}\)

The use of mechanical equipment to provide positive pressurization in hot humid climates has benefited historic structures by keeping the harsh exterior climate at bay. Because historic buildings were not constructed as tightly as modern buildings they are

\(^{150}\) Glenn Keyes Architects, “Aiken-Rhett House” (November 12, 2003), Mechanical Plans, Sheet No. M2, Preservation and Museum Department Files, Historic Charleston Foundation, Charleston, SC.

\(^{151}\) Ibid.
prone to higher amounts of air leakage. Creation of positive pressure inside the Art
Gallery means that the outside air is at a lower pressure. The higher pressure air from
inside the space will constantly be seeking equilibrium by trying to move outside to the
area of lower pressure. This helps prevent the infiltration of hot, humid exterior air to
the inside of the Art Gallery; thus, reducing the probability of moisture damage to the
historic building materials and the collections housed within.

To this date, the conditioning of the furred space to prevent condensation inside
the Art Gallery wall cavities has been successful in preventing damage to the historic
fabric. Unfortunately, the inside of the wall cavities and space above the ceiling were
not accessible during this project, so any presence of condensation or resulting damage
was not detected. There are, however, a few areas inside the Art Gallery where the
decorative plaster cornice is damaged and paint on the ceiling is peeling. The plaster
damage is attributed to a water leak at the roof around the chimney that has been a
problem since the Gallery was constructed. The peeling paint on the ceiling is around
the opening for the skylight and is likely a result of UV damage or higher temperatures
closer to the opening.

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152 Glenn Keyes, interview by author, Charleston, SC, November 15, 2011. Richard Marks, interview by
author, Charleston, SC, February 23, 2012. Glenn Keyes is the property architect for the Aiken-Rhett
House and was the architect for the Art Gallery restoration project. Richard Marks was the general
contractor who restored the Art Gallery and has remained involved in property and provided consulting
on other projects.
Operating Procedures

As a house museum, the Aiken-Rhett House staff has a list of operational policies that they follow each day for opening and closing of the house. Most of the operational procedures involve managing the interior environment to provide ventilation and control natural light. The procedures were last updated in June 2009, and include protocols for times when temperatures inside the house exceed 80°F. When staff members first arrive onsite in the mornings, the doors, windows and shutters in the house are opened, starting with the basement and working up to the second floor. None of the doors or windows on the third floor are utilized in order to protect the collections that are currently stored on this level.

Any specific instructions related to controlling the interior environment are provided in the operating policies. First, there are a few rooms in the house in which the shutters are to be closed if the sun is too bright. These rooms include the first floor Library, and the second floor Northwest Dressing Room, Southwest Bedroom and Southeast Bedroom. The Northeast Dressing Room on the second floor can have its shutters open, but the window must remain closed to prevent the wallpaper from blowing in the wind. There are also precautions for some of the furnishings laid out in the operating policies. For instance, the table in the Library is deteriorating from high moisture levels inside the house, so if there is a heavy rain occurrence, the window must only be cracked slightly open. Also, the shutters on the south side of the second floor must always remain closed unless it is cloudy or rainy outside. The goal of this
procedure is to protect the furniture in the two second floor bedrooms from the harsh summer sun. In these same rooms, the shutters on the east or west side of the house are to be closed when the sun is particularly bright to help further protect the furniture. In the Art Gallery, only the shutters on the east side of the room can be opened, while the shutters on the west side stay closed to prevent sun damage to the artwork collection. The windows in the Gallery remain closed because the space is air conditioned. At the end of the museum day, around 4:30 PM, the staff begins to close up the house. From closing time until the next morning, the entire house is shut up with no ventilation, except for what is provided by the existing HVAC systems.

The Historic Charleston Foundation created a “Heat Safety Policy for Summer Operations” at the Aiken-Rhett House. The safety policy lists precautions that the staff members are supposed to take when the heat index reaches over 80°F. If the heat index reaches 100°F or more, then the house museum is closed down and does not reopen that day. While it does not specifically state this in the policy, it can be assumed that when the house is “closed” that all of the same operational procedures are followed and the building is shut up until the following day. If this is indeed the case, then the heat built up inside the house during the day does not have enough means to leave the

153 The shutters may also be used to reduce the amount of condensation on the exterior of the window sashes since the HVAC system has been installed.
155 Winslow Hastie to Aiken-Rhett House Staff and Museum Department, “Heat Safety Policy for Summer Operations at the ARH,” interoffice memorandum, July 3, 2009, Historic Charleston Foundation, Charleston, SC.
house during the night. Historically, houses were ventilated during the night (“nighttime ventilation”) because the outside air during this period is slightly cooler and drier, thus providing a more comfortable interior environment. Perhaps nighttime ventilation is an option the Aiken-Rhett House staff could pursue in the future to help alleviate the climatic extremes that exist during the summer months.

In short, there are three existing mechanical climate control systems in the Aiken-Rhett House. The system for the Art Gallery provides cooling / heating, dehumidification and pressurization for the only space in the museum that is interpreted as being restored. Several fine artworks are displayed in the space, therefore necessitating the more tightly controlled interior environment. Similarly, the staff-occupied areas of the basement are cooled and heated by the gas-packaged system, but the system is not designed to provide positive pressurization for the space. Although areas of the basement were renovated when Historic Charleston Foundation acquired the property in 1995, many of the finishes are still original and can be seen in their deteriorated state. Lastly, the top three floors of the main house have a forced-air heating system that provides minimal heating in the winter. Since the installation, the system has been successful in preventing condensation from forming on interior surfaces. Despite the success of these three systems, there are still no means of mechanical cooling or dehumidification throughout the majority of the main house.

These areas of the Aiken-Rhett House are untouched by restorers and allow visitors to

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see the passage of time through the layers of original building finishes. For that reason, protection and conservation of these historic building elements are important in keeping this place of memory alive.
Chapter 4 - Methodology

The hot and humid subtropical climate of Charleston has helped accelerate the
deterioration of the Aiken-Rhett House over the period of its two century existence.
Since the building was converted into a house museum in the 1970s, climate control
systems were installed in different areas of the house because either their use changed
(basement level) or there was a desire to better protect the historic building fabric and
collections (forced-air heating in main house and Art Gallery). The existing systems
installed in the Aiken-Rhett House provide limited spaces with conditioned air, while the
majority of the main house remains without cooling or dehumidification during long,
hot and humid seasons. This exposure to the extremes of the Charleston climate has
driven the stewards of the historic property to seek out new climate control
recommendations for their house museum. Although collections are taken into
consideration, this study aims to identify the most appropriate type of climate control
system with the protection of the building and its finishes as the priority, and collections
and visitor comfort as secondary priorities. The building is the largest artifact in the
museum; therefore, it should be given priority over collections that are not stationary.
Important considerations for the appropriateness of a climate control system are
intrusion on historic building fabric, ease of implementation, and costs of installation,
operation and maintenance. To help create a final recommendation for the Aiken-Rhett
House, four research questions were included in this study:
1. **What are the current physical conditions of the building, its finishes and HVAC systems?**

2. **What are the preferred interior environmental conditions desired for the Aiken-Rhett House? What are the current interior air properties and do they meet current museum environmental standards?**

3. **What type of current climate control systems are being employed in other similar historic house museums and what have been their outcomes?**

4. **Are there new technologies or trends in the heating, ventilation and air-conditioning (HVAC) industry that could be utilized at the Aiken-Rhett House to achieve the desired interior climate?**

In efforts to determine the most suitable type of climate control system for the property, observations, interviews, and research were employed to collect current and historical data about the Aiken-Rhett House. First, a building conditions assessment was conducted to find the current state of the Aiken-Rhett House and its HVAC systems. At the same time, environmental monitoring took place to determine the current indoor air properties in the house museum. Next, interviews and site visits were conducted with similar historic house museums to gain knowledge of their successes and failures in climatizing their historic structures. Lastly, archival research and interviews with professionals helped uncover new technologies or trends in the HVAC industry that could benefit the Aiken-Rhett House. The data collection procedures for this study are divided and explained as they relate to each of the four research questions.
**Question 1: What are the current physical conditions of the building, its finishes and HVAC systems?**

*Measurement Instrument: Building Conditions Assessment*

A Building Conditions Assessment was completed by the researcher to fully understand and interpret the current physical state of the Aiken-Rhett House. This step was important for two reasons: 1) to record the existing conditions of the building’s interior and exterior and 2) to find sources of current moisture intrusion and air infiltration. A first step in controlling the humidity inside a structure is to correct sources of water intrusion.\(^{157}\) Any water leaks or rising damp problems must be addressed before climate control system recommendations can be made. In addition to finding water intrusion problems, the main purpose of the building conditions assessment was to find current issues related to moisture infiltration and air leakage in the Aiken-Rhett House. As discussed in *Chapter 2*, moisture can enter a building in a liquid or gas state by means of capillary action (rising damp), vapor diffusion, and infiltration. Each of these methods of moisture movement into (and out of) a building can result in damage to building materials and finishes, like wood rot, cracking paint or peeling wallpaper. Only conditions in the building related to moisture and air infiltration were recorded during the inspection. After the building components were inspected, the existing mechanical systems in the main house were reviewed to determine their functionality.

The conditions assessment was conducted using three types of documentation:

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completion of inspection forms, marking up of architectural drawings, and photography of specific locations.

As stated above, the two climate control issues predicted to exist inside the house were moisture intrusion and air infiltration. These two problems are not easily observed in action; however, they produce damage to building fabric that is visible and easily recognizable. Therefore, two types of observed variables were recorded during the condition assessment, 1) those relating to the visible effects of moisture intrusion and air infiltration and 2) those relating to the sources of water intrusion and air infiltration. Some of the observed variables that represent the visible effects of these issues are efflorescence, mold, plaster loss, peeling paint, peeling wallpaper, rising damp and rot. Observed variables that represent the sources of these issues are cracks in plaster walls or ceilings, holes in flooring systems, and exterior doors and windows. These observed variables were used to create a standard inspection form for the building conditions assessment of the Aiken-Rhett House. An example of the inspection form is shown on the following page.
Moisture Intrusion & Air Infiltration
Interior Inspection

<table>
<thead>
<tr>
<th>Building Component</th>
<th>Effects</th>
<th>Sources</th>
<th>Notes</th>
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<td>Floors</td>
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</table>

Other notes:

Key:
Effects of Air & Moisture Intrusion:
Ef = Efflorescence, Mo = Mold, Mi = Mildew, ML = Mortar loss, PL = plaster loss, PP = Peeling paint, PW = Peeling wallpaper, Ro = rot, RD = rising damp, WD = water damage

Sources of Infiltration:
ED = exterior door, EW = exterior window, CC = plaster ceiling cracks, WC = plaster wall cracks, FI = holes/cracks in floor
The standard inspection form includes the room name and number, the date and time of the inspection, weather conditions on that date, and the type of HVAC systems serving the room. The form lists interior building components that were evaluated for moisture intrusion and air infiltration: walls, ceilings, doors, windows, and floors. A key is located at the bottom of the form to help explain the abbreviations for each issue. The survey form also provides ample amount of space for the researcher to include general notes about the room or notes specific to a certain building component. In conjunction with the inspection form, the researcher marked up floor plans to show where certain problems were located. The floor plan drawings used in the conditions assessment were created by the Historic American Buildings Surveys (HABS) in 1985. The same HABS drawings were used to record issues on the exterior of the building as well. Each elevation drawing was marked up to show where moisture intrusion or air infiltration problems existed. Lastly, multiple photographs were taken of the interior rooms and the exterior elevations using a 12-megapixel Kodak digital camera. The date stamp function on the camera was employed to easily document when each photograph was taken.

In addition to the water intrusion and air infiltration conditions assessment, an inspection was conducted on the existing HVAC systems in the Aiken-Rhett House. These systems were examined visually because diagnostic testing equipment was not

158 Average temperature and relative humidity data was provided by NOAA’s National Weather Service Forecast Office on their Daily Climate Reports at http://www.nws.noaa.gov/climate/index.php?wfo=chs.
available to the researcher. Photographic documentation and detailed notes were taken about the mechanical equipment and its current physical condition. In addition to the survey, archival research was conducted to find information about any HVAC maintenance issues, service reports and past installation projects.

Data Collection Procedures

The building conditions assessment of the Aiken-Rhett House took place during the months of October and November 2011. The researcher visited the property once or twice a week for one to two hours at a time to conduct the survey. Investigations were only conducted on weekdays during regular business hours of the Aiken-Rhett House. The researcher conducted the assessment onsite with a self-created field kit that included the following items: camera, moisture meter, flashlight, measuring tape, pen, paper, clipboard, colored pencils, and HABS architectural drawings. Interior conditions were recorded first, starting with the third floor and working down to the basement level, moving west to east through each floor. Exterior conditions and the HVAC equipment were examined last.

As previously stated, the date and time of each inspection were recorded prior to the start of survey period. The weather conditions were gathered at a later time from the Weather Underground website that provides historical local weather data. For the

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159 The conditions assessment took place over approximately a seven week period. It was started on October 7, 2011, and was completed on November 22, 2011.
160 Regular hours of operation for the Aiken-Rhett House are Monday – Saturday 10am – 5pm and Sundays from 2pm – 5pm.
purposes of this conditions assessment, the average, high and low temperature and relative humidity statistics were listed on the final survey forms in conjunction with the dew point temperature. This temperature and relative humidity data was taken into account when interpreting the conditions assessment findings.

The process of documenting a room would begin with the close visual examination of the plaster walls and ceilings and their respective finishes. The first item the researcher looked for was water leaks. After this, issues such as peeling paint or wallpaper, surface cracks, and areas of plaster loss were noted. Next, the doors, windows and their frames were visually examined for damage from moisture intrusion and air infiltration. Some of the telltale signs are wood rot on or near an exterior opening, finish failure (like peeling paint), and doors or windows siting unevenly in their frames. Lastly, the floor system in each room was examined for hints of water intrusion or air infiltration. Issues with flooring are cracks where a wall meets the floor or an area where the wood floorboards are separating apart. Additionally, any signs of biological growth (fungus, mold or mildew) were recorded and photographed. If a certain area of the room appeared to have water damage or rising damp, then a moisture meter tool was used to read the moisture content. In this instance, an exact moisture content measurement was not the goal; the tool was used as an alarm to identify areas that need further attention. If the moisture meter was used, the readings were recorded by
After all necessary notes were logged and photographs taken, the researcher marked the architectural floor plans to locate problems. Mark ups were color coded for different types of problems for easy identification and interpretation (for example, water damage is coded blue, peeling wallpaper is coded pink and mold or mildew is coded green).

After all of the interior rooms in the Aiken-Rhett House were surveyed, the exterior of the structure was visually examined. Each elevation was observed, starting with the north elevation of the house and working clockwise to end on the west elevation of the structure. Any issues related to water intrusion, such as rising damp or biological growth, were recorded on the exterior elevation drawings. These mark ups were also color coded according to the type of problem (for example, rising damp is coded pink and mildew is coded green). Also, photographs with date stamps were taken of any exterior problems found.

Lastly, the mechanical equipment that is currently installed onsite at the Aiken-Rhett House was surveyed. As previously stated, no diagnostic equipment was available to test the mechanical systems; therefore, the functionality of the systems is based on visual observations and maintenance records. The three areas in the main house that

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161 The Tramex Moisture Encounter tool uses an absolute scale for wood materials and a relative scale for plaster, brick, drywall, and roofing materials. The Tramex moisture meter is a non-destructive tool that has three different measurement ranges for testing different materials (wood and timber; drywall and roofing; plaster and brick). This tool is placed flat against a building material surface and then coplanar electrodes send out low frequency signals to determine the moisture content of the material expressed as a percentage.
contain mechanical equipment are the attic, the basement under the Art Gallery and the exterior area under the piazza on the south side of the East Wing. Visual inspection of the equipment was conducted to determine its physical condition. The manufacturer and model number for each piece of equipment were recorded to find product data online through manufacturer websites. Serial numbers were used to help determine when a certain product was manufactured; thus providing important information about the age of the equipment and how long it has been in operation. Also, the ductwork and insulation in these mechanical areas were visually inspected for items like types of ductwork, configuration, damaged insulation, condensation, or damaged hangers. All findings were recorded and photographed to be collated in the final survey form. In addition, the existing equipment and distribution systems were compared to the construction documents for the original installation of the HVAC systems. Any differences in the configuration of the systems compared to the mechanical plans were noted. While examination of the HVAC equipment is important, the main focus of this conditions assessment was the historic building and its finishes.

**Data Analysis**

The building conditions assessment of the Aiken-Rhett House was conducted to seek out any current water leaks or sources of moisture intrusion and air infiltration into the building. It also served to document the current physical state of the Aiken-Rhett House. The photographs from the survey were compared to historical photographs to help determine the deterioration of the building components over time. Results of the
survey were used to determine the effects that excess moisture and unconditioned air had on the historic building and its finishes. Based on the findings, corrective action suggestions were given depending on the type, severity and cause of the deterioration.

When designing an HVAC system, the interior environmental problems need to be corrected. For example, if some of the historic finishes are peeling due to excessive moisture in the air, then a means of humidity control needs to be installed. The problems found during the conditions assessment of the building were used in conjunction with the results to the other research questions to help provide the final recommendation for the Aiken-Rhett House climate control system.

**Question 2: What are the preferred interior environmental conditions desired for the Aiken-Rhett House? What are the current interior air properties and do they meet current museum environmental standards?**

*Measurement Instrument: HOBO Data Loggers*

One of the first steps in recommending an HVAC system for the Aiken-Rhett House is to establish the desired interior environmental conditions. To determine the desired interior climate conditions for the Aiken-Rhett House, the researcher interviewed three Historic Charleston Foundation staff members for their preferred standards and any particular concerns they may have regarding climate control systems. These preferences and concerns of the HCF staff members were taken into account during final recommendation stage of the Aiken-Rhett House study. The next step in recommending a climate control system is to determine what the current interior air
properties in the Aiken-Rhett House are and if they meet current museum environmental standards as set forth by the conservation and HVAC industries. Routine measurements were taken over a period of time to determine the interior air properties in the house. A simple tool used for this purpose is an electronic temperature and relative humidity data logger.

This study used the HOBO H8 family of data loggers to record the air properties of the interior conditions at the Aiken-Rhett House. More specifically, the HOBO Data Logger model number RH/Temp/Light/External - H08-004-02 and model number Temp/RH - H08-003-02 were used. The H08-004-02 model has the ability to take measurements of temperature, relative humidity and light intensity; however, only the temperature and relative humidity readings were utilized, as light was not a variable considered in this project. Both data loggers calculate dew point temperature as well. The H08-004-02 and H08-003-02 Data Loggers have a programmable start date and time, as well as a programmable sampling rate. This means that an individual data logger can be programmed to start taking temperature and humidity readings on a specific date and at a specific time. Also, the data loggers can be programmed to take readings at specific time intervals chosen by the user. In this study, the HOBO data loggers were programmed to take readings once every thirty (30) minutes. After the

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162 A detailed explanation of the current museum environmental standards is provided in Chapter 5: Results.
period of data sampling was completed, the loggers were downloaded with the Onset Computer Corporation’s BoxCar Pro software. The sampled readings were then compiled and the measurements were used to analyze the interior air properties.

**Data Collection Procedures**

Six HOBO data loggers were used to collect temperature and relative humidity readings in the Aiken-Rhett House. Three of the loggers (model H08-004-02) were owned by the Historic Charleston Foundation and were sampling the interior conditions since April 2011. The other three data loggers (model H08-003-02) were deployed in the house by the researcher in October 2011.

First, batteries (lithium CR-2032) were replaced in each logger to ensure their functionality. Next, all previously collected information on the logger was deleted and the unit was reset using the BoxCar Pro software. The data logger is connected to the host computer with a USB cable, which instigates the startup of the BoxCar software. Once the software program has started, the data logger can be renamed and reset by using the “Launch” option. Because the three data loggers owned by Historic Charleston Foundation were already setup, the three data loggers from the researcher were programmed to take readings at the same time intervals. Using the software program, the time interval to take readings was set for every thirty (30) minutes. The Start Date

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164 The researcher was given access to the Onset Computer Corporation’s BoxCar Pro software on a host computer at the Historic Charleston Foundation office in the Nathaniel Russell House.

165 The three HOBO data loggers (model H08-003-02) used by the researcher were provided by an advisory committee member on this thesis project.
was selected as October 27, 2011, and the Start Time was delayed to 5:30PM (17:30) to provide ample time for the researcher to set the loggers up inside the house before they started recording.\textsuperscript{166} Based on the storage capacity of both HOBO data logger models, the devices could measure readings for up to 82 days, 17 hours and 30 minutes. Despite this capacity, the researcher collected recorded measurements from the data loggers approximately once every four weeks at the beginning of each month (November 2011-February 2012) the study took place.

The three HOBO devices deployed by the researcher were numbered corresponding to the floor level of the house in which they were located. This idea was taken from the numbering system used by the Historic Charleston Foundation on their devices. For example, the loggers numbered “1” were used on the first floor of the house. All of the HCF data loggers were located on the west side of the building, in the southwest rooms on the first through third floors. The curators at HCF did not monitor the basement or attic conditions because no collections or historic decorative arts existed in these spaces. Because the researcher only had three data loggers available, these were placed on the east side of the house on the first through third levels of the East Wing. It was decided to locate the data loggers on the east side of the house to be able to compare air properties on opposite sides of the house that occurred at the same

\textsuperscript{166} This Start Date was arbitrary. It was chosen because this is when the Historic Charleston Foundation had time to show the researcher the protocol for using the HOBO data loggers. \textit{Note:} During the study, it was found that the data loggers owned by HCF were actually taking readings once every hour, instead of once every 30 minutes like the loggers provided by the researcher. Therefore, when analyzing the measurements from the researcher’s loggers in \textit{Chapter 5}, only the measurements recorded at the start of each hour were used to be able to compare measurements taken at the same time by HCF’s loggers.
time. The chart and floor plans below provide the names and locations of each data logger deployed in the Aiken-Rhett House:
<table>
<thead>
<tr>
<th>HOBO Data Logger No.</th>
<th>Location</th>
<th>Dates</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1st Floor, West Parlor (102), fireplace mantle on north wall</td>
<td>5/20/2011-2/3/2012</td>
</tr>
<tr>
<td>2</td>
<td>2nd Floor, Southwest Bedroom (202), marble top bureau in southeast corner of room</td>
<td>5/20/2011-2/3/2012</td>
</tr>
<tr>
<td>3</td>
<td>3rd Floor, Southwest Bedroom (302), dresser on west side of the room</td>
<td>5/20/2011-2/3/2012</td>
</tr>
<tr>
<td>1b</td>
<td>1st Floor, East Wing, Dining Room (108), fireplace mantle on east wall</td>
<td>10/27/2011-2/3/2012</td>
</tr>
<tr>
<td>2b</td>
<td>2nd Floor, East Wing, Withdrawing Room (208), fireplace mantle on east wall</td>
<td>10/27/2011-2/3/2012</td>
</tr>
</tbody>
</table>

Table 4-1: The names, locations and dates of the HOBO data loggers used in the Aiken-Rhett House climate control study. See floor plans below showing the locations of each device.

Figure 4.1: First floor plan showing the locations of HOBO data loggers 1 and 1b. Source: Image from property file at Margaretta Childs Archives, Historic Charleston Foundation, Charleston, SC.
Figure 4.2: Second floor plan showing the locations of HOBO data loggers 2 and 2b. Source: Image from property file at Margaretta Childs Archives, Historic Charleston Foundation, Charleston, SC.

Figure 4.3: Third floor plan showing the locations of HOBO data loggers 3 and 3b. Source: Image from property file at Margaretta Childs Archives, Historic Charleston Foundation, Charleston, SC.
After the pre-determined four week period concluded, the researcher downloaded the recorded measurements from each individual data logger. This was conducted onsite at the Aiken-Rhett House using a tool called the HOBO Shuttle data transporter - H09-003-08.\(^{167}\) The HOBO Shuttle allowed the researcher to offload the data loggers and relaunch them in the field without the use of a computer. In the field, each data logger was connected to the Shuttle via an interconnect cable. After the offloading was complete, the Shuttle would test and then relaunch each logger. On relaunch, the Shuttle would synchronize the sampling time intervals with the logger’s previous deployment intervals.

The last step required to collect measurements from HOBO data loggers was to download the information stored on the Shuttle to the host computer. The Shuttle was connected to the computer with the same USB cable originally used to launch the data loggers. Once connected to the computer, the BoxCar Pro software starts up, and the “Readout” option is selected from the Logger menu. The software then offloads all of the data logger measurements and saves them in a separate file for each logger on the computer. Also, the BoxCar program checks the battery life of the HOBO Shuttle and synchronizes its clock with the host computer. Once offloading is completed, the data from each logger is exported into a Microsoft Excel spreadsheet to be used by the researcher during data analysis.

\(^{167}\) Product specifications for the HOBO Shuttle data transporter - H09-003-08 can be viewed at http://www.onsetcomp.com/products/communications/h09-003-08.
Data Analysis

Analysis of the air properties was performed using a line and bar charts. First, all of the measurements from a single data logger were compiled into one spreadsheet and then the data was formatted as a table to make it easily searchable. Next, the hourly measurements of temperature, relative humidity and dew point temperature were plotted on line charts. The current museum standards were also plotted on the charts as flat lines to show the acceptable upper and lower levels of temperature and relative humidity. Locations where the temperature or humidity levels went above or below the acceptable ranges were examined more closely. When incidences like this occurred, the air properties of that individual day were plotted on a separate graph. On these individual charts, temperature is still represented by lines, but relative humidity is represented by bars to make the chart easier to read. The weather conditions on the days that incidences occurred were then compared to the interior conditions in the house to see if any correlation could be determined. Any unusual occurrences represented by large spikes in the line charts were also investigated to determine their cause. Lastly, the interior air properties of each floor and each side of the house were analyzed to determine the relationship of the environmental conditions to each other and potential causes and effects. The interior air property findings are important to the Aiken-Rhett House study because they show when and where different areas of the building are affected by extreme temperature and humidity levels. This information will
be used to make the final recommendations for climate control methods in different parts of the house.

**Question 3: What type of current climate control systems are being employed in other similar historic house museums and what have been their outcomes?**

**Setting**

The Aiken Rhett House is located on the downtown peninsula of Charleston, South Carolina, at 48 Elizabeth Street. The building is situated at the northeast corner of Elizabeth and Judith Streets in the Mazyck-Wraggborough neighborhood of the city’s Old & Historic District. A selected group of other historic house museums were examined as comparative case studies for the Aiken-Rhett House climate control system. All but one of the case study sites used in the research are located in the Old & Historic District as well.

A few blocks to the southwest of the Aiken-Rhett property in the same neighborhood, sits the Joseph Manigault House at 350 Meeting Street. The Manigault House is on the east side of Meeting between Ashmead Place to the south and John Street to the north. Also, the Nathaniel Russell House is located at 51 Meeting Street in the South of Broad area of downtown Charleston. The Russell House is situated on the west side of Meeting Street between Tradd Street and Prices Alley. Thirdly, the Heyward-Washington House is also located South of Broad, one block east of Meeting.

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Street, on the west side of Church Street. Lying at 87 Church Street, the Heyward-Washington property is between St. Michaels Alley and Tradd Street. The last case study examined was Drayton Hall, a plantation house located nine miles northwest of downtown Charleston at 3380 Ashley River Road. Located in the Ashley River Historic District, the plantation house of Drayton Hall sits between the north side of Ashley River Road and the Ashley River.

Figure 4.5: Map showing the location of Drayton Hall (yellow marker at top left) in relation to the Aiken-Rhett House (red marker at center). Source: Image from Google Earth.

**Case Study Sites**

The sampling procedure used to select historic house museum case studies was purposive sampling. A purposive sample is a nonrandom group where the members are selected based on certain criteria established by the researcher in regards to the research questions the study aims to answer. The criteria considered for selection in the Aiken-Rhett House study included: location, size, building materials, current HVAC systems, use, and age.

Only historic buildings located in the greater Charleston area were selected as case studies. Case study sites needed to be located in the same climate zone as the
Aiken-Rhett House and preferably the same type of geographic region for a more accurate comparison. The next requirements for participants were their size and building material composition. Sites selected needed to be large, thick walled masonry structures with interior plaster walls and significant historic finishes similar to the Aiken-Rhett House. Masonry structures have thermal mass that can greatly affect their interior environmental conditions; so no wood structures were selected as case studies. The sample group was also selected based on their current climate control systems, with the goal being to examine a range of different types of methods. Case studies included one structure with no mechanical climate control system, one partial conditioned structure (heating and restricted cooling) and two fully conditioned structures (heating and cooling). Next, the use of the buildings needed to be similar to the Aiken-Rhett House, which operates as a historic house museum with some delegated office space, storage space and gift shop and staff lounge. Lastly, the age of each building was considered during the sampling process. Because the Aiken-Rhett House dates to 1820-22, buildings with original construction dates earlier than 1720 or later than the 1850 were not considered.

After reviewing the available pool of historic house museums in Charleston, the following sites were selected: Drayton Hall (1738-42), Joseph Manigault House (1803), Heyward-Washington House (1772), and Nathaniel Russell House (1808). Drayton Hall is the only site that does not have any type of mechanical climate control systems. The Joseph Manigault House is partially climate controlled and the Heyward-Washington
House and Nathaniel Russell House are both entirely climate controlled. Descriptions of these historic house museums are included in *Chapter 5: Results*.

Because there are no historic house museums in the greater Charleston area that have geothermal heat pumps systems, it was necessary to look outside of Charleston or at a building within the city that has a different use. Two sites with geothermal systems were considered for primary case studies, but one is located outside of South Carolina (Historic Kenmore Plantation in Fredericksburg, VA), and the other (Middleton-Pinckney House) is used as an office building, even though it is located in Charleston. Ultimately these sites were not selected for primary case studies, but they are mentioned in *Chapter 5* to provide examples of geothermal systems in historic houses.

*Measurement Instrument: Historic House HVAC System Questionnaires & Site Visits*

Four historic house museums with different types of HVAC systems were selected for case studies. The researcher created a list of pertinent questions relating to climate control systems that are used at historic house museums. These questions were compiled into a questionnaire that was used during interviews on site visits to the case study properties. Interviews were conducted with a historic house museum staff member who is involved in the day to day operation of the building. Questions included basic information about the building and the interviewee, along with specific questions
about the HVAC systems. Most of the questions related to the reasons for installation of an HVAC system at that particular property and the outcomes of the installation. The questionnaire seeks to gain the opinions of the staff members who are intimate with the museum properties because ideally they have the most concern for the appropriate stewardship of the property. The main purpose of the questionnaire was to determine how different types of climate control systems effect historic structures.

**Data Collection Procedures**

After the desired historic house museum case studies were selected, each site was contacted to ask if they would be willing to participate in the Aiken-Rhett House climate control system study. All four candidates agreed to participate in the project and were willing to let the researcher conduct site visits that included an interview and a tour of the facility. Each site visit was scheduled with the person who would be interviewed and also provide the house tour. The researcher was referred to the interviewees by other staff members because they had the most knowledge of the HVAC systems and their effects on the historic building fabric and the collections. Not all interviewees were on site at the house museums every day, but they were involved with the day to day operations of the facility.

Visits started with the interview and ended with the walk-through of the building. This procedure was chosen because it allowed the researcher to have a better understanding of the current HVAC systems installed in the house before the actual tour
took place. Because the systems and any problems were discussed before the tour, the interviewee was aware of the issues to show the researcher while walking through the building. The length of the site visits depended on the complexity of the HVAC systems onsite; however, all were completed within 1.5 to 2 hours. The majority of the time was spent on the interview process and discussion; while the house walk-through and photographs typically took about 30 minutes to complete.

The interview was conducted one-on-one with the historic house museum staff member during regular operating hours. The questionnaire form created by the researcher was used as the guideline for the interview process. Each interviewee was given a hard copy of the questionnaire during the interview to look over as the questions were asked verbally by the researcher. The questions were asked in order of the questionnaire; though some responses to questions at the beginning of the questionnaire helped to answer questions near the end. The researcher used a laptop to input answers to the questions electronically on the questionnaire form. After each site visit, the researcher edited the questionnaire form to correct any grammar or spelling mistakes made during the interview process. The forms were then sent electronically to the interviewees for review and comment to ensure the researcher had not made mistakes or misinterpreted what the interviewee stated. This also gave the interviewee the opportunity to add any further comments that they make have omitted at the time of the site visit. Lastly, any comments or changes requested by the interviewee were made to the questionnaire forms. The finalized questionnaire forms and photographs
from the walk-throughs were used to conduct analysis on the historic house museum case studies.

**Data Analysis**

The historic house museum case studies were analyzed based on the type of HVAC system installed at the property. After the site visits were completed, an examination of the HVAC related problems was undertaken. Using the questionnaires from the interview process, the researcher categorized climate control related problems with the types of HVAC systems being used. Examples of successes and failures were reviewed to understand the pros and cons of each type of system from an operational standpoint. The researcher used the lessons learned from the case study properties to help choose the appropriate climate control system recommendation for the Aiken-Rhett House.

**Question 4: Are there new technologies or trends in the heating, ventilation and air-conditioning (HVAC) industry that could be utilized at the Aiken-Rhett House to achieve the desired interior climate?**

**Data Collection Procedures**

Current practices regarding climate control for historic buildings in warm, humid climates were researched through online databases and historic preservation and conservation related organizations and research institutions. Industry professionals were also interviewed to find new climate control technologies or trends that could benefit the Aiken-Rhett House.
Data Analysis

Research findings were analyzed to determine which new climate control technologies and trends would be appropriate to apply at the Aiken-Rhett House. If findings were deemed inappropriate, then reasons are provided for why the item is not a suitable application for the Aiken-Rhett historic house museum.
Chapter 5 - Results

The results gathered during the Aiken-Rhett House climate control study are organized by the four research questions first introduced in Chapter 1. Research findings are presented in the order of all four questions. Interpretations of the results are presented in Chapter 6: Conclusion, along with the final recommendations for the Aiken-Rhett House.

Question 1: What are the current physical conditions of the structure and its finishes?

After the last member of the Rhett family moved out of the house in the late 1960s, preventive maintenance and updates to the house ceased until it was turned into a house museum in 1975. The Charleston Museum had intentions of restoring the Aiken-Rhett House, but because of financial reasons the major restoration project was never undertaken. Even so, the Museum did add an air conditioning system to the Art Gallery, restored the Grand Foyer and the piazza, and added the water closet in the first floor back stair hall during their ownership period. During the late 1970s, the Historic American Buildings Survey (HABS) documented it creating architectural plans and taking photographs of the existing conditions of the property. These photographs provide benchmarks for the current study to compare the state of the building and its finishes now to the conditions thirty years ago.
Currently, the majority of the Aiken-Rhett House is not climate controlled, which the owners think has a negative effect on its historic finishes. The first floor Art Gallery and the basement level both have air conditioning systems, but the rest of the building has only a forced air heating system for use during cooler periods. The Art Gallery restoration was completed in 2004 and the basement level was renovated in 1996 to provide working spaces for the house museum staff. Historic Charleston Foundation does maintenance on the house, but only what is in line with their conservation philosophy for the property. Though the exterior openings and stucco were restored in the mid-2000s to help weatherize the building, the Art Gallery is the only interior space that has been restored since the Charleston Museum era. Therefore, the finishes there are the newest and the best maintained.

Inevitably, the hot humid climate in Charleston has taken a toll on the historic house over the nearly two centuries of its life, but the deterioration has increased since it has been used as a house museum. Because collections are stored on the third floor and the house is not occupied at all times, the use of traditional passive techniques has been greatly reduced. Also, portions of the building like the Art Gallery and basement level have been closed off from the rest of the house in order to keep the conditioned air in those spaces only. Consequently, the reduction in natural air flow and air conditioning only parts of the house have resulted in accelerated deterioration of the historic structure and finishes.
For this study, the current state (2011) of the deteriorated building materials was documented in order to gain a better understanding of the effects of the Charleston climate on the Aiken-Rhett House. Because it is impossible to control humidity inside any structure that has water intrusion problems like roof leaks and rising damp, these issues must be addressed before any type of climate control system can be installed.\textsuperscript{169} While discovering water leaks was a major component of the condition assessment, other goals included finding sources of moisture intrusion and air infiltration problems. In addition, the existing mechanical systems in the Aiken-Rhett House were inspected to determine their functionality.

For detailed review of the results of the conditions assessment, the Moisture Intrusion & Air Infiltration Interior Inspection forms are located in \textit{Appendix B}. There is an inspection form for each room on the ground through third floors. The marked-up architectural drawings are located after the inspection forms in the same appendix. To help identify room names and numbers, labeled floor plans are included at the beginning of the \textit{Appendix B}. The Mechanical Systems Inspection forms are located at the end of \textit{Appendix B}.

Findings

The first priority, therefore, of the Aiken-Rhett House Condition Assessment was to locate any current water leaks. Several locations in the house had evidence of past water damage, but the leaks or sources of this damage had already been fixed. For example, there are water stains on the north wall of the third floor Southwest Bedroom above the firebox and evidence of water intrusion in northeast corner of the third floor Northwest Dressing Room. The evidence of water leaks found during the inspection are attributed to Hurricane Hugo damage in 1989 and were repaired shortly thereafter.

Figure 5.1: Water stain on the north wall of the third floor Southwest Bedroom. This source of water intrusion is no longer active and is attributed to damage during Hurricane Hugo. Photograph by author.

While the inspection for water leaks yielded negative results, there is clear evidence of rising damp issues on the Basement Level where the foundation walls are in contact with the moist ground. Currently, the north side of the house never gets dry,
evident by the mildew and biological growth on the north elevation (figure 5.2). Several rain leader downspouts empty into the back service yard on this side of the house. Also, the area of the yard closest to the house is paved with bricks. These bricks are very porous and absorb moisture from the ground and from the rainwater, never getting fully dry. Options to help minimize the rising damp problem would be to redirect the rainwater downspouts and to improve drainage away from the backside of the house.\footnote{Sharon C. Park, “Holding the Line: Controlling Unwanted Moisture in Historic Buildings,” National Park Service Preservation Brief #39, 1996, http://www.nps.gov/hps/tps/briefs/brief39.htm (accessed September 16, 2011).}

![Figure 5.2: Rising damp issues on the north elevation of the house have led to biological growth on the bottom of the wall and the adjacent brick pavers. Photograph by author.](image)

Based on the inspection results, it appears that a majority of the interior issues are related to high relative humidity and temperature levels. Rapid fluctuations in temperature and relative humidity levels are causing the interior finishes to deteriorate and eventually fail. Though the Aiken-Rhett House recently underwent a restoration of
its exterior coatings, the interior plaster walls and ceilings are in poor condition with many cracks throughout the house. The interior plaster ranges from poor to fair condition depending on the room, except for the Art Gallery where it was recently restored. The cracks in the plaster range in size from hairline to ¾” wide of various lengths. In addition, most rooms in the house have at least some small area of plaster loss with exposed wood lath. Some rooms are in worse condition -- for instance, the entire ceiling of the second floor Northeast Dressing Room is missing plaster. These cracks and areas of plaster loss provide more opportunities for the exterior air and moisture to infiltrate the interior of the Aiken-Rhett House.

Figure 5.3: Complete plaster loss on the ceiling of the second floor Northeast Dressing Room. Photograph by author.

Restoration of the interior plaster is currently not an option based on the conservation interpretation of the house museum. If the ultimate decision is made to install a typical climate control system, the Foundation should consider repairing the
cracks and replacing lost plaster to create an air barrier because the main way moisture enters a building through a wall cavity is by air infiltration, not permeability. Also, current research has shown that hairline cracks can introduce the same amount of moisture into a building as a whole wall can through moisture permeation.\textsuperscript{171} On the other hand, a solution to the crack issue could be by means of positive pressurization of the building to adequately offset the “humid leaks.”\textsuperscript{172} Positive pressurization requires fresh outside air intake to provide enough air exchanges in the building to reduce the potential for biological growth and condensation in wall cavities, as well as to compensate for leakage to the outside. For this to be accomplished in the South, the outside skin of the building needs to be tighter than the inside skin, while both allow vapor diffusion to easily occur through their materials. If one or both sides of the wall cavity are impermeable, then the potential for condensation inside the cavity increases.\textsuperscript{173} Positive pressurization could be built in to a new climate control system or the use of passive methods of climate control could be increased to improve the amount of ventilation through the interior space.

\textsuperscript{172} Ibid., 26.
\textsuperscript{173} Ibid., 27.
One of the most sensitive finishes in the Aiken-Rhett House is its historic wallpapers, some of which date to the 1850s. The high humidity levels in the house have allowed moisture to penetrate the paper and the plaster. Because the wallpaper paste is water soluble, when it gets damp, there is a high potential for mold growth. Moisture will eventually remove the paste from walls or the ceilings and the paper will separate from the substrate and peel off.\textsuperscript{174} This condition can be seen throughout the Aiken-Rhett house. Another wallpaper issue associated with moisture is the failure of the paint or pigments of the applied color or pattern. Water soluble paint pigments can be easily damaged by moisture, whether it is in the form of humidity, condensation or water.

intrusion. An example of this type of failure occurs in the first floor West Parlor, where a majority of the 1850s wallpaper paint has either faded or deteriorated because of high levels of humidity in the house.

![Wallpaper paint failure on the north wall of the first floor West Parlor. Photograph by author.](image)

Figure 5.5: Wallpaper paint failure on the north wall of the first floor West Parlor. Photograph by author.

The historic paint coatings in the Aiken-Rhett House are in moderately to severely damaged condition with most of the paints either peeling, cracking or alligatoring. These deterioration conditions occur not only on walls and ceilings, but also on doors, windows, wood trim and wainscoting. The peeling paint is caused by water vapor moving through the wall cavities and getting trapped behind the layers of paint. Cracking paint occurs when the coating becomes too brittle and it can no longer expand and contract when temperature or humidity levels in the house fluctuate. The alligatoring paint is an advanced stage of cracking, and the coating no longer has the
ability to protect its substrates from moisture intrusion. Paint is also subject to biological attack from mold and mildew in places where the paint surface remains wet for too long.

![Image of paint alligatoring on window frame and paint cracking on window sill](image)

Figure 5.6: Examples of paint alligatoring on the window frame in the Main Stair Hall (left) and paint cracking and alligatoring on a window sill in the second floor Northwest Dressing Room (right). Photographs by author.

Because the first, second and third floors are not air-conditioned, it is necessary to implement some sort of climate control methods to change the temperature and humidity levels in the house to help better protect the historic finishes. One passive option is to increase the use of natural ventilation throughout the house to keep interior surfaces drier by more air circulation. This could be accomplished through use of the operable windows and shutters on the third floor of the house. Portable fans could be placed in the two stairwells to help pull the warm, humid air up to the third floor and out through the windows on that level.

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175 Weaver, Conserving Buildings, 222.
Other sources of air infiltration and moisture intrusion are the exterior doors and windows. These underwent restoration in the mid-2000s during the exterior envelope restoration project to help weatherize the building. Even though this project was completed only a little over five years ago, some of the windows and doors do not sit correctly and will need to be properly fitted into their respected frames to ensure the least amount of air infiltration possible. Because of the high levels of heat and humidity in Charleston, these exterior wood elements are constantly subjected to shrinking and swelling cycles which result in their not fitting appropriately in their frames. Also, many windows and doors in the house have cracks around their frames, which contribute to moisture and air infiltration into the house. Copper weather stripping is installed on the windows, but no weather seals are installed on the doors. Perhaps, weather stripping could be added to the exterior doors to help reduce air infiltration. Because historic buildings are designed to breathe, there is not much that can be done about this issue without significant alterations to historic fabric. Once again, mechanical positive pressurization of the building or increased use of passive methods appear to be two viable, potential options. To use passive elements effectively, windows, shutters, and doors need to be on a yearly inspection cycle with plans for remedial repair probably every other year. While this type of maintenance may appear expensive, it would likely be less expensive when compared to the cost of constantly running an HVAC system to positively pressurize a building the size of the Aiken-Rhett House.
The existing mechanical systems in the Aiken-Rhett House are operating properly and are functioning as they were designed. Maintenance records and service reports were examined to find any problems with the HVAC systems since their installation. The forced air heating system equipment is less than ten years old, no recent mechanical issues were found in the records, and the system has an expected ten more years of use before replacement is anticipated. The Art Gallery equipment, however, had failures in 2009, and the fan motors and capacitors had to be replaced in the outside condenser and the fan coil unit. This was only five years after the systems started operation. The location of this equipment was the likely cause of its failure in such a short period of time. The fan coil unit is located in the cellar below the Art Gallery and the condenser is located in a narrow alley between the north side of the Gallery and the stable building. These two locations are always moist and do not receive much ventilation, therefore creating a perfect environment for the corrosion of metal mechanical parts. The basement level gas-packaged system was recently replaced in 2010 for similar reasons. Its location under the first floor piazza also creates an environment that is humid and receives inadequate ventilation. The evaporator coil in the previous system was severely corroded and approximately fifteen years old; therefore, the decision was made to replace the entire unit.
Figure 5.7: The heat pump for the Art Gallery climate control system is located in a narrow alley between the Gallery addition and the stable building (left). The gas/electric packaged system serving the staff-occupied areas of the basement is located underneath the piazza on the south side of the East Wing (right). The reduced amount of ventilation in both areas has contributed to the shorter lifespan of the equipment. Photographs by author.

All of the systems are under a maintenance contract and are serviced quarterly. During the condition assessment, only minimal maintenance issues were found. Torn ductwork insulation was the most common issue. There were also some minor housekeeping issues like wrong sized filters and storing items on top of the HVAC equipment. These minor issues should be addressed and quarterly maintenance should continue. One item that might present a problem in the near future is the corrosion of the copper refrigerant lines that run between the fan coil unit and the condenser unit. It appears that the condensate line from the fan coil has dripped onto the copper lines, causing them to corrode. The condition is still minor, but should be addressed before the lines need to be completely replaced.
Figure 5.8: View of the copper refrigerant lines with corrosion evidence directly below the PVC condensate line exiting the fan coil unit (left). Close-up of the corrosion on the refrigerant lines (right). The improperly sized air filters for the fan coil unit can be seen in both photographs. Photographs by author.

Conclusion

The conservation practices currently being employed at the Aiken-Rhett House go hand in hand with Historic Charleston Foundation’s interpretation philosophy for the house museum. The Foundation has adopted a conservation approach for the entire property and there are no current plans to restore the site. Only minimal interference and stabilization methods are used to prevent the structure from deteriorating further. One of the main attractions about the Aiken-Rhett House is the fact that it has not been restored. Visitors enjoy seeing the deteriorated historic finishes, and leaving them in place has fostered many studies about the property. Furthermore, the museum is essentially a mid-nineteenth century time capsule because so little has changed on the interior since the 1870s. Because it is rare to find examples of surviving interior finishes, especially those without restorations, those in the Aiken-Rhett House are well worth
conservation. In fact, renowned paint analysis expert Susan Buck states in her dissertation that “the Aiken-Rhett House may be the only house in the city that retains most of its nineteenth-century finishes and fittings.”

This being said, building materials can have only a certain life expectancy before they fail or intervention is needed. The Foundation also inherited several problems that are relatively modern and might be restored at least partially by simply recognizing the period of significance at the end of the family occupancy in the 1960s. Hurricane Hugo damage and subsequent inappropriate paint finishes might be addressed in that manner. Though the Aiken-Rhett House has a conservation mission, something needs to be done to prevent the interior historic building materials from deteriorating even more. If the long-term master plan for the property is to not ever restore it, then a more intensive stabilization campaign is needed. The historic paint coatings that are peeling could be stabilized and reattached with a water-soluble adhesive, much like the work that occurred at Drayton Hall in 2003. The historic wallpaper coverings could also undergo a similar stabilization campaign using a water-soluble paste to re-adhere the peeling papers to the substrates. Though stabilization campaigns are very expensive,


177 An example of inappropriate paint finishes would be the dark gray color in the Double Parlors on the first floor. In 1981, the walls in these two rooms were painted during the filming of the movie Swamp Thing.

178 Susan Buck, Richard Wolbers, and Christine Thompson, “Drayton Hall Treatment Report: Paint Consolidation Project” (report submitted to Drayton Hall, April 2003), 2. The historic paint at Drayton Hall dating from 1880s was consolidated with a solution of Aquazol 500 in 2003. The paint has been stabilized, but it is still fading because of UV light.
installation and maintenance of a mechanical climate control system is also cost prohibitive and it can endanger the historic integrity of the structure. Perhaps the cost saved by increasing the utilization of passive climate control methods in lieu of new mechanical equipment could be used to stabilize the interior finishes in the house. This condition assessment is a helpful first step towards the selection of a climate control system because it defines the specific conditions in the building that need attention thereby avoiding an over-engineered solution.

Question 2: What are the preferred interior environmental conditions desired for the Aiken-Rhett House? What are the current interior air properties and do they meet current museum environmental standards?

Preferred Interior Environment for the Aiken-Rhett House

To gain an overall perspective of the preferred interior environmental conditions for the Aiken-Rhett House, the researcher interviewed three staff members in the Preservation and Museums Department of the Historic Charleston Foundation. The three staff members were the Curator, the Property Coordinator, and the Associate Director of Museums. These people were chosen because each would provide a different perspective on the needed climate control requirements. Curators are typically focused on the collections and decorative finishes in house museums; a property manager is typically concerned with appropriate conservation of the building and its
historic finishes; lastly, museum directors typically combine their concerns with visitor and staff comfort.

It is not surprising then that each of their responses reflect their daily responsibilities and concerns. Two simple questions were asked to each interviewee: 1) in your opinion, what are the optimal temperature and relative humidity ranges for the Aiken-Rhett House? 2) are there any particular issues or areas of concern that should be considered when a climate control system is recommended? In response to the first question, the Curator stated that she had always been taught that 70°F and 50% RH is the standard, but she knows that it is not a realistic option for the Aiken-Rhett House. She went on to say that her “preferred standards” for the house museum are 70-75°F and 50-55% RH ± 2%. Though the Curator’s preferred standards are very close to the standard year-round, mid-point climate control level of 70°F and 50% RH, they are slightly more lenient allowing for small fluctuations in temperature and humidity. The Property Coordinator’s response to the same question was that the preferred temperature and humidity levels would be what are best for the structure and the historic finishes. She adds that both the temperature and humidity setpoints should prevent excessive moisture from forming on the interior of the house; so, that means

179 Brandy Culp, interview by author, Charleston, SC, December 30, 2011.
180 April Wood, e-mail message to author, December 12, 2011. April Wood’s official title is “Manager of Easements & Technical Outreach” but she is currently the “Acting Property Coordinator,” fulfilling these duties as well.
the interior temperatures should fluctuate with the seasons and the house should be warmer in the summer and cooler in the winter.

When the Associate Director of Museums was asked the question about preferred relative and humidity levels in the Aiken-Rhett House, her response was much more general. The Associate Director did not provide specific temperature or relative humidity levels, but instead stated that her preferred interior climate conditions are whatever levels are best for the building, its finishes and the collections, without accelerating their deterioration rates. The office of the Associate Director of Museums is located in the Aiken-Rhett House; so, she is perhaps the most familiar of the three with the day-to-day environmental conditions inside the museum. She concluded that the interior temperature and humidity levels during the winter are stable and much more comfortable for the occupants ever since the forced air heating system was installed. In the winter, the heating system maintains the interior temperature above 60°F to prevent condensation from forming; but it also keeps the staff and visitors much more comfortable. According to the Associate Director, the conditions that need to be addressed now are the extreme heat and humidity that occur towards the end of the summer in August and September. After the thermal mass of the Aiken-Rhett House has completely heated through by the end of the summer, the house is very hot and humid and sometimes has to be closed to visitors because of the extreme environment. The Associate Director of Museums suggests that the end of the summer is when climate

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control in the house really needs to be addressed.\textsuperscript{182} Although she did not mention it initially, these concerns are centered on visitor and staff comfort; but these are also the times when the organic building materials face the most risk.

The second question asked the three staff members if they had any specific areas of concern that one should be conscious of when recommending a climate control system for the Aiken-Rhett House. Although the Curator’s highest concern is for the paper objects in the house, she is concerned about all of the objects and their reactions to the interior climate, sun exposure, air pollutants and air circulation from portable fans (for example, fans blowing historic wallpaper around). Furthermore, the Curator is interested in the long-term sustainable preservation of the structure, its finishes and the collections, with all three being equally important, there needs to be a middle ground to satisfy the climate requirements for all three. She acknowledges that from a conservation and curatorial perspective that the best thing for the collections is removal from the house; however, removal (or even replica furnishings) is not consistent with the Foundation’s mission for the Aiken-Rhett House.

The Property Coordinator responded to the second question with concern about damage to historic materials and HVAC system installation costs. When a climate control system is selected for the Aiken-Rhett House, the Property Coordinator wants minimal alterations to the historic fabric of the building for installation of HVAC equipment and

\textsuperscript{182} Valerie Perry, interview by author, Charleston, SC, February 6, 2012.
its associated distribution systems. Also, the climate control system must maintain proper moisture levels inside the building so there are no negative impacts on sensitive materials like wallpaper and paint. Lastly, the Property Coordinator had concerns over the initial installation cost of a climate control system and the cost for sealing the building envelope enough to render the system effective.\footnote{April Wood, e-mail message to author, December 12, 2011.} Along the same lines as the Curator, the Associate Director of Museums agrees that the paper collections are the most fragile objects in the Aiken-Rhett House and that the best option for the collections would be removal to a fully climate controlled facility. She also commented that it is the nature of materials to deteriorate over time, but a climate control system should be selected that will help inhibit this deterioration, not accelerate it.\footnote{Valerie Perry, interview by author, Charleston, SC, February 6, 2012.}

Evidently, there are differing perspectives among the Preservation and Museums staff at the Historic Charleston Foundation about what is best for the Aiken-Rhett House for climate control. The curatorial staff would like to see tighter control over the interior environment, while the museum and property managers will accept a wider range of temperature and humidity levels; however, all of the staff shares one common goal: they want to do what is best for the building, its finishes, and the collections.

Unfortunately, what is best for the collections is not always what is best for the historic building and vice versa. Perhaps the interpretation philosophy of the Aiken-Rhett House
will need to change to seeing these items separately, in order to best protect the structure and the collections it currently exhibits.

**Current Museum Environmental Standards**

Prior to World War II, there was no universally accepted standard for temperature and relative humidity levels for museums and historic buildings. During the war, several collections in England were stored in quarries with constant temperature and humidity levels around 60°F and 60% RH. It was found that these fine art collections fared much better in the constant environment of the quarries than in their normal museum environments. After the War, the 60°F and 60% RH standard was established as the guideline for temperature and relative humidity levels in museums and archives. Over the years, the “museum environmental standard” developed into the ranges of 70°F ± 2°F and 50% RH ± 5%. The standard aimed to maintain interior mid-point temperature and humidity levels throughout the year without any seasonal drift. The standard is nearly impossible to achieve and results in great expenditures for operating HVAC equipment. Though there were some who questioned this standard, it was blindly accepted by most museum and conservation professions until the 1990s. Rebekah K. Wood, wrote her master’s thesis “Determining Correct Temperature and Relative Humidity Ranges for Historic House Museums” on this very subject. She puts it best when she states the standard “grew out of arbitrary decisions, made by building

engineers, scientists, and museum administrators in the first half of the twentieth century, and was based upon limited scientific testing, the capabilities of the environmental control equipment available at that time, and the experience of successful wartime underground artifact storage." In the 1970s and 1980s, conservationists became increasingly aware that the current museum standard was causing harm to historic buildings and questions were raised about wider acceptable ranges of climate control systems.\textsuperscript{187}

In the early 1990s, the Smithsonian Institution Conservation Analytical Laboratory (CAL) and the Canadian Conservation Institute (CCI) conducted scientific research to identify allowable fluctuations in relative humidity levels for the preservation of museum collections. Both teams published several papers and articles during this time that addressed the climate control guidelines for museums. While most of these works are geared more towards organic object conservation rather than organic building materials, the scientists were trying to define environmental standards that would benefit both collections and buildings because of their symbiotic relationship. It is hard to address one and not the other, especially when dealing with historic house museums that typically display collections. In a 1996 \textit{APT Bulletin} “Humidity and Moisture in Historic Buildings: The Origins of Building and Object Conservation,” J.P. Brown and William B. Rose summarized the research from the CAL.

team and the CCI of allowable relative humidity ranges for organic artifacts as the following:

Variation of RH of ±10% RH (whether daily or yearly) about a central level between 45 and 55% RH presents a low risk of mechanical damage for almost all organic objects; variation ±15% RH about a central level is low risk for most, but not all, organic objects; variation ±20% RH about a central level is dangerous to some composite objects; variation ±40% RH about a central level is destructive to most organic objects if the extreme levels are maintained long enough for the object to react. The smaller variations do not represent “ideal” conditions in that, for some organic materials, considerations of increased chemical deterioration at mid-range humidities may make a lower set-point and variation desirable. Response times will vary according to the materials, the mode of manufacture, and the way it is displayed. If the more quickly responding organic objects such as paintings are enclosed in a suitable microclimate, then ambient room conditions can vary widely without increased mechanical damage.\(^{188}\)

The ultimate conclusion of the studies by CAL and CCI is that museum collections can withstand larger fluctuations in relative humidity than previously thought, without suffering mechanical damage. The scientists from CAL state in one of their articles that it has been known for a long time that extreme humidity levels (high or low) can cause damage to materials.\(^{189}\) A more recently accepted concept is that large spikes in relative humidity over short periods of time can actually cause more damage.\(^{190}\) Therefore, any special collections that require tighter relative humidity and temperature ranges should be exhibited in microclimates such as climate controlled display cases. Brown and Rose


take this notion a step further and say that one option to solving the conflict between
the environmental needs of the collections versus those of the building is not to display
materials that are sensitive to humidity in historic buildings. While this option may not
follow certain house museum interpretation philosophies, a worthwhile principle here is
simply “one should not destroy a building, just to display a particular artifact in it.” 191

After the CAL and CCI studies in the early 1990s, museums and conservation
institutions worldwide have started endorsing wider relative humidity and temperature
ranges. These institutions are creating new “museum environmental standards” that
better suit the needs of the collections and the historic buildings they are housed in. The
American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE)
included a chapter on climate control standards for museums and archives in their 1999
edition of their ASHRAE Handbook. After Stefan Michalski conducted his relative
humidity research with the Canadian Conservation Institute in the early 1990s, he was
invited to be on ASHRAE’s subcommittee that was responsible for writing the new
chapter and was responsible for the section about relative humidity and temperature
specifications. 192 In the 2007 ASHRAE Handbook, “Chapter 21: Museums, Galleries,
Archives, and Libraries” there are two important tables that are used in the Aiken-Rhett
House study as the “current museum environmental standards.”

191 Erhardt, Mecklenburg, Tumosa and McCormick-Goodhart, “The Determination of Allowable RH
Fluctuations,” 12.
192 Stefan Michalski, “The Ideal Climate, Risk Management, the ASHRAE Chapter, Proofed Fluctuations,
and Toward a Full Risk Analysis Model” (paper presented at the Experts’ Roundtable on Sustainable
Climate Management Strategies, Tenerife, Spain, April 2007), 2.
The table titled “Table 3 - Temperature and Relative Humidity Specifications for Collections” provides set points and allowable dry-bulb (DB) temperature and humidity fluctuations based on the level of climate control desired for a particular building.\footnote{American Society of Heating, Refrigerating, and Air-Conditioning Engineers, 2007 \textit{ASHRAE Handbook: HVAC Applications} (Atlanta, GA: ASHRAE, 2007), 21.13, Table 3.}

Five levels of climate control are listed for buildings that fall into the “General Museums,
Art Galleries, Libraries, and Archives” category. Class “AA” and “A” are for buildings where precision control over the interior climate is needed with little to no risk of mechanical damage to collections. Buildings that fall under these classes are designed to be able to maintain the year-round mid-point temperature and humidity levels. Most historic buildings will not fit into the Class “AA” or “A” category unless significant alterations to their structures occur. The next two classes “B” and “C” appear to be better for historic house museums that display collections. Class “B” offers precision control, but with seasonal fluctuations of 50% ±10% RH (or 40-60% RH) and temperatures set between 59°F to 77°F with allowable fluctuations of up to 18°F, but never reaching over 86°F. In regards to collections risk, Class “B” control provides moderate risk to some highly sensitive collections, small risks to some paintings and photographs, and no risks to most books and artifacts. The Class “C” control level is designed to prevent all high risk extremes, with allowable relative humidity levels between 25-75% and temperatures above 59°F, mostly below 77°F and rarely over 86°F. Mold begins to grow at humidity levels that exceeding 75%RH and humidity levels below 25% RH will cause materials to dry out and crack or become distorted. The risk to collections with Class “C” control is high for very sensitive objects, moderate to most paintings and photographs, and a small risk to most books and artifacts. Both Class “B” and “C” levels of control will render chemically unstable collection pieces “unusable” in a matter of decades, or even less time if they are consistently exposed to temperatures
over 86°F; however, the table also states that cold winter temperatures will double the life of these objects.

Table 4  Classification of Climate Control Potential in Buildings

<table>
<thead>
<tr>
<th>Category of Control</th>
<th>Building Class</th>
<th>Typical Building Construction</th>
<th>Typical Type of Building</th>
<th>Typical Building Use</th>
<th>System Used</th>
<th>Practical Limit of Climate Control</th>
<th>Class of Control Possible</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncontrolled</td>
<td>I</td>
<td>Open structure</td>
<td>Percy, stocks, bridge, sawmill, well</td>
<td>No occupancy, open to viewers all year</td>
<td>No system</td>
<td>None</td>
<td>D (if benign climate)</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>Sheathed post and beam</td>
<td>Célus, barns, sheds, ulos, orchard</td>
<td>No occupancy, Special event access</td>
<td>Exhaust fans, open windows, supply fans, attic venting, No heat</td>
<td>Ventilation</td>
<td>C (if benign climate) D (unless damp climate)</td>
</tr>
<tr>
<td>Partial control</td>
<td>III</td>
<td>Uninsulated masonry, finned and sided walls, single glazed windows</td>
<td>Boat, train, lighthouse, rough frame home, forge</td>
<td>Summer hours: Closed to public in winter; No occupancy</td>
<td>Low-level heat, summer exhaust ventilation, humidistat heating for winter control</td>
<td>Heating, ventilation</td>
<td>C (if benign climate) D (unless hot, damp climate)</td>
</tr>
<tr>
<td></td>
<td>IV</td>
<td>Heavy masonry or composite walls with plaster; Tight construction; storm windows</td>
<td>Finished houses, church, meeting house, store, inn, some office buildings</td>
<td>Stuff in isolated rooms; gift shop; Walk-through visitors only; Limited occupancy; No winter use</td>
<td>Ducted low-level heat. Summer cooling, on/off control; DX cooling; some humidification; Retard capability</td>
<td>Basic HVAC</td>
<td>B (if benign climate) C (if mild winters) D</td>
</tr>
<tr>
<td>Climate controlled</td>
<td>V</td>
<td>Insulated structures, double glazed, vapor retardant, double doors</td>
<td>Purpose-built museums, research libraries, galleries, exhibits, storage rooms</td>
<td>Education groups. Good open public facility; Unlimited occupancy</td>
<td>Ducted heat, cooling, reheating, and humidification with control dead band</td>
<td>Climate control, often with seasonal shift</td>
<td>AA (if mild winters) A B</td>
</tr>
<tr>
<td></td>
<td>VI</td>
<td>Metal wall construction, interior rooms with sealed walls and controlled occupancy</td>
<td>Vaults, storage rooms, cases</td>
<td>No occupancy; Access by appointment</td>
<td>Special heating, cooling, and humidification with precision constant stability control</td>
<td>Special constant temperature environments</td>
<td>AA A Cool Cold Dry</td>
</tr>
</tbody>
</table>

Source: Adapted from Council (1995).

Figure 5.10: The table above was used to determine the most appropriate building class for the Aiken-Rhett House. The building possesses qualities in two categories that are shown as the items highlighted in yellow. Source: Table from American Society of Heating, Refrigerating, and Air-Conditioning Engineers, 2007 ASHRAE Handbook: HVAC Applications (Atlanta, GA: ASHRAE, 2007), 21.14, Table 4.

The second valuable table for the Aiken-Rhett House study is “Table 4 - Classification of Climate Control Potential in Buildings.” This table is intended to be used with Table 3, as it provides the Class of Control (AA, A, B, C, D) that is possible to achieve with different types of buildings based on their construction, use and types of HVAC
systems. The Aiken-Rhett House falls in between building Class “III” and “IV” on this table because it has qualities that are listed under both classes. Both classes fall under the “Partial Control” category with Class “IV” building types being able to achieve tighter levels of climate control that Class “III” buildings. For instance, Class “III” buildings are constructed with uninsulated masonry, framed walls, and single glazed windows -- all of which describe the Aiken-Rhett House. On the other hand, Class “IV” buildings are constructed of “heavy masonry or composite walls with plaster” which the Aiken-Rhett also has, but this class of buildings also have “tight construction” and storm windows, which the building does not. Next, Class “IV” buildings are described as finished houses, such as this museum, and Class “III” buildings are described as “boat, train, lighthouses, or rough framed houses” which clearly does not describe the Aiken-Rhett House. Also, the study house does not fit directly into either type of building’s class typical use, as they are both closed in the winter while the Aiken-Rhett remains open for tours. The last descriptor on the table is the “Practical Limit of Climate Control” and states that Class “III” buildings can use heating and ventilation, while Class “IV” buildings are capable of using basic HVAC systems. Finally, the last column on the table provides the Class of Control that is possible for each type of building. Class “III” buildings are able to achieve class “C” control if in a benign climate and class “D” level control if the building is not in a hot and damp environment. Meanwhile, Class “IV” buildings are able to

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provide Class “B” level of control if in a benign climate, Class “C” control if the location has mild winters, and also Class “D” with no qualifiers. After trying to label the Aiken-Rhett House as either a Class “III” or “IV” type of building, one can see that the structure fits somewhere in between. If it were said to be a Class “III” building, then it can only provide a Class “C” level of climate control because “D” is not an option as Charleston has a hot, humid climate. On the same note, if the Aiken-Rhett were said to be a Class “IV” building, then Class “C” level of climate control also appears to be the best choice because “D” puts too many collections at risk and Class “B” suggests that Charleston is a mild climate. While Charleston has mild winters, the summers can be extremely hot and humid, therefore not qualifying for the “benign” climate option. With either building type, the best choice for this museum is Class “C” level of climate control, which entails preventing all high risk extremes by keeping humidity within 25-75% RH and temperatures rarely exceeding 86°F DB.

People who operate historic house museums may scoff at the idea of putting their collections in any type of risk by selecting Class “C” or even Class “B” levels of climate control. As most house museums realize, their largest “artifact” is the building itself, and their climate control methods should try to minimize the damage to both the building and the collections. Finding this optimum level is difficult, but research over the last twenty years has proven that historic building materials and collections can both tolerate wider fluctuations in humidity and temperatures than previously thought. Moreover, the research has also determined that smaller differences between inside
and outside temperatures are better for the building and the collections. Greater fluctuations in the interior environment that correspond with seasonal changes are needed to achieve this.

To summarize, the application of this research means that in the summer time the interior temperatures and relative humidity levels will be higher; and in the winter time interior temperature and humidity levels will be lower to more closely match the exterior environment. Historic buildings have been accomplishing this passively for a majority of their existence; however, in the last fifty years or so, HVAC systems were installed in these buildings to create a year-round, mid-point interior environment. This altered the natural equilibrium between a historic building and its external environment and resulted in unnecessary and sometimes detrimental damage to historic fabric. In the last ten years or so, there has been a movement to transition to more passive and low-tech climate control methods that minimize the difference between the interior and exterior environments in historic buildings. This movement has been researched largely in hot, humid climates by the Getty Conservation Institute and will be discussed in greater detail in the results subsection for Question 4.

**Interior Air Properties at the Aiken-Rhett House**

The interior air properties at the Aiken-Rhett House were monitored and recorded over a course of several months. The three data loggers owned by the Historic Charleston Foundation and located on the west side of the house provided data from
May 20, 2011, through February 3, 2012, for a period of a little over seven months. The three data loggers provided by the researcher, located on the east side of the house, recorded data from October 27, 2011, through February 3, 2012, for a little over three months. Unfortunately, the time frame of this study did not allow for a complete year of data to be recorded, which is the typical standard in the industry. The interior air property data collected during the study was compared to the ASHRAE Class “C” Control level. Class “C” (25-75% RH, 59-86°F DB) was selected as the “current museum environmental standards” for the Aiken-Rhett House to identify any occurrences when the interior air properties were in the “high risk” zone, meaning the humidity levels were below 25% or above 75%, and that the temperature was below 59°F or above 86°F. The goal of the air monitoring was to determine when the interior environment was harmful for the collections and the building and to address these specific time periods by means of some type of climate control. The detailed results for interior environmental monitoring are located in Appendix C.

After all of the collected data were plotted on line graphs, the high risk occurrences became visible and easy to recognize. Examination of the graphs showed that most of the temperature extremes occurred between June and the beginning of September on all three floors. There were unusual occurrences in the third floor southwest bedroom during the month of November where the temperature was spiking between 90-105°F each day around 4:00PM. Climate reports were checked with the National Weather Service and there were no unusually high temperature in November,
the highest being 81°F recorded on the 21st. Also, the data recorded in the north bedroom of the third floor east wing showed temperatures at these times between 64-75°F. It was then realized that the HOBO data logger in the southwest bedroom was placed almost directly under the diffuser for the forced air heating system. The heating system must have turned on everyday around 4:00PM in the afternoon, thus causing the temperature spikes recorded by the HOBO loggers. For these reasons, the high temperatures in November are deemed outliers and were not taken into consideration when recommending climate control methods. Because there were no data loggers on the east side of the house during the summer months, no data can be presented about high temperatures.

On the west side of the Aiken-Rhett House, the second floor was the only level that ever had temperatures below the recommended 59°F. Two days in December and six days in January saw temperatures below 59°F; however, the recorded temperatures never fell below 57°F. These lower temperatures can be attributed to the fact that the only heated air delivered directly to the second floor by the forced air heating system is in the Withdrawing Room in the East Wing. Even though the Aiken-Rhett heating system is programmed to operate when temperatures fall below 60°F, the heated air may not circulate enough to keep the west side of the second floor above the setpoint on very cold days.
While only the second floor on the west side of the house had temperatures below the recommended 59°F, the east side of the house saw lower temperatures on all three floors during the fall and winter months. Temperatures fell below 59°F for a total of ten days on the first floor from the end of October to the middle of January, sixteen days on the second floor from December to mid-January, and four days on the third floor in January. Similar to the west side of the house, temperatures never fell far below the 59°F benchmark. The lowest recorded temperature on the first floor was 55.97°F, 56.66°F on the second floor, and 58.04°F on the third floor. Even though the heating system delivers air directly to the first floor dining room, where the data logger was located, the colder temperatures can be attributed to the fact that warm air rises and there are large windows in this room, as well as a firebox that could pull warm air out of the room via the stack effect. As previously mentioned, the lower temperatures on the second floor are likely caused by minimal heated air being delivered directly to this level of the house. The east side of the Aiken-Rhett House is cooler year-round because it is shielded from the sun by the neighboring house that abuts up to the property line. Also, the east side of the house receives only morning sun, which is weaker than the afternoon sun received by the west side of the house. The potential for solar heat gain is much greater on the west side of the house, making the rooms warmer throughout the year.

The relative humidity levels throughout the Aiken-Rhett House fluctuated much more than the temperature levels. On the west side of the building, the first floor had
the most frequent occurrences of humidity exceeding the recommended 75% maximum, followed by the second floor and then the third floor. This is explained by the fact that the first floor is the lowest level (above the basement) and is closer to the ground and is affected from rising damp or insufficient site drainage more than the other levels. Also, the first floor is cooler than the other two floors, which means that relative humidity levels can be higher. As we discussed in the psychrometrics section, air at higher temperatures has lower relative humidity levels because hot air can hold more moisture than cold air. Along this same note, because the air on the third floor is warmer, it has lower relative humidity levels and fewer occurrences of high risk humidity levels than the rest of the floors. In fact, the relative humidity on the west side of the third floor never exceeded 78%, while the second floor reached 91.8% and the first floor maximum was 87.1%. The second floor had slightly higher levels of humidity than the first floor because conditioned dry air from the basement level leaks into the first level of the house through cracks between the floorboards. On the east side of the house, the frequency of high relative humidity levels mimicked the west side with the first floor having the most occurrences and the third floor the least. The first and second floors never had humidity levels exceed 89.3% and 89.2%, respectively, and the third floor reached only 80.7% RH.

When daily weather records were compared to dates with humidity levels greater than 75% RH, it was found that on these days a rain or fog event occurred that created the higher levels of humidity inside the house. The few dates that did not have rain or
fog, but still had high relative humidity levels, were attributed to days when ambient temperatures were very close to the dew point temperature. To help support the statement that rain or fog events create the high humidity levels inside the Aiken-Rhett House, one can see that every data logger except the southwest room on the third floor recorded a large spike in humidity levels on December 27, 2011. On this date, a rain event occurred when temperature levels were mild, between 50-66°F, which resulted in relative humidity levels up to 94% outside and 91.8% inside on the second floor. Clearly, when extra moisture is added to the exterior air by rain or fog, the humidity levels inside the Aiken-Rhett House are increased.

Occurrences of low relative humidity levels inside the Aiken-Rhett House were rare compared to the amount of high level occurrences. A few incidences of low humidity levels happened in November, but most were in January. When the low humidity levels were checked against daily weather records, it was found that the occurrences were on days with no rain events and low dew point temperatures, well below the minimum ambient temperature recorded for each day. In addition, the west side of the building experienced lower humidity levels more frequently than the east side of the house. This happens because the east side of the house is cooler year-round, resulting in higher humidity levels, while the west side tends to be warmer, resulting in lower humidity. Moreover, the relative humidity never fell below 23.4% on either side of the Aiken-Rhett House; therefore, the levels are less than 2% away from the recommended low of 25% RH. It should be noted that the winter season during which the interior air
properties were recorded was uncommonly warm and mild. Perhaps if there had been a regular winter season with colder temperatures, then there would have been more incidences of relative humidity levels below 25%.

According to the recorded interior air properties, the interior environment in the Aiken-Rhett House meets the Class “C” level of climate control throughout a majority of the year. There are, however, specific periods during the year when temperature and humidity levels do not meet the recommended levels (25-75%RH, 59-86°F). In the summer, temperatures above 86°F and relative humidity levels above 75% tend to occur between June and the beginning of September. There are occasional random spikes in humidity levels throughout the fall and winter season, but these can be attributed to rain or fog events. Regardless, on days where these high level extremes occur, the interior air needs to be cooled and dehumidified to bring it into the acceptable range of environment standards. Low levels of temperature and humidity tend to occur mostly in January, with occasional random incidences in November and December. These low extremes never fall much lower than a few degrees or percentage points below the 59°F and 25%RH standard, which is most likely because of the forced air heating system currently operating at the Aiken-Rhett. In order to bring the low level extremes back into the recommended Class “C” climate control standards, small amounts of heating and humidifying are needed. In conclusion, a careful monitoring study such as this one can result in less expenditure and greater good to the house and its collections. This justifies the data collection process and counters the belief that this information is
gratuitous. It is certainly voluminous, but it is important for the basis of sound climate management decisions.

**Question 3:** What type of current climate control systems are being employed in other similar historic house museums and what have been their outcomes?

In order to gain perspective on the types of climate control systems being utilized by similar historic house museums in the Charleston area, four sites were selected as case studies. The case study process involved visiting each house museum and conducting an interview and site walk-through with a member of the operations staff. The goals of the interview process were to determine what type of climate control systems are used at the house, what effects the system has had on the house, and what the museum staff would like to change about each system. Problems that these systems have caused for the historic structures are used to help determine what climate control systems are inappropriate for the Aiken-Rhett House. A summary of all four case studies are presented with a brief description of each building, its climate control systems, and any current issues caused by the system. The actual HVAC Questionnaires and photographs from the site visits are located in *Appendix D*. In addition to the four case studies in Charleston, a brief discussion of the geothermal systems used at Kenmore Plantation in Virginia and the Middleton-Pinckney House in Charleston are included at the end of the section. Data was collected about both sites; however, neither is
considered an official case study because of their differences in location and building use, respectively.

*Drayton Hall*

![Drayton Hall](image)


Drayton Hall is a plantation house located on the Ashley River approximately nine miles northwest of the downtown peninsula of Charleston. Built between 1738 and 1742, the house is considered one of the greatest examples of Georgian-Palladian architecture in the United States. The structure is rectangular in plan with the primary façade facing Ashley River Road in the southwest direction, and the rear façade facing the Ashley River in the northeast direction. This load-bearing masonry structure is two-stories over a full basement with an attic capped by a standing seam metal roof. The total area of the building is 10,920 square feet, which includes all three levels of the
house. There are five rooms on each floor with the exception of two small dressing rooms off of the north chamber on the second floor. A three-bay, two-story portico is centered on the southwest elevation and a grand two-story stair hall is located in the northeast side of the building. Fireboxes are in every one of the five main rooms on the first and second floors, which would have provided heat to the spaces when the house was used as a residence. Each room on every floor has at least one exterior wall with exterior openings to provide natural light and ventilation into the space. The windows at Drayton Hall are double-hung wood sash, with single-pane glass. No exterior shutters are currently installed on the building, but there are interior louvered shutters that were installed in the house in the late-nineteenth century.

The property remained in the Drayton family until 1974, when it was purchased by the National Trust for Historic Preservation and converted into a historic house museum. The Trust operates Drayton Hall under a conservation philosophy and has never restored the building. Drayton Hall is unique and much like the Aiken-Rhett House in the fact that it retains most of its late-nineteenth century finishes. Minimal electrical services are installed in the house to provide lighting for visitors and to operate fans during warm periods. This plantation house is not climate controlled by mechanical means, only by natural, passive methods. Unlike many historic house museums, the National Trust does not display any collections or furniture inside the building. Conserving the building and its historic finishes is the main priority and any collections or artifacts are stored in a climate controlled facility on site. Drayton Hall was selected as a case study because it has never been restored, like the Aiken-Rhett House, and because it is important to include a house museum that utilizes passive methods to control its interior environment.

The current passive cooling methods used at Drayton Hall include the operation of the windows, doors and the interior louvered shutters. Each morning windows and interior shutters are opened according to the temperature and location of the sun. Because UV damage is a major concern to the staff, the interior louvered shutters are opened only enough to provide light for visibility. Charleston is prone to hot and humid summers which can create an environment in the house that is uncomfortable for visitors as well as harmful to the historic finishes. The heat and humidity require the use
of these natural ventilation methods previously mentioned. The protocol for ventilating the house is as follows: if the outside temperature exceeds 75°F, then windows are opened; if the temperature regularly exceeds 80°F, then box fans are used; and if the heat index reaches 115°F, then the house is closed to the public.195 Because Drayton Hall is a large masonry structure, its thermal mass keeps the interior climate relatively moderate throughout most of the year. The basement provided a cool place to seek refuge during the hot summer months, while the upper floors were most likely warmer during the winter because of heat’s natural tendency to rise. The floor to ceiling heights on the first and second of Drayton Hall are approximately 13’-1” and 14’-4”, respectively. These high ceilings help to stratify the air and pull the warmer air towards the ceilings and keep the cooler air at the lower levels of the rooms near the occupants. Since the building has been operated as a house museum, the fireboxes are no longer used to provide heating; so, there are no current means, either passive or mechanical, used to heat the building in cooler periods.

Figure 5.13: Examples of the use of interior louvered shutters (left) and a typical firebox (right) in Drayton Hall. Photographs by author.

195 Patricia Smith, Interview by author, Charleston, SC, December 13, 2011.
Surprisingly to some, there are very few problems at Drayton Hall related to interior climate control. The occupants may be uncomfortable at times during the height of the summer and winter months, but the building is faring quite well. Condensation is the one problem that does occur, though infrequently, in the basement and stair hall after rapid changes in exterior temperatures. Similar to the Aiken-Rhett House, condensation forms on the interior surfaces when the exterior temperatures warm up very rapidly after a cool night and the thermal mass of the building does not have enough time to adjust. Concern over the deterioration of the historic finishes in the house led to installation of a high-tech climate monitoring system in the mid-1990s and early 2000s. The main goal of this system was to electronically gather data about problem occurrences (like condensation on interior surfaces) and their simultaneous weather conditions to be able to predict when these “problems” might occur again. Unfortunately, the climate monitoring system was complicated to operate, the output data was difficult to interpret and it never functioned as it was originally intended; so, it was removed from the house in 2010, though it had not been used in years. The failed climate monitoring system resulted in operational procedures for Drayton Hall that rely more on staff awareness of the exterior climate and the management of the interior through use of passive climate control features. At the same time the monitoring system was developed, a group of experts stabilized the historic interior paint and

\[\text{\textsuperscript{196}}\] No official operational procedures exist in writing for opening and closing the plantation house at Drayton Hall. There are procedures for the opening and closing of the entire property, but none exclusively for the house.
plaster throughout the house. Perhaps, the Aiken-Rhett House can take a page out of Drayton Hall’s book and better utilize its architectural features that provide natural ventilation and cooling to the house. In order to make this idea successful, a house museum needs an educated and engaged staff to participate in the interior climate management. Removing the collections from the house and stabilizing the existing historic finishes are some other ideas to consider as well.

**Joseph Manigault House**

![Image of the Joseph Manigault House](image)

Figure 5.14: South elevation of the Joseph Manigault House with the two-story piazza centered on this façade. The smaller, semi-circular piazza is visible on the west (left) side of the house. Photograph by author.

The Joseph Manigault House, built in 1803, is a prime example of a Federal style Charleston townhouse constructed around the turn of the nineteenth century. The Manigault House is located on the east side of Meeting Street, between John Street and Ashmead Place, with its primary façade facing north towards John. This large brick
structure is comprised of three stories over a full basement with an attic and a slate roof. The total area of the house is 9,044 square feet including the basement level. The main block of the house is rectangular in plan, with a round stair hall centered on the north elevation and protruding rounded bay windows on all three floors at the southeast corner of the house. A three-bay, two-story piazza is centered on the south façade and a smaller semi-circular, two-story piazza is located on the west elevation. Fireboxes are in the main rooms on each floor and would have been used as the heating source when the Manigault house was a residence. Every room in the house has exterior openings to provide natural light and ventilation for the space. The Manigault House has double-hung, wooden sash windows, with single-pane glass. There are no exterior shutters on the building, but there are interior pocket shutters that are used to control light. Acquired by the Charleston Museum in 1933, the Joseph Manigault House has operated as a house museum ever since and has undergone restoration projects in 1980s and 1990s after Hurricane Hugo. As part of the interpretation of the museum, collections are displayed throughout the house.

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197 Jonathan H. Poston, The Buildings of Charleston (Columbia, SC: University of South Carolina Press, 1997), 612-613. The restoration dates were also confirmed in the interview with Melanie Wilson, Chief Interpreter of Historic Houses for the Charleston Museum.
The Joseph Manigault House is partially climate controlled with a mechanical heating and cooling system that includes a boiler and a split DX system (comprised of a fan coil unit and outside air-cooled condenser). All of the HVAC equipment and associated ductwork is located in the basement, except for a wall-mounted ductless split DX system that provides cooling only for the staff lounge located in the northeast corner of the first floor. Only the first floor of the building is heated during the cooler periods, allowing the heat to rise to the other floors by natural convection. The boiler provides the heat for the system and the fan coil unit distributes the heated air to the first floor through the ductwork run under the first floor in the basement. The air is delivered to the spaces by registers installed in the floor. The same air distribution system is used for cooling the first floor Dining Room during the summer. The fan coil unit and air-cooled condenser operate as a DX system to provide cooling only for this room. Metal plates
are inserted into the ductwork to seal off the Dining Room ductwork branch and block
the cool air from being transported to the other rooms on the first floor. The decision
was made by the Charleston Museum to air condition the Dining Room to help make the
visitors more comfortable; the hour tour begins in the Dining Room and the visitors
spend the most time in this one room. The HVAC systems in the Manigault House run
only during operating hours, from 8:00AM to 5:00PM every day.

While the Joseph Manigault House has mechanical climate control methods,
passive methods of cooling the building are also used. During the summer, windows are
open during regular operation hours to provide natural ventilation. Except in the Dining
Room, where the door and windows remain closed. The interior pocket shutters are
used to control natural light; however, their operation does affect the temperature
inside the house. For example, if the shutters are opened in the summer, the heat gain
through the windows increases and the interior temperatures rise. In the winter, the
heat loss through the windows increases if the shutters are opened and the interior
spaces get cooler. In essence, the Manigault House was selected as a case study because
of its mixed combination of mechanical systems and use of passive cooling methods,
both of which are comparable to the current Aiken-Rhett House climate control
methods.
There are a few problems associated with the climate control systems at the
Joseph Manigault House; however, the staff actually has more problems related to the
heating system than to the lack of a cooling system throughout the building. The heating
system dries out the furniture when it is operating; therefore the staff has taken some
measures trying to remediate this problem. First, portable humidifiers are brought into
the Library and Dining Room to help add moisture to the dry air. Second, the floor
registers are covered with Plexiglas while the humidifiers are in operation to prevent the
distribution of more dry air into the interior spaces. This solution seems to be working;
however, the museum staff would prefer to have humidification incorporated into the
heating system, so that portable humidifiers would not have to be used.

On another note, there are two current issues involving the cooling mode of the
Manigault House HVAC system. The first is caused by improper placement of the
controls for the Dining Room cooling system. The thermostat for the Dining Room is located inside the adjacent Staff Lounge, directly under the air distribution for a ductless air conditioner. Therefore, when the ductless unit in the Staff Lounge is operating, it is blowing cool air on the thermostat for the Dining Room, resulting in a false reading for the actual temperature in the space. The museum is currently looking into adding a remote thermostat inside the conditioned space to provide accurate measurements.

The second problem associated with the cooling system also involves the Dining Room. Because this room is the only mechanically cooled room in the house during the summer, the windows are kept closed and the interior door is shut to keep the cool air inside the room. This creates an environment that is different from the rest of the house and significantly different from the exterior. The vapor pressure differential in the Dining Room causes condensation to form on the windows and shutters, which has resulted in mildew. The Dining Room situation at the Manigault House resembles the Art Gallery at the Aiken-Rhett House in that it is the one historically interpreted room in the building that is air conditioned and essentially sealed off from the rest of the house. The main difference is the relative amount of this interface.
The Heyward-Washington House, built in 1772, is a Georgian style double-pile house located on the southern portion of the downtown peninsula of Charleston.

Situated on the west side of Church Street between St. Michaels Alley and Tradd Street, the primary façade of the building faces east, fronting on Church. The Heyward-Washington House is a load-bearing masonry structure with a hipped slate roof and is comprised of three stories over a raised basement and an attic. The total area of the structure is 6,776 square feet including the basement level. The Heyward-Washington House follows the central hall floor plan with four rooms on each floor, two on each side of the hall. Two inboard chimneys have a firebox in every room on all floors; these were
the original heating source for the house, although they are no longer used. All of the rooms in the Heyward-Washington House have windows that originally served to provide natural ventilation and lighting. The windows are double-hung, wood sash with single-pane glass and each has exterior shutters and interior pocket shutters.

The house was originally built for Thomas Heyward, Jr., a signer of the Declaration of Independence, from whom it gets its namesake. The “Washington” part of the house name comes from the fact that George Washington stayed at the house in 1791 for a weeklong visit. The Heyward-Washington House was purchased by The Charleston Museum in 1929, and at this time, the first floor had been reconfigured for a store. The Museum restored the original first floor configuration and the building was
opened to the public as the city’s first house museum in 1930. As part of the interpretation of the house museum, period-appropriate furnishings are displayed on the first and second levels of the building. All three stories of the Heyward-Washington House are heated and cooled by mechanical equipment located in the basement, attic and kitchen building. This site was chosen as a case study primarily to examine the effects of a hot water heating and chilled water cooling system on an historic house and the service buildings that were modified to accommodate the system.

The HVAC system at the Heyward-Washington House is an all-air system comprised of a chiller, a remote condenser and a boiler in the kitchen building and three air handler units in the main house. Two air handlers in the basement serve the first and second floors of the house and a third air handler in the attic serves the third floor. The chilled or hot water is piped underground from the kitchen building to the basement or attic, where it enters the cooling / heating coils in the air handler units. After the air handlers condition the air to the required setpoints, the air is then delivered to the conditioned spaces through supply ductwork and then returns to the air handlers through a network of return ductwork. The ductwork serving the first level of the house runs under the flooring (ceiling of the basement) and delivers the air through floor-mounted registers. The second floor ductwork is run up from the basement through closets on each side of the chimneys, and then branches out to run under the second

level flooring to floor-mounted registers located in the conditioned spaces. The third floor receives its conditioned air from the air handler in the attic. Ductwork is installed along the floor of the attic (or ceiling of third floor) and delivers air via ceiling-mounted diffusers. Just like the Joseph Manigault House, the mechanical system at the Heyward-Washington operates only from 8:00AM to 5:00PM every day. The building automation system is electronically controlled by the Museum’s controls subcontractor in Columbia, South Carolina. Unfortunately, this means that anytime the Museum needs to change the heating or cooling setpoints or have the equipment turned off or on, they have to contact their subcontractor in Columbia to do it remotely. The typical setpoints for the house museum are 72°F and 50% relative humidity. Because the Heyward-Washington House is fully climate controlled, the Museum does not operate the windows or shutters to provide natural ventilation. The exterior shutters always remain open on the first and second floors and closed on the third floor, except if there is a hurricane threat. The interior pocket shutters are used to control the light and its damaging effects on the collections.
When the current mechanical system was first installed in the Heyward-Washington House in the mid-1990s, there were problems with the interior plaster cracking. After a couple of years of plaster repairs, the building became acclimated to the system and there have been few issues since. Also, when the HVAC system was installed in the kitchen building, interior walls on the second floor were removed to fit in the equipment. The staff has noticed areas of missing plaster inside the kitchen building, which they think is caused by the vibration of the mechanical equipment. The remote air-cooled condenser in the kitchen building also creates a lot of noise that detracts from the visitor experience when they are outside in the gardens behind the house. Another issue with the climate control system is the formation of condensation on the outside of the windows in the main house. The condensation forms when the hot, humid outside air comes into contact with the cool glass on the windows. As discussed before, frequent condensation can increase the deterioration rate of building materials.
because they are damp for long periods of time. Perhaps the most common problem associated with the Heyward-Washington climate control system is the maintenance and repairs on the larger pieces of equipment, which are now over fifteen years old. Constant repairs for the aging equipment can add up to large expenditures for an historic house museum; and unfortunately, replacement of the system is inevitable.

The preservation goal of this museum is very different from the Aiken-Rhett house because the collections are the main priority of the HVAC system. Most of the visitors who come to the Heyward-Washington House are there to see the large collection of original Charleston furniture that dates to pre-1800. With the collections being the priority, the system functions as designed to keep temperature levels constant and relative humidity levels low. The furniture collection is stable and the constant interior environment seems to be good for the building as well. On the other hand, the cost to maintain this constant indoor environment in a hot, humid climate can be astronomical at times. The Museum has had utility bills in the past that are close to $4,000 for one month.

Some important things can be learned from the Heyward-Washington House in regards to the Aiken-Rhett House climate control system. Installation of a chilled water system is intrusive on historic fabric, yet it can provide tight control over the indoor

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200 Ibid. The $4,000 utility bill included all utilities, but most were attributed to operating the HVAC system.
environment which is needed for special collections. Unfortunately, to maintain a constant year-round environment for the collections will result in the short term utility bills and the long term replacement costs that come with an HVAC system. The Aiken-Rhett House displays collections, though not so many and none as rare as those in the Heyward-Washington House. Perhaps the collections at the Aiken-Rhett House should be limited to the fully climate controlled areas of the building in the Art Gallery and in the basement. Though this idea does not go along with the current interpretation of the museum, it would better benefit the collections.

*Nathaniel Russell House*

The Nathaniel Russell House, built in 1808, is a Federal style brick townhouse located on the downtown peninsula of Charleston. Sitting on the west side of Meeting Street between Tradd Street and Prices Alley, the principal east façade of the building
fronts on Meeting. Comprised of three stories over a raised basement and an attic, this large brick structure with a slate roof totals approximately 9,600 square feet. There are three rooms on all three floors of the original main house. Over the years, the two-story kitchen building was attached to the main house with a two-story hyphen, and a small one-story service building was erected to the rear of the kitchen building to form one long building complex. The most famous feature of the Russell House is the floating spiral staircase that spans all three floors. A service stair is located in the northwest corner of the main house and a small staircase is located in the kitchen building to provide access to the second floor of the kitchen and the hyphen. Fireboxes are located in every room in the original main house except the first floor front room. Like most historic houses, all of the rooms have exterior openings to provide light and natural ventilation. The windows in the house are double-hung, wood sash with single-pane glass. There are no exterior shutters on the Russell House, but there are interior pocket shutters in the main house. Blinds or curtains are used in rear portions of the building complex.
The Nathaniel Russell property was acquired by the Historic Charleston Foundation in 1955 and has operated as a historic house museum ever since. As part of the interpretation of the museum, the Foundation displays period appropriate furniture and decorative arts in the house. The structure has undergone several periods of alterations, but after damage from Hurricane Hugo in 1989, the main house was restored and new HVAC systems were installed. The existing chilled water cooling and hot water heating system provides conditioned air to all three levels of the main house as well as the rear additions. Mechanical equipment is installed in the attic, basement and rear service buildings. The priorities of the climate control system are visitor comfort, the historic finishes and protecting the collections. The Russell House was selected as a case study to provide another example of a hot water heating and chilled water cooling system utilized in a historic house museum. Though this is the same type of system installed at the Heyward-Washington House, there are differences between

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Poston, 262.
the two systems that make each a worthy case study. Both house museums have air
handler units located inside the basement and attic spaces of the buildings; but the
choice of locations for the chiller, boiler and condenser in each house is different.

Like the Heyward-Washington House, the Russell House has an all-air type of
HVAC system that uses air as the medium to heat or cool the conditioned spaces. The
chiller and boiler are located in the rear service building and the remote air-cooled
condenser is located in the southwest corner of the rear parking lot. Hot and chilled
water piping runs from the service shed through the ceilings of the kitchen building and
hyphen to main house, delivering the water to the five air handler units located
throughout the building complex. Three air handlers serve the main house and two
serve the rear additions. In the main house, supply and return ductwork runs from the
first floor to the third floor through the small closets in the main stair hall. Conditioned
air is distributed to the interior spaces through a variety of diffusers and registers. In the
museum spaces, the terminal outlets are hidden above the door frames, but in the
working spaces (gift shop, ticket office, staff lounge, offices) the terminal outlets are
installed in more visible locations like the floor or ceiling. The Russell House HVAC
system is controlled by a direct digital control building automation system and it
operates continually. The temperature setpoints for museum are between 68°F to 70°F
almost year round. Currently, there are no direct humidity controls; the mechanical

202 M. Dennis Knight, “Nathaniel Russell House Energy Audit,” (report for Historic Charleston Foundation,
Charleston, SC, September 12, 2011).
system has only the ability to control temperature and to try to influence the relative humidity levels through these means. Because the Nathaniel Russell House is fully climate controlled, the windows are not used for ventilation. The interior pocket shutters are utilized to protect the collections from light. The shutters are opened and closed throughout the day depending on the location of the sun.

Figure 5.22: Examples of interior pocket shutters being used to control light (left), and a wall-mounted diffuser hidden over a door architrave (right). Photographs by author.

During the installation of the mechanical system, historic fabric was removed and altered to be able to fit the large air handler units inside the building and their associated ductwork and terminal outlets. The installation of all of the chilled water and hot water piping in the building creates the potential risk of water leaks. Even though the Russell House system lacks humidity control, most problems with the historic finishes are related to human error (like bumping the walls). This being said, the lack of humidity control has created mildew problems on the supply diffusers on the second and third floors of the working spaces. Condensation forming on the windows is another
problem associated with the climate control system. Most of the time the condensation forms on the exterior of the windows, but occasionally it occurs on the interior.\footnote{Brandy Culp, interview by author, Charleston, SC, December 30, 2011.} Once again, this is caused by the difference in temperature and humidity levels on the inside and outside of the building and can increase the deterioration rate of the historic window materials. The occupants of the Russell House have complaints about wide swings in temperature and humidity levels making some areas in the house cool while others are hot and vice versa. Also, there is concern from the curatorial staff about the effects of the temperature and humidity fluctuations on the decorative and fine art collections. Some other complaints about the Russell House climate control system are noise and vibrations inside and outside of the building. The remote air-cooled condenser is located near the back of the garden. Visitors can hear the equipment running when they are in the rear part of garden and it detracts from the historic site experience. Inside the house, occupants can hear the noises created by the mechanical piping. Like the Heyward-Washington House, the age of the Russell House HVAC system means there is constant mechanical repair work.

Climate control systems are installed in buildings to have tighter control over their interior environment. The Nathaniel Russell House provides an example where the mechanical system is not providing the intended level of control and is causing harm to elements of the historic building (especially windows). Most likely, the system is not functioning correctly because of its age and the lack of humidity control. The Foundation
plans to make updates to the HVAC system soon to correct these problems. The Aiken-Rhett House can learn from the Russell House in that well-intended climate control systems can actually jeopardize a historic building. A mechanical system needs to provide appropriate levels of temperature and humidity control for it to be effective and beneficial for a historic structure, avoiding over-engineered solutions.

Middleton-Pinckney House

Figure 5.23: The primary south facade (left) and the first floor plan (right) of the Middleton-Pinckney House. Source: Floor plan of the Middleton-Pinckney House. From the property file located at the Margareta Childs Archive, Historic Charleston Foundation, Charleston, SC. Photograph by author.

The Middleton-Pinckney House, built in 1796, is currently used as the headquarters for the Spoleto Festival USA. This Federal-style house is three stories over a full finished basement and an attic and totals approximately 8,500 square feet. The load bearing brick masonry exterior is covered with stucco and the roof material is standing seam metal. In 2001-03, the Spoleto office building underwent a major restoration and at that time a geothermal heat pump system was installed. The
A geothermal system was chosen because of the potential for long-term savings, environmental benefits, and visual and audible aesthetics. The geothermal system is very quiet and there is not visible equipment on the exterior of the building as the water loops are buried underground.

While the all of the above mentioned benefits of the geothermal systems are very appealing, the system at the Middleton-Pinckney House has had a few functionality problems. When the system was first installed in 2003, it was value-engineered from a commercial grade system down to a residential system to keep costs lower. Because of the use and size of the building, the smaller residential system had a water circulating pump failure in December, 2010. This led to the costly replacement of the smaller pumps with larger commercial grade water pumps, which have helped the system operate more efficiently since that time. Even before the pump issue, Spoleto was having problems with getting the entire building cool enough in the summer. Installation of the larger pumps has helped, but portable windows units are still used on the top floor of building during the summer. Another problem associated with the climate control system is the drying out and cracking of the floor boards on the top floor from the dry hot air when the system is in heating mode. Lastly, some of the heat pumps installed above the ceilings in the conditioned spaces have had water leaks, causing damage to the plaster ceilings and necessary repairs.
Discussion with the building manager of the Middleton-Pinckney House led to an interesting theory about geothermal systems in downtown Charleston. The thought is that the wells are not deep enough for the geothermal systems to be capable of adequately cooling large buildings. For example, the historic City Hall building in downtown Charleston had to install a water chiller in its geothermal system in order to cool the building to the required setpoints. Installation of a large, loud and expensive piece of equipment like a water chiller defeats the purpose of a geothermal system both aesthetically and environmentally, as well as decreasing the potential for long-term cost savings. Because of the high initial costs and major site excavation required for the installation of geothermal systems, they are not always practical options for historic house museums. One must be careful to select a geothermal heat pump system that is sized correctly for their building, especially in downtown Charleston where the subsurface conditions have not proved favorable for optimum performance.
Kenmore Plantation is located in Fredericksburg, Virginia, and was built in the 1770s by George Washington’s sister, Betty. The two-story brick plantation house was saved from demolition in the 1920s by the Kenmore Association (now The George Washington Foundation) and eventually converted into a historic house museum. In 2008, the Foundation completed an eight year restoration project that included installation of a geothermal heat pump system. The primary goal for the geothermal system at Kenmore was to stabilize interior temperature and relative humidity levels to provide an appropriate balance for the structure, collections and occupant comfort.\textsuperscript{204}

All of the equipment for the geothermal system was installed in a newly constructed underground vault located behind the kitchen building and the wells were installed

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underneath the staff parking lot towards the rear of the property. This configuration contains all of the water piping for heat exchanging in the vault and out of the historic house. Only conditioned air is delivered to the house through a ductwork system installed inside the chimney flues. A building automation system was installed to regulate the setpoints of system, provide constant interior environmental monitoring, and to coordinate with the fire protection system.\textsuperscript{205}

Thus far, the Kenmore geothermal system has been a success in maintaining the desired interior setpoints for the historic house museum. In fact, Kenmore designed their new HVAC system based on the new museum environmental standards explained under Question 2. Kenmore uses summertime setpoints of 70°F and 50-55% RH and wintertime setpoints of 66°F and 30% RH, and 60°F and 30% RH when the site is closed to the public in January and February.\textsuperscript{206} The control system gradually adjusts the temperature and relative humidity setpoints upwards in the spring until the system reaches the summer highs and then adjusts the setpoints downwards in the fall until the system reaches the winter lows. This allows the interior climate of the house to drift with the different seasons, creating a lower vapor pressure differential between the inside and outside environments, preventing condensation forming on interior surfaces. One of the lessons learned from the operation of Kenmore’s geothermal system is that

\textsuperscript{206} Ibid. These setpoints resemble the Class “B” level of control for museum buildings listed in the 2007 ASHRAE Handbook.
the new museum environmental standards equal greater operating efficiency for the
HVAC equipment because they are not constantly running to maintain a year-round,
mid-point interior climate. As a result, the equipment will have a longer useful life and
utility costs are lower.  

In spite of all of the benefits of the Kenmore geothermal system, the system had
a leak in the underground water lines in the late spring of 2008. The source of the
problem was the failure of two connectors where the underground PVC piping
transitioned into copper piping directly outside of the underground mechanical vault. In
order to fix the issue, the entire geothermal system needed to be shut down and the
house museum closed to tours for two days. Kenmore was closed to the public and
staff, and the passive methods of maintaining the interior environment were utilized. All
of the interior shutters and doors in the building were closed to prevent as much solar
heat gain and air infiltration as possible; also, no one was allowed into the building until
the geothermal system was back online. The thermal mass of the building was able to
keep the interior temperatures within 2-degrees and the relative humidity within 5-
percentage points of the setpoints. This situation provides an excellent example of
when passive climate control methods are successfully employed to maintain safe
interior environments for buildings and collections during problems with modern HVAC
systems. In addition, the issues Kenmore had with their geothermal system remind us

208 Rebekah Wood, e-mail message to author, February 23, 2012.
that “no modern day HVAC system is without its pitfalls, even when it is supposedly an infallible state-of-the-art system.”

Question 4: Are there new technologies or trends in the heating, ventilation and air-conditioning (HVAC) industry that could be utilized at the Aiken-Rhett House to achieve the desired interior climate?

After the interior environmental standards for museums were improved in the early 1990s, a movement towards more sustainable and passive climate control methods developed in the latter part of the decade. This trend sparked scientists and conservationists from around the world to rethink the use of modern, high-tech HVAC systems in our historic buildings. What developed was the idea that the interior environments of historic buildings could be maintained at appropriate levels for collections and the building itself, by increased use of passive and natural methods in combination with low-tech, simple mechanical systems. The combination of these techniques allow for seasonal temperature and humidity fluctuations that are better for the building and the historic artifacts, and they consume less energy and are more sustainable. Some of these ideas that are relevant to the climate control issues as the Aiken-Rhett House are presented in the following pages.

Air Circulation to Reduce Extremes


209 Rebekah Wood, e-mail message to author, February 23, 2012.
Techniques.” By this time, it seemed to be the consensus among conservationists that rapid, large spikes in temperature and relative humidity levels are much worse for historic structures than consistent extreme exposure (high or low).\textsuperscript{210} Brown states that these extremes and their effects can be managed by “careful condition assessment, consistent monitoring, and managing the air flow” within the historic structures.\textsuperscript{211} This article highlights the importance of continuous environmental monitoring and using a historic building’s architectural features to control airflow. By effectively managing airflow throughout a historic building, the damage caused by high levels of temperature and humidity to building materials and collections can be alleviated. In structures that are uninsulated and not tightly sealed, like the Aiken-Rhett House, Brown offers the following techniques to mitigate extreme temperature and humidity levels: natural ventilation, ceiling or room fans, whole-building exhaust fans and forced air mechanical systems.\textsuperscript{212} These suggestions will be taken into consideration when making the final recommendations for the Aiken-Rhett climate control system.

\textit{Heating, Ventilation \& Dehumidification System}

In the late 1990s, the Getty Conservation Institute (GCI) started research on issues associated with the conservation of collections and buildings in subtropical and tropical climates. This eventually developed into a multi-year project called “Alternative


\textsuperscript{211}Ibid., 46.

\textsuperscript{212}Ibid., 48.
Climate Controls for Historic Buildings (2003-2010)” in which experts from around the world participated. The main goal of this project was to find “economical and sustainable application of techniques previously developed by the GCI to prevent fungal and bacterial attacks through improvement of the physical environment of collections in historic buildings in hot and humid regions.”²¹³ In order to accomplish this goal, GCI conducted five case studies in various locations around the world in similar hot, humid climates. The case study locations included Jekyll Island, Georgia, the Canary Islands in Spain, two locations in Brazil and one in Beijing, China. During this project in 2007, the Getty organized a conference in Tenerife, Spain, called the “Experts’ Roundtable on Sustainable Climate Management Strategies.” At this conference, experts gathered to share their knowledge about alternative methods to conventional climate control and to identify areas that needed further research. Several papers presented at the Experts’ Roundtable are valuable resources for the Aiken-Rhett House study. The discussion papers and documentation from all of the case studies can be found on the Getty Conservation Institute website under “Our Projects.” The Jekyll Island case study is the only one of the five that is located in the same humid, subtropical climate as Charleston; therefore, the alternative climate control methods used in that case study were reviewed for their applicability to the Aiken-Rhett House.²¹⁴

²¹⁴ Jekyll Island, GA is located in the same “Cfa” Köppen-Geiger climate classification as Charleston, SC.
The same year as the Experts’ Roundtable, a team from the GCI’s Alternative Climate Controls for Historic Buildings Project published a study titled “Testing Alternatives to Conventional Air-Conditioning in Coastal Georgia” in an *APT Bulletin*. The team was led by Shin Maekawa, senior scientist at GCI, who was also the head of its Environmental Studies Laboratory and holds degrees in mechanical engineering and conservation science. Another team member, Vincent Beltran, was an assistant scientist at GCI and researched microclimates for cultural object conservation and climate control technologies for historic buildings. The third and final team member, Franciza Toledo, was a private consultant from Brazil who had a PhD in museum studies and focused research on the conservation of movable cultural property.\(^{215}\) The site chosen for their study was Hollybourne Cottage on Jekyll Island, Georgia, and it was completed in six phases over five years (June 2000 – October 2005). The goal of the Hollybourne Cottage case study was to stop the decay of the building by improving the interior climate with means other than conventional HVAC systems in an economical, technologically simple way that caused minimal damage to the historic fabric.\(^ {216}\) The research team knew that maintaining an interior environment below 75% relative humidity could significantly reduce and even prevent biological damage to the building.\(^ {217}\) As a result, the objective of the Hollybourne Cottage system was to

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\(^{217}\) Ibid., 3.
maintain indoor relative humidity levels below 70%, which is 5% below this microbial-growth threshold. The Getty team accomplished their goal by installing a climate control system that used a combination of heating, dehumidification and ventilation. In addition to the low installation costs, the system’s operational costs were only a fraction of what it would cost to run a typical HVAC system.\textsuperscript{218}

Though the Hollybourne Cottage is not used as a historic house museum, the climate control system is a practical and feasible solution to the problems at the Aiken-Rhett House because they are both located in coastal climates of the southeastern United States. The cottage was built in 1890 and is two-and-a-half stories over a full basement and an approximate total area of 11,300 square feet. The foundation is constructed of brick, the exterior walls are tabby and the interior walls and ceilings are plaster over wood lath. Though the exterior walls of the Aiken-Rhett House are entirely brick, the tabby walls at Hollybourne provide a similar thermal lag for the interior environment of the building. Various configurations of convection heaters, dehumidifiers, and ventilators were tested throughout the six phases of the study.\textsuperscript{219}

\textsuperscript{218} Maekawa, Beltran and Toledo, “Testing Alternatives to Conventional Air-Conditioning in Coastal Georgia,” 8-10. The operational costs of the Hollybourne Cottage system ranged from 27-73% less expensive than the operational costs for a typical HVAC climate control system, depending on the phase of the project. In addition, the capital costs for the Hollybourne Cottage system ranged from $1.84 to $2.50 per square foot (depending on the phase), whereas a typical HVAC system would cost $10 per square foot for heating only to $50 per square foot for complete climate control. Actual capital costs for the Hollybourne Cottage system ranged from $11,800 to $19,100 depending on the project phase. The initial installation required 200 man-hours for an added cost of $9,000 per phase; therefore total costs would be between $20,000 to $30,000 for equipment and installation.

During the first three phases, the Hollybourne Cottage climate control system used humidistatic controls for the heaters and ventilators that would operate as described below:

The heaters were selected to produce an increase of only several degrees in the space. A programmable controller activated the ventilators whenever the outside relative humidity was below 70% and the inside relative humidity was higher than 70%. The ventilators ran until the basement’s relative humidity was reduced to 65% or less. The heaters were activated whenever both outside and inside relative humidity exceeded 75%. The heater ran until the inside relative humidity was reduced to less than 70%, the outside relative humidity had fallen below 70% (at which time the ventilator would activate), or when the air temperature in that space reached 30°C (86°F).

In the last three phases of the case study, dehumidifiers were added into the basement configuration. The ultimate conclusion from the Hollybourne Cottage study was that creating a buffer zone in the basement and attic would protect the floors in between by controlling the environment in these buffers spaces to reduce the transfer of high humidity or heat from the exterior. The high levels of humidity in the basement during the summer were reduced by using heating or dehumidification. Heating the air in the cooler basement area reduced the relative humidity because warmer air can hold more moisture. Alternatively, dehumidification can be used to directly remove moisture from the air. Also, if the basement receives little visitation, then the ventilators in this area can be removed. In addition, the extreme environment in the attic was controlled by

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ventilation in the summer and heating in the cooler periods. GCI states that the heating equipment is less expensive and requires less maintenance than the dehumidifiers; but, the dehumidifiers have lower energy costs.\(^{221}\) Overall, the supply and exhaust ventilators had the lowest operational costs, representing only 11-percent of the total operating costs during the project phase when ventilation was used the most.\(^{222}\)


The GCI team argued that ventilation on the floors between the attic and basement was not wise from a preservation standpoint; however, visitation and summer work would require the use of ventilation for human comfort.\(^{223}\) Because the Aiken-Rhett House receives visitation all year, the use of ventilation for improving visitor


\(^{222}\) Ibid., 8.

\(^{223}\) Ibid., 10.
comfort and safety might also be considered. Though ventilation will increase interior humidity levels, the GCI team states that “short-term elevations will not cause significant microbial activity” as long as dehumidification or heating is used during unoccupied hours (night time for the Aiken-Rhett) to return the humidity levels below 70% RH inside the house. Thus, if natural ventilation methods are employed at the Aiken-Rhett House during the day to alleviate the interior environmental extremes on human comfort, then some type of dehumidification process will be needed during off-hours to bring the relative humidity back into the safety zone.

Figure 5.26: Examples of the types of convection heaters (left) and supply ventilators (right) that were used in the Hollybourne Cottage project. Source: Image from The Getty Conservation Institute, “Alternative Climate Controls for Historic Buildings (2003-2010) – Project Images,” The J. Paul Getty Trust, http://www.getty.edu/conservation/our_projects/science/climate/index.html (accessed March 9, 2011).

The alternative climate control system employed at Hollybourne Cottage succeeded in keeping the interior relative humidity levels below the microbial threshold of 75% RH. After the system was installed and operational, the average basement relative humidity levels ranged between 61-67% RH and the average temperatures

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ranged from 71.3-75.3°F. In the attic, where extreme heat levels were the primary concern, the maximum air temperatures were reduced from 106.6°F to 95.2-102.0°F after the system was installed. Even though the average temperatures in the attic were higher, the maximums were lower than before the system was installed. After heating was installed in the attic, the average relative humidity levels were equal to or below 65% RH. GCI states that if thermal insulation is installed on the roof it would help prevent solar heat gain in the summer and heat loss in the winter and the need for the attic system heating component in the winter may be reduced or even removed completely. On the first and second floor, the average air temperatures ranged between 72-77°F and the average relative humidity levels were equal to or below 69% for the first floor and 65% for the second floor. Basically, the Hollybourne Cottage system reduced the relative humidity levels, but slightly increased temperatures on each floor of the building.

The Hollybourne Cottage system is a plausible solution to the climate control issues at the Aiken-Rhett House. Visitor comfort is a secondary priority of this system, which is also a condition of the Aiken-Rhett study. This type of heating, dehumidification and ventilation system is custom-designed and focuses on the needs of each individual floor in the building. This type of approach to climate control issues at the Aiken-Rhett House could be beneficial. The concept of focusing on the needs of different areas of

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226 Ibid.
the house (like the Art Gallery versus the third floor) instead of applying the same treatment to the entire house seems like an appropriate solution to better protect the building and its finishes. This climate control system, with added ventilation modifications for the health of building occupants, has the potential to succeed at the Aiken-Rhett House.

Ventilation, Dehumidification & Cooling System

Another case study in the GCI’s Alternative Climate Controls for Historic Buildings (2003-2010) project was conducted at the library of the Casa de Rui Barbosa Museum in Rio de Janeiro. This building was constructed in 1850, and was converted into Brazil’s first house museum in 1930. The building has a five-room library on the first floor that is home to the original book collection of Rui Barbosa, as well as antique furniture and artworks. Over 37,000 books are stored in custom-built bookcases that line the walls of the library. The goal of the Casa de Rui Barbosa case study was to provide a safe interior environment for the collections while also increasing the visitor comfort. On this note, the Barbosa Museum case study takes the Hollybourne Cottage project one step further in its attempt to provide comfort for building occupants with alternative methods to conventional HVAC climate control. In 2004, the GCI began their case study in Brazil and five years later the research team presented their paper “Climate Controls


The Barbosa Museum project is discussed as an alternate option to the Hollybourne Cottage system because of its consideration of collections and human comfort in the system design. Though both these items are secondary to the Aiken-Rhett climate control study, this option may be preferred by the Historic Charleston Foundation because it does take occupant comfort and collections into account, and the building operates as a historic house museum. Even though this case study focuses on climate control for a portion of the building, the understanding is that this system can be applied to an entire structure. Furthermore, the Barbosa Museum contains significant paper objects (books) that are a primary concern for the stewards of the property, much like the Aiken-Rhett House and its wallpaper.

The goal of the Barbosa Museum climate control system was to keep relative humidity below 65% to protect the collections from biological growth and mechanical damage while allowing the temperature to vary. The GCI states that “the control of both temperature and relative humidity is technically difficult and costly, especially in historic buildings in hot and humid regions; therefore, we focused our efforts on maintaining a
stable range of relative humidity. This statement makes a good point in that it is very costly to maintain both temperature and humidity setpoints, as the Heyward-Washington House case study proved. By actively controlling only the relative humidity levels inside the library, the operating costs of the system were reduced. In order to adequately address the occupant comfort issue, minimal cooling is provided when temperatures reach above 82.4°F (28°C). Higher levels of air movement and high air exchange rates in areas adjacent to visitors were also used to improve human comfort. The conditioned air is delivered to the library in locations that are close to the visitors with the intention of protecting the collections from higher levels of air movement.

The Barbosa Museum climate control system is comprised of a supply outside air ventilator and split DX air-conditioning unit in the basement and an exhaust ventilator in attic. The dehumidification is provided by a reheat coil that is located downstream of the air-conditioning unit. The controls for the system are comprised of a programmable control unit (PLC) and two temperature and relative humidity sensors located inside the library and outside the building. Ductwork runs under the first floor (basement ceiling) and delivers air to the library through thirty spiral-type diffusers installed in the floor along the visitor paths. The hot air is removed from the attic by the exhaust ventilator

\[^{228}\text{Maekawa, Carvalho, Toledo and Beltran, “Climate Controls in a Historic House Museum in the Tropics,”} 2.\]

\[^{229}\text{Ibid.}\]
installed in a duct that runs through an existing skylight to the roof. The system has five modes of operation: ventilation, dehumidification, hybrid, cooling, and hibernation (off). Because historical climate data showed that the ventilation mode of the climate control system is feasible for only 10-percent of the year, it was expected that the system would operate mostly in the dehumidification mode.

Figure 5.27: Schematic of the dehumidification operation mode of the Casa de Rui Barbosa Museum climate control system. Source: Image from Shin Maekawa, Claudia Carvalho, Franciza Toledo and Vincent Beltran, “Climate Controls in a Historic House Museum in the Tropics: A Case Study of Collection Care and Human Comfort” (paper presented at PLEA2009 – 26th Conference on Passive and Low Energy Architecture, Quebec City, Canada, June 22-24, 2009), Figure 4.

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230 Maekawa, Carvalho, Toledo and Beltran, “Climate Controls in a Historic House Museum in the Tropics,” 4.
231 Ibid., 3.
In order to implement this climate control strategy, the Barbosa Museum building envelope was repaired to reduce infiltration and the original passive climate control features were “reinstated as much as possible.” Fortunately, the exterior envelope of the Aiken-Rhett House has recently been restored, which would help reduce the capital costs if this option was selected. Next, the paper items were cleaned and placed back into repaired bookcases in the Barbosa Museum library. In addition, the windows and doors in the building must remain closed at all times to reduce the intrusion of dust and polluted outside air.

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232 Maekawa, Carvalho, Toledo and Beltran, “Climate Controls in a Historic House Museum in the Tropics,” 3.
The Barbosa Museum climate control system was successful in creating a safe environment for the historic building and the collections, as well as providing human comfort. The interior relative humidity was maintained at below 65% while the temperature was allowed to fluctuate between 71.6-82.4°F (22-28°C). These interior climate conditions prevented condensation, reduced air pollution and particulates, and increased human comfort. The actual level of air movement was lower than designed; however, visitors still said the environment was “comfortable,” “cooler,” and “fresher and drier.”233 Also, the Barbosa Museum climate control system had occurrences when the interior conditions would drift from the setpoints. It was determined that the cause of the problem was the complex controls program in combination with too many operational modes. Although the solution to the controls problem was not provided, GCI states that equipment adjustments were made after monitoring. The last issue that the GCI team confronted with the Barbosa Museum system is that they were unable to find a contractor that would accept a maintenance contract. Even though the climate control system is comprised of “standard off-the-shelf equipment,” the unfamiliar system design was a deterrent for maintenance contractors.234

Like the Hollybourne Cottage system, the climate control system implemented by the GCI at the Casa de Rui Barbosa Museum is a potential solution for the Aiken-Rhett House. Through use of ventilation, dehumidification and cooling, the Barbosa

233 Maekawa, Carvalho, Toledo and Beltran, “Climate Controls in a Historic House Museum in the Tropics,” 6.
234 Ibid.
Museum system successfully maintained a safe interior environment for the building, its finishes and collections, while also keeping the occupants comfortable. As mentioned previously, the collections and visitor comfort are a secondary priority for the Aiken-Rhett House study; however, if there is an appropriate climate control system that can achieve optimum levels of temperature and humidity for all parties concerned, then it is well worth examination.

**Utilizing Passive Architectural Features for Sustainable Climate Control**

Another paper presented at the Experts’ Roundtable on Sustainable Climate Management Strategies by Michael C. Henry in 2007, was “The Heritage Building Envelope as a Passive and Active Moderator: Opportunities and Issues in Reducing Dependency on Air-Conditioning.” This paper discusses the new challenges the preservation field must face with ever-increasing energy costs and the need to protect our historic buildings and collections. Because historic buildings are inherently sustainable, Henry argues that the conservationists should take advantage of original building design instead of turning to expensive and energy consuming HVAC systems for climate control. Henry uses the simple shutter example for demonstrating that original architectural features of historic buildings are multifunctional. Shutters are used for security, privacy and also for controlling solar heat gain, light, and moisture intrusion.\(^\text{235}\)

Other architectural features in historic structures -- like operable windows, doors, high...

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ceilings, multi-level porches, and ventilation shafts -- should be utilized to help maximize the benefits of passive climate control.

The main point of Henry’s paper is that, as responsible stewards of historic properties, we should not “contribute to the exacerbation of the very climatic effects that can threaten their longevity” through use of “higher-capacity mechanical systems that consume more energy and emit more carbon compounds.” He goes on to say that a sustainable approach to climate control in historic buildings should be a part of their management philosophy, as it can have the largest impact on conservation, capital and operating costs, as well as energy use. These sustainable ideas presented by Henry are directly applicable to the Aiken-Rhett House study. Henry makes an excellent point: why should we use mechanical systems that hurt the environment which will only end up hurting the building more in the long run?

Along this same note, Stewart Brand, the author of *How Buildings Learn*, states that “since about 30 percent of operating costs in most buildings goes to paying for energy, significant money for maintenance, tuning, and remodeling of the building can be freed up by designing in energy efficiency through well-proven techniques.” He goes on to list passive methods of climate control like orientation to the sun, vegetation for shading and appropriate choices in building material colors depending on the

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climate. An example of this idea is to use monies saved on implementation of passive climate control methods instead of a modern HVAC system to help pay for a historic finishes stabilization campaign in the Aiken-Rhett House. In addition to passive climate control methods being sustainable and requiring less operational costs, they also provide an opportunity to invest in other aspects of a historic building, like maintenance. For this purpose, the final climate control recommendation for the Aiken-Rhett House will be as sustainable as possible, keeping the goal of low energy consumption in mind with the overall preservation goals of the management of the facility.
Chapter 6 - Conclusion

The study of the Aiken-Rhett House was undertaken to help determine what type of climate control system would be the most appropriate for the historic structure, while also serving the primary purpose of protecting the building and its remarkable historic finishes. The collections and visitor comfort were secondary priorities considered throughout the study. The study included four research questions that helped the researcher develop final climate control recommendations for the Aiken-Rhett House.

Discussion of Results

*Question 1: What are the current physical conditions of the building, its finishes and HVAC systems?*

The current physical state of the Aiken-Rhett House, its historic finishes and HVAC systems were documented through a building condition assessment conducted during October and November of 2011. No existing water leaks were found, though there was evidence of water damage that had been repaired shortly after Hurricane Hugo in 1989. The exterior stucco and limewash coatings were recently restored, so the main concern on the exterior of the building is rising damp which has caused biological growth on the north side of the building. There is also evidence of rising damp inside the basement where efflorescence is visible on the brick walls and areas of plaster are lifting. The interior plaster on the top three floors of the house is in poor-to-fair condition and has significant cracking and areas of loss. Also, the paint coatings are in
moderate to severe condition and are peeling, cracking and alligatoring, with some locations showing complete loss. Lastly, the historic wallpaper finishes in the house are in poor condition, having suffered significant loss with a majority of the remaining wallpaper peeling off its substrate and the paint pigments failing.

Based on visual inspection and review of quarterly service reports and maintenance records, the existing HVAC systems in the Aiken-Rhett House are functioning properly in the climate controlled portions of the main house. Currently, only minimal maintenance issues need to be corrected like repairing small tears in duct insulation and ensuring filters are fitted properly in the Art Gallery fan coil unit. Based on the conditions assessment, maintenance records, and interviews there is no reason why the current HVAC systems should not remain in operation until the end of their useful lives. At that time, these systems should be reevaluated to see how they fit into the current climate control strategy for the Aiken-Rhett House. Also, the locations of the current HVAC equipment and distribution systems were well-planned and designed to take advantage of the less architecturally significant spaces inside the house, especially in the attics and water closet chases. If a new climate control system is installed in the Aiken-Rhett House, then some of the existing HVAC equipment may need to be removed to provide space for the new system. In addition, the existing ductwork distribution system can be reused and incorporated into a new climate control system.
The deteriorated conditions inside the Aiken-Rhett House are partly attributed to the high levels of temperature and relative humidity inside the house during the hot and humid summer months. The decreased use of original architectural features that provide natural ventilation and air circulation, especially on the third floor, has led to increased temperature and humidity levels throughout the house. Currently, collections are stored on the third level of the house, so the windows and shutters on this level are not used for ventilation. The lack of air circulation on the third floor creates a stagnant environment where the temperature and humidity levels during the summer are extreme. In order to keep interior surfaces drier and decrease the risk of moisture damage, the air circulation on the third floor of the house needs to be increased, especially during the height of the summer. This can be accomplished through mechanical systems, or increased use of windows and fans; however, in order to protect the sensitive collections currently stored on the third level, they should be moved to a more appropriate climate-controlled facility.

The deteriorated conditions inside the Aiken-Rhett House are also attributed to lack of repairs and upgrades that would occur if this historic property did not have a conservation philosophy. The museum interpretation of the house is one which leaves the interior finishes as is, intervening only to stabilize if necessary. If the house was to be fully restored, maintenance and repairs would be required on a continual basis. This would, however, detract from the experience of being in a place that has so many original finishes. This is not the case at the Aiken-Rhett House and the historic building
materials and finishes are deteriorating simply because of their age. Building materials
can only last so long before some sort of intervention is necessary, even if the materials
are of the utmost quality.

In addition to aging, the Aiken-Rhett is subject to deterioration from increased
visitation that is a part of its change from a residence to a museum. In 2010, over 33,000
visitors roamed through the historic building.238 Though visitors are guided along roped-off
paths throughout much of the museum, inevitably, someone will bump against a
frame or accidentally touch a wall which results in additional wear on the building and
its finishes. Floors and stairs are also worn more because of the large amount of people
walking through the house. Furthermore, large visitation numbers result in higher levels
of carbon dioxide and moisture (from sweating or breathing) inside the house, which
can lead to chemical deterioration of the original building materials. While limiting
access to the Aiken-Rhett House is probably not a viable or desirable option to
visitation-related deterioration, this issue is something that the Foundation should be
aware of and plan for, but also accept as part of the success of the museum.

Historic photographs show that the Aiken-Rhett House was in good condition in
the late 1950s, while the house was still lived in by family members and before the large
influx of tourists. After the last family member moved out in 1968, the house fell into a
state of disrepair because it was left empty and not maintained. When the Charleston

238 Valerie Perry, e-mail message to author, March 9, 2012. Also confirmed by April Wood, e-mail message
to author, March 9, 2012.
Museum acquired the property in 1975, the organization had intended to restore the house, but financial constraints prevented appropriate action. Damage caused by Hurricane Hugo and the lack of funding needed to keep such a large property maintained, saw the property fall further into disrepair during the Museum ownership. When Historic Charleston Foundation took over the property in 1995, they adopted a conservation approach that is still in place today.

While the Aiken-Rhett House is a rare example of a building that retains most of its nineteenth-century finishes, it will not be able to hold on to them forever, especially if open to large numbers of people and events. At some point in the future, the Aiken-Rhett House will reach a state where it needs serious intervention and repairs to prevent failure. The exterior of the building has recently been restored to help prevent further deterioration of the interior. Perhaps, more active stabilization of the interior will soon need to follow. This discussion brings up the question of the future interpretation of the Aiken-Rhett House and the long-term master plan for the property. These are complicated subject matters that involve issues outside the scope of this climate control study. Historic Charleston Foundation, however, is currently working on putting together a panel of experts to help make these decisions about the future of the Aiken-Rhett property. For now, the ultimate goal of this study is to provide recommendations for the protection of the house and its finishes in their current physical state of conservation.
As mentioned in Chapter 5, if the conservation philosophy of the Aiken-Rhett House continues, a serious stabilization campaign for the historic finishes needs to be considered regardless of the final recommendations for climate control. If the Foundation decides to increase use of passive climate control methods instead of a mechanical system, the monies saved could be used for the stabilization of historic paints and wallpapers.

**Question 2: What are the preferred interior environmental conditions desired for the Aiken-Rhett House? What are the current interior air properties and do they meet current museum environmental standards?**

The interviews conducted with Historic Charleston Foundation staff members to determine the preferred interior environment for the Aiken-Rhett House yielded results that aligned with the daily responsibilities of each staff member. The Curator desires temperatures ranging from 70-75°F and humidity levels ranging from 50-55% RH ± 2%, the Property Coordinator assumes that temperature and humidity levels in the house will need to be higher in the summer and lower in the winter, and the Associate Director of Museums would like to slow the deterioration of the building, its finishes and the collections. Over the last fifteen years or so, the current museum environmental standards have changed significantly. The year-round mid-point level of control (70°F ± 2°F, 50% RH ± 5%) that was commonly accepted since World War II has given way to wider acceptable ranges of temperature and humidity. These newer standards are based on scientific research that confirms organic building materials and artifacts can
withstand large, gradual fluctuations in temperature and relative humidity without mechanical damage; however, major changes in short time periods can actually cause more damage than extremely high or low temperatures and humidity. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) incorporated the new museum environmental standards in their 1999 ASHRAE Handbook and have continued to publish them in every subsequent issue. These new museum environmental standards are better for historic buildings because they allow for seasonal drift and decrease the difference between interior and exterior environments, thus decreasing the potential for moisture migration into the building.

Interpretation of the ASHRAE standards concluded that the Aiken-Rhett House, without any improvements, is currently capable of achieving the Class “C” level of interior environmental control, which prevents all high risk extremes to collections by keeping humidity levels between 25-75% RH and dry-bulb (DB) temperatures usually between 59-77°F, but rarely over 86°F. The interior air properties at the Aiken-Rhett were monitored over a period of several months to determine if they met the ASHRAE Class “C” level of control. When the interior air properties do not fall within the Class “C” temperature and humidity levels, there is potential for damage to the building and the collections. These are the occurrences that need to be addressed by some means of climate control.
Interior environmental monitoring results showed that the west side of the Aiken-Rhett House is generally warmer than the east side of the house year round. Data was not collected on the east side of the house during the summer, but the data from the west side showed that the temperature and humidity extremes occur from June to the beginning of September. In the winter, temperatures rarely fall below 59°F throughout the entire house, with the third floor of the house being the warmest level and the second floor being the coldest. This is a result of the forced air heating system providing heat to only one room on the east side of the second floor during the winter.

The relative humidity levels in the Aiken-Rhett House fluctuated more than the temperature levels, with the first floor having the highest humidity levels, followed closely by the second floor, and the third floor having the lowest. This is attributed to the fact that warmer air can hold more moisture; therefore, the floor with the highest temperatures would naturally have the lowest relative humidity levels. Comparison of daily weather records to incidences of high relativity levels in the house showed that a rain or fog event occurred on those dates. Contrarily, incidences of low relative humidity occurred on days with no rain events or with dew point temperatures well below the minimum ambient air temperature occurring on that day. In addition, the west side of the building has lower relative humidity levels than the east side of the house because it is typically warmer.

During the period of data collection, the majority of interior air properties for the Aiken-Rhett House fell within the ranges of Class “C” level of control. The incidences of
high risk extremes are the conditions that need to be mitigated by means of climate control, either passive or mechanical. Of course, this means that increased monitoring of interior air properties would be required in order to better predict high risk occurrences. Data loggers should be placed in every room in the house and even the basement and attic spaces to accurately depict the interior environment throughout all areas of the house. Certain staff members (building managers, museum directors and senior docents) would need to be trained on how to use interior environmental data loggers and how to interpret the data they record.

The existing forced-air heating system rarely allows temperatures to fall below 59°F in the main house during the winter. Therefore, additional sources of mechanical heating are not needed. A simple solution to the few incidences of low heat and humidity would be to use portable space heaters and humidifiers in the rooms that are usually affected during the periods of concern (for example, the second floor Withdrawing Room). In the summer, temperatures on the third floor never reached above 94°F on the west side of house, which is assumed to be hotter than the east side because of its greater exposure to solar heat gain. Increasing air circulation and ventilation with electric fans and operable windows should help alleviate the hot temperatures on the third floor of the house during the summer. This should also help pull some of the warmer air from the first and second floor up to the third floor and out the windows. High interior humidity levels were not just limited to the summer time, with some occurring during rain or fog events in the winter months. Portable
dehumidifiers could be used during levels of raised humidity in pre-determined locations like the lower levels or east side of the house. Lastly, because rain or fog events lead to elevated levels of humidity inside the building, the operating policies may need to be changed to ensure that windows and shutters are closed during these times or only left open on areas of the building that are shielded by the piazza. This should not be an issue in the winter because doors and windows are closed when the heating system is operating to keep the warm air inside. In the summer, however, closing all the windows and doors during rain events may lead to a stagnant indoor environment. Fans and dehumidifiers will need to be used during these times, and perhaps the upper sash of windows could be cracked slightly to help with ventilation, but shutters should be closed to keep out as much moisture as possible.

Question 3: What type of current climate control systems are being employed in other similar historic house museums and what have been their outcomes?

Four historic house museums in Charleston, South Carolina, were selected based on their similarities to the Aiken-Rhett House and for the different types of climate control systems used at each property. Evaluations were based on site visits and interviews to determine the climate control systems’ effects on the houses and typical problems associated with each. Although no historic house museums in Charleston currently use geothermal heat pump systems, examples of these systems are included because they are becoming more popular among house museums (like Poplar Forest and Montpelier). The two sites chosen for the geothermal discussion are Kenmore
Plantation, a historic house museum in Fredericksburg Virginia, and the Middleton-Pinckney House, a historic house converted into an office building in Charleston, South Carolina.

**Drayton Hall (1738-42)**

Drayton Hall was selected as a case study for three primary reasons: 1) it has no mechanical climate control systems, 2) no collections are displayed inside the house, and 3) it has never been restored. Drayton Hall is considered “unconventional” by today’s standards because passive methods are utilized to manage the interior environment. With the exception of electric fans, the original architectural features of the house, like operable windows and interior shutters, are used to control light and solar heat gain, while also allowing for natural ventilation. Periodically, condensation forms on the walls in the basement and stair hall when a warm day follows a cold night; but this problem is rare. After a failed attempt at a high-tech climate monitoring system, the staff at Drayton Hall has altered their operating procedures for opening and closing the house to better control the interior environment. Perhaps, the Aiken-Rhett House can increase use of its passive systems and make slight changes to its operational policies to help mitigate high levels of temperature and humidity during the summer.

No collections are displayed inside Drayton Hall because the building is not climate controlled. While complete removal of collections from the Aiken-Rhett House may not be an interpretation option, perhaps some of the most sensitive objects should
be removed from the house. If this is not desirable, then the sensitive objects could be exhibited in climate controlled display cases or moved to a section of the house that is heated and cooled, like the Art Gallery or basement level. Similar to the Aiken-Rhett House, Drayton Hall retains most of its late nineteenth century paint finishes which have deteriorated over the years from age, UV light and moisture intrusion. In 2003, Drayton Hall undertook a paint consolidation project in order to protect its long-standing existence. One of the primary reasons for wanting to install a climate control system at the Aiken-Rhett House is to protect its historic finishes. Drayton Hall is an example of a historic house museum that has been successful at protecting its finishes without a mechanical system; however, Drayton Hall does not have historic wallpaper finishes, like the Aiken-Rhett, which are highly sensitive to moisture. A stabilization campaign for wallpaper finishes can be very expensive; but so can the installation, operation and maintenance costs for an HVAC system. As mentioned previously, the costs saved on a new HVAC system could be utilized to stabilize the historic finishes at the Aiken-Rhett. If Drayton Hall can successfully slow the deterioration rates of its finishes and not use a mechanical climate control system, there is hope for the Aiken-Rhett House to do the same. Regardless if a HVAC system is installed or not, it seems that the wallpaper and paint at the Aiken-Rhett House will need to be stabilized sometime in the near future in order to save them. To borrow another quote from the inventor / designer and popular writer Stewart Brand, “a successful building has to be periodically challenged and
refreshed, or it will turn into a beautiful corpse.” This reminds us that buildings are alive, and just like humans, buildings need preventative maintenance to help them last longer.

**Joseph Manigault House (1803)**

The Joseph Manigault House was selected as a case study because it is a partially climate controlled house museum, like the Aiken-Rhett. The Manigault House is mechanically heated on the first floor letting the air rise naturally to the upper levels of the house. There are problems with the furniture drying out in the winter because of the heating system; so, portable humidifiers are used to add moisture to the air. Also, the staff uses pieces of Plexiglas to help redirect the warm air from the vents away from the furniture. In the summer, the first floor Dining Room is the only room in the house, besides the staff lounge, that is air conditioned. Consequently, the Dining Room is the only room in the house that has mildew or condensation problems occurring on the windows. The cause of the condensation and mildew is most likely the vapor pressure differential between the Dining Room and the exterior. Other contributors could be that the system runs only during museum operating hours or that the thermostat has been located improperly in the adjacent staff lounge. Other areas of the house are kept cooler in the summer by use of operable windows and interior pocket shutters. There are no problems in the Joseph Manigault House associated with the historic paint finishes and climate control, as any chipping or peeling is attributed to the age of paint.

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(over fifteen years old). Though collections are displayed inside the building, no problems have occurred in areas with passive climate controls methods.

Even though the Joseph Manigault House has been restored it provides a good comparison for the Aiken-Rhett House because both buildings are only partially heated or cooled using a combination of different climate control systems. Both houses are heated during the winter, and both have spaces that are cooled during the summer. The Aiken-Rhett House is larger in size and has larger HVAC systems, but the general concept is the same. In theory, a historic house museum in a hot, humid climate can utilize both mechanical and passive methods to successfully manage its interior environment without harming the building or its finishes. Some lessons learned from the Joseph Manigault House are that the proper location of thermostats is necessary and that humidity controls are an important component for cooling and heating systems in order to avoid moisture problems. Low interior humidity levels during the summer will result in moisture migration into the building, while low interior humidity during the winter will result in mechanical damage to building materials or collections.

**Heyward-Washington House (1772)**

The Heyward-Washington House was selected as house museum case study because it is fully climate controlled building that uses a standard chilled water system. The installation of the HVAC system at the Heyward-Washington House was successful in hiding the large pieces of equipment from the visitors view. Unfortunately, the chiller
and condenser located on the second floor of the Kitchen Building are very loud and they are easily heard by visitors when they are touring the gardens. This detracts from the historic site experience for the visitors and also provides a noisy working environment for the house museum staff. Also, the location of these large pieces of HVAC equipment in the Kitchen Building has resulted in the loss of historic fabric, like the removal of interior walls on the second floor and plaster loss from equipment vibrations. The outbuildings on the Aiken-Rhett property, especially the slave quarters, are just as historically important as the main house and some may argue even more important. Therefore, it would not be appropriate to install mechanical equipment inside the outbuildings at the Aiken-Rhett House.

Another success of the chilled water system at the Heyward-Washington House is providing a constant, year-round mid-point interior environment (72°F, 50% RH) for the collections. Providing this stable interior environment for the collections comes at a large price, with monthly utility bills in the range of a few thousand dollars. In addition to the high operational costs, the interior finishes in the building took a few years to acclimate to their new interior environment which required multiple plaster repairs. In its current state, the Aiken-Rhett House will not be able to provide a year-round, mid-point level of climate control for its collections. As discussed in the results for Question 2, this mid-point level of control is not beneficial for the building or its finishes. Therefore, it may be best to remove the collections, or at least the most sensitive
objects, from the Aiken-Rhett House and store them in a climate controlled facility where temperature and humidity levels can be monitored with precision.

Another consequence of the installation of the chilled water system in the Heyward-Washington House is the presence of condensation on the exterior of the windows in the main house. As discussed in Chapter 5, condensation causes building materials to deteriorate at a quicker rate, which will result in more frequent maintenance or repairs on the windows. While this effect of providing a constant interior environment is easily visible, we are unable to see what is occurring inside the wall cavities at the Heyward-Washington House. While it cannot be confirmed, there is a strong likelihood that moisture is migrating through the exterior brick walls and condensing on the backside of the interior wood lath and plaster. This may lead to significant moisture damage in the future which will be hidden from view until indications such as peeling paint or lifting plaster develop.

Chapter 5: Results pointed out that the HVAC system in the Heyward-Washington House is controlled remotely from Columbia, South Carolina, and operates only during business hours of the museum. The benefits of the remote control is that staff members do not have the ability to change the setpoints of the system at will; however, this may cause some frustration because, if the setpoints do need to be changed or if the system needs to be turned off or on, then the staff has to go through Columbia. The fact that the system is shut down every day at 5:00PM when the house...
museum is closed to visitors leads to a question: what happens if the temperature or humidity levels inside the house drift outside of the setpoints of the system during the unoccupied hours? It can be assumed that during the height of the summer or winter that the house would not be able to maintain the mid-point level of control, even with its large thermal mass. How does this affect the collections during the unoccupied hours of the museum? While these questions will not be answered in this study, they lead to the conclusion that climate control systems should probably operate twenty-four hours a day, especially if it is necessary to maintain strict setpoints. In any case, they should be monitored all the time to see if and when problems may occur.

The last issue with the chilled water system in the Heyward-Washington House is simply its age. The HVAC system is over fifteen years old and is nearing the end of its useful life. As a piece of mechanical equipment gets older, the amount of maintenance and repairs and costs usually increase. Also, the replacement of a HVAC system is inevitable as the typical useful life of HVAC equipment can range between fifteen to thirty years; however, external factors can lead to shorter or longer lifespans. Regardless, all mechanical systems will need to be replaced eventually, resulting in large expenditures for design of the new system, the purchasing of the new equipment and installation of the system, as well as demolition of the old system. Once a new system is in place, a regime of operating and maintenance needs to be established and a new set of maintenance requirements put in place. There is often a "breaking in" period and future maintenance costs are difficult to predict. Replacement is not a straightforward
proposition. In short, some important factors to consider for the Aiken-Rhett House climate control system are the estimated useful life of the HVAC equipment, the anticipated maintenance and repairs, and the inevitable replacement or updating of the system.

**Nathaniel Russell House (1808)**

The Nathaniel Russell House was selected as a case study to provide another example of a fully climate controlled house museum that uses a chilled water system. Similar to the Heyward-Washington House, the air handlers at the Nathaniel Russell are located within the historic structure in the basement and attic spaces. By contrast, the Nathaniel Russell House has located its large pieces of mechanical equipment in rear service sheds that are not significant historic spaces; however, one large piece of equipment, the air-cooled condenser, is located at the rear corner of the staff parking lot, which is in close proximity to the gardens at the back of the property. When operating, the condenser is very loud, like the one at the Heyward-Washington House, and has resulted in comments from visitors.

The main complaints about the chilled water system at the Nathaniel Russell House are the lack of humidity control and the variation in temperature and humidity levels between the different zones in the house. Currently, the staff is trying to influence humidity levels through the temperature, but this has yielded unsatisfactory results. The inability of the Nathaniel Russell HVAC system to control humidity has led to concern
over the effects on the decorative and fine arts collection inside the house. The physical evidence of improper humidity levels is the condensation on the windows and the mildew on the diffusers in staff-occupied areas of the building. Like the Heyward-Washington House, the condensation forming on the windows is a sign of a larger problem. The condensation will cause more frequent repairs to the windows, but the moisture intrusion through the exterior walls may be causing hidden damage, such as mold, mildew or rot, on the backside of the interior plaster. This situation highlights the importance of maintaining interior temperature and humidity levels closer to the exterior conditions to limit the amount of vapor diffusion or air infiltration across the building envelope.

The chilled water system at the Nathaniel Russell House is over twenty years old and very near the end of its useful life. Like the Heyward-Washington system, it requires constant repairs and maintenance that result in expenses in addition to the normal operating costs. Needless to say, the chilled water system at the Nathaniel Russell House will be replaced sometime in the near future. The plan is to reuse much of the existing distribution systems to minimize removal or damage to historic fabric. Humidity controls will also be included in the new system design. Nevertheless, it can be assumed that the capital costs will be high, no matter what type of new HVAC system is designed.

Even though the final recommendations for the Aiken-Rhett House will not include a chilled water system, it was necessary to examine these systems to
understand the advantages and disadvantages they offer for a historic house museum. With proper humidity control, like at the Heyward-Washington House, a constant mid-point interior environment can be provided for collections. The consequences of maintaining this constant environment in a historic structure is high operational costs and potential damage to the building and its finishes. In addition, the installation of a chilled water system requires considerable space to locate the large pieces of mechanical equipment. If these spaces are not available, they may need to be created by removal of historic fabric or construction of mechanical rooms. Also, removal of historic fabric will be necessary to install the piping and ductwork distribution systems. With large amounts of water piping running through a building, there is always a potential for a leak, which could be very detrimental. For these reasons, a chilled water system will not be considered as a final recommendation for the Aiken-Rhett House. There are not portions of the site or building which can be sacrificed.

**Geothermal Systems: Middleton-Pinckney House & Kenmore Plantation**

In *Chapter 5*, the benefits of geothermal systems were discussed -- namely, the potential for long-term energy savings, sustainability, and lack of visible and audible exterior equipment. The disadvantages of geothermal systems are their high initial costs, major site excavation, and high repair costs if problems do occur. For example, the Middleton-Pinckney House incurred high expenses when the water pumps failed a few years after the system was installed. Similar to a chilled water system, there is a potential for water leaks when a geothermal system requires water to be piped
throughout the building for distribution to the heat pumps. Fortunately, some geothermal systems can keep all of the HVAC equipment and water distribution systems in a separate mechanical space which reduces the impact on the historic building. For instance, all of the equipment for the geothermal system installed at Kenmore Plantation was isolated in an underground mechanical vault. Unfortunately, the ability to do this requires significant expenditures as well as the available space to create a separate mechanical room. Despite the advantages of geothermal systems, it does not seem like a practical or appropriate solution to the Aiken-Rhett House climate control issue. The extensive money spent on such a system would likely detract from the money that might be spent on the conservation of the house itself. In the case of Kenmore, the money was donated specifically earmarked to build this system and not for other items. Also, the amount of site excavation would require extensive archaeological work that would only add to the cost. Furthermore, there has not been a good record of geothermal system functionality in downtown Charleston. Therefore, a geothermal system will not be considered for final recommendation for the Aiken-Rhett House.

**Question 4: Are there new technologies or trends in the heating, ventilation and air-conditioning (HVAC) industry that could be utilized at the Aiken-Rhett House to achieve the desired interior climate?**

Over the last twenty years, conservation professionals and scientists at renowned research institutions have proven that historic buildings, finishes and collections can withstand larger fluctuations in acceptable temperature and relative
humidity levels. As long as these fluctuations occur gradually, the buildings and collections fare better because less moisture infiltrates the interior environment. This research has fostered a movement to shift conservation practices in hot and humid climates towards more sustainable, technologically simple climate control systems used in conjunction with passive methods. Typical HVAC systems are expensive to install, operate and maintain and eventually they will need replacement. In addition, there is no guarantee that a conventional HVAC system will actually maintain the desired interior environment. In response to these issues, the Getty Conservation Institute (GCI) organized a multi-year study to find alternative “economically sustainable” and “technologically simple” solutions to climate control for historic buildings in hot, humid climates. GCI conducted five case studies all over the world, implementing different systems to see which was successful at achieving the interior climate goals at each site. Two of the case studies were discussed in Chapter 5: Results, Hollybourne Cottage in Jekyll Island, Georgia, and the Casa de Rui Barbosa Museum in Rio de Janeiro, Brazil.

At Hollybourne Cottage, a five year project tested different configurations of convection heaters, ventilators and dehumidifiers. The goal was to maintain indoor relative humidity levels less than 75% to prevent microorganism (insects, fungi, and bacteria) attacks. The most successful equipment configuration conditioned only the basement and attic levels of the building, creating a buffer zone for the first and second floors. On this note, the temperature levels in the staff-occupied areas of the basement at the Aiken-Rhett House may need to be increased in order to reduce humidity levels in
this space and the consequent spreading of elevated humidity levels to the first floor. Meanwhile, using ventilation on the floors between the basement and attic was not advised; however, it was acknowledged that ventilation may be needed for human safety and comfort when the spaces are occupied. This is the difference between the Hollybourne Cottage and the Aiken-Rhett House. The Aiken-Rhett House is occupied seven days a week by visitors and staff, while the Hollybourne Cottage is not a museum and is vacant a majority of the time. Because ventilation will be needed for the building occupants at the Aiken-Rhett House, off-hours dehumidification or heating would need to be employed if this type of climate control system is used.

The Hollybourne Cottage climate control system was custom-designed, based on the individual needs of each floor which were determined after of twelve months environmental monitoring. After the interior climate of the building and the microclimate around the site were monitored for one year, the GCI team was able to create their interior target conditions and design a system that could reach these goals. One year of monitoring is the industry standard and should be conducted at the Aiken-Rhett House before any climate control system is designed. Equally important, all of the equipment in the Hollybourne Cottage system was humidistatically-controlled, meaning that the relative humidity levels (not the temperature) triggers the operation of the equipment. As we saw in *Chapter 5*, all of the historic house museum case studies, especially the Joseph Manigault House and the Nathaniel Russell House, demonstrate the importance of controlling interior humidity. Improper levels of humidity can lead to
moisture migration into the building resulting in condensation or the formation of mildew of mold on interior surfaces. Lastly, the GCI team warned about equipment noise from the dehumidifiers and ventilators. A simple resolution to this problem is the placement of these pieces of equipment away from the visitor path through the house museum.

The second case study conducted by GCI was at the Casa de Rui Barbosa Museum in Rio de Janeiro, Brazil. As stated in Chapter 5, this case study takes the Hollybourne Cottage project one step further and adds human comfort into the equation. Even though human comfort is a secondary priority in the Aiken-Rhett study, it is necessary to discuss this climate control system as it may be a potential option for Historic Charleston Foundation in the future. Instead of providing only heating, ventilation and dehumidification like the Hollybourne Cottage, the project at the library in Casa de Rui Barbosa Museum also utilized cooling. The goal of this case study was to provide a safe environment for the collections by keeping relative humidity levels below 65% and allowing temperatures to vary. Human comfort was provided by air movement near the building occupants and cooling when temperatures exceeded 82.4°F. All of the equipment for this climate control system except for the attic ventilator was installed in the basement of the building.

Once again, the Getty team was successful in their endeavors to provide “economically sustainable” and “technologically simple” climate control methods in hot
and humid climates. Though the project was a success, the team did run into a couple problems during the installation and operation of the system. The difficulties of installing floor diffusers resulted in lower air movement near the occupants than originally designed. In spite of this, visitors felt that the interior environment was improved and more comfortable. Also, the complexity of the control system and too many operational modes resulted in times when the interior environment in the library drifted from the set points. No specific resolutions to the control problems were described; however, it was noted that adjustments to the equipment were made.

The climate control system installed in the Casa de Rui Barbosa Museum is a possible option for the Aiken-Rhett House. If human comfort becomes a priority for the house museum, then this system has the advantage over the Hollybourne Cottage system. A foreseeable problem with using this system at the Aiken-Rhett would be the location of all the equipment. At the Barbosa Museum, a majority of the equipment and ductwork is located in the basement; unfortunately, this is not an option at the Aiken-Rhett House because the basement level is either staff spaces or part of the interpreted space. Perhaps, the equipment could be installed in the attic spaces, but structural reinforcement and safety devices (like condensate overflow alarms) may be needed. Another problem with the Barbosa Museum system would be the installation of all of the supply diffusers necessary to increase the air movement near the visitors. Because the visitors at the Aiken-Rhett House walk through all of the historically significant spaces on the first and second floors, there are no obvious options for locations to
install supply air diffusers. One conceivable idea would be utilization of the existing ductwork in the water closets on each floor; however, this would only serve the east side of the building. Another idea would be to utilize the existing chimneys to run ductwork. Every room inside the Aiken-Rhett House has fireboxes (except the stair halls); however, most of these have been retrofitted to burn coal which would prove difficult to use for running ductwork.

The key phrases for all of the Getty Conservation Institute case studies in hot humid climates are “technologically simple” and “economically sustainable.” All of the pieces of mechanical equipment used in the GCI studies were standard “off-the-shelf” units. While this means the initial costs for equipment is less expensive than conventional HVAC systems, the GCI team found that they were unable to find mechanical contractors that were willing to enter into service agreements because of the unfamiliar equipment design.240 This issue may be problematic to some, but there are house museums that function without maintenance agreements for their HVAC systems. For instance, the Joseph Manigault House does not have a service agreement with a mechanical contractor; however, if there is an HVAC problem, the house museum has a preferred contractor that they use.241 Another solution to not having maintenance contract would be to have a trained person on staff who can maintain the

240 Shin Maekawa, Claudia Carvalho, Franciza Toledo and Vincent Beltran, “Climate Controls in a Historic House Museum in the Tropics: A Case Study of Collection Care and Human Comfort” (paper presented at the PLEA2009 – 26th Conference on Passive and Low Energy Architecture, Quebec City, Canada, June 22-24, 2009), 6. The service agreements would be for regularly scheduled maintenance of the equipment that the client would pay a fee for, not warranting the equipment from failure within a specified period.

241 Melanie Wilson, interview by author, Charleston, SC, December 14, 2011.
equipment. If and when a problem occurs with the off-the-shelf equipment, then the cost for a mechanical contractor to make a site visit may be cheaper than paying for a continual service agreement. In any case, there needs to be an established protocol for monitoring equipment and deciding when an outside mechanical contractor is contacted for services. Furthermore, if a piece of equipment fails, then it may be cost effective to purchase a new piece of equipment instead of repairs because of the low capital costs. Still, these pieces of equipment are technologically simple and require little maintenance and have fewer parts that may fail or require repair. In fact, during one full year of operation the system at Hollybourne Cottage did not need any maintenance or repairs.

In addition to the case study work, the Getty Conservation Institute organized the Experts’ Roundtable on Sustainable Climate Management in 2007, where a paper presented by Michael C. Henry helps establish sustainable goals for the final climate control recommendations for the Aiken-Rhett House. Though a majority of the paper focuses on increasing use of original architectural features for passive climate control, the underlying meaning is the sustainable approach to heating or cooling historic buildings. Henry argues that in today’s world of ever-increasing energy costs and climate change that we should take advantage of historic building design instead of relying on high-tech energy-consuming HVAC systems. He goes on to say that the HVAC systems we use to “protect” our historic buildings and collections produce pollution and climate changing effects that contribute to their demise. These ideas presented by Henry make
one want to rethink the use of large, high-tech HVAC systems in historic buildings altogether. He urges people to be responsible stewards of their historic sites and to revert to passive methods of climate control through use of architectural features to help save our historic properties and the environment from future harm.

One must remember that mechanical air conditioning is a relatively new invention and was not widely used in Southern residences until the 1970s. The long-term effects of HVAC systems on historic buildings have yet to be seen. The notion that mechanical HVAC systems are unhealthy for historic buildings and that we should return to passive methods of climate control could be called a “change-back phenomenon.” The “change-back phenomenon” is another idea presented by Stewart Brand in his book *How Buildings Learn*. He explains it as “change is often followed by reversal of the change, because the prior pattern lingers as the most conspicuous alternative, because people are understandably conservative about their physical space, and because most change is really undertaken as a trial, no matter what people say at the time. And most trials are errors.”242 In this application, the “trial” is a high-tech HVAC system which may eventually be deemed inappropriate for use in historic buildings, and climate control management may “change-back” to more passive methods.

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242 Brand, *How Buildings Learn*, 172. While this quote is used in his discussion of office building layout and design, it is a concept that can be applied to all sorts of building components and systems. For instance, used in this discussion about HVAC systems it is easily applied and understood.
One final idea that should be taken from the Getty research is the concept of preventative conservation. In the past, toxic fungicides and disinfectants were used to treat biological problems in buildings and collections in hot, humid climates. These reactive, treatment-based approaches to conservation have decreased in use as concerns for health and safety have increased. Now, problems are averted before they have a chance to start by using proactive, preventative approaches to conservation. Therefore, the appropriate management of interior environmental conditions in historic buildings can help prevent problems that in the past would have been treated reactively and are dependent on closely monitoring situations especially when something new is being tried.

Final Conclusion / Recommendation

Review of Current Best Practices

Preservation Brief 24

*Preservation Brief 24* was used as a guideline during the Aiken-Rhett House study, even though implementation all of the recommendations was not feasible. The six planning steps and four design activities are beneficial for planning and designing a new HVAC system for a historic building, but because of the limited extent of this study not all of the suggestions were utilized. The most useful of all of the six planning steps for this project was step three: undertake a condition assessment of the existing building and its systems. Most of the recommendations outlined in planning step three

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were completed, including documentation of the current physical conditions of the building materials and HVAC systems, as well as finding any current sources of air infiltration or moisture intrusion. If a qualified design team of architects, engineers and preservation consultants were assembled as suggested in step two, they would be responsible for determining the system requirements based on the local building codes and the prioritization of architecturally significant spaces. Evaluation of the advantages and disadvantages of different HVAC system options as recommended in step six would also be the responsibility of the qualified design team. While this Aiken-Rhett project is a feasibility study to a certain degree, issues such as code requirements and actual installation or life-cycle costs were not included, rather a concentration on the aesthetic aspect of preservation which is in keeping with the conservation philosophy of the Foundation for this property. Because the actual design of a new climate control system is not included in the Aiken-Rhett House study, the four design activities were not employed. Even so, some of these activities are discussed in the final recommendations. For example, the operational times of the climate control system that are mentioned in design activity two are discussed in the final recommendations for the Aiken-Rhett. Lastly, as mentioned in Chapter 2, the “HVAC Do’s and Don’ts” provide a list of best practices in an easily accessible checklist format.

Overall, the planning and design guidelines provided in the Brief are good best practices to follow during selection of a new HVAC system for a historic structure. Still, this Brief is now over twenty years old and needs to be updated to include technological
advances in both the HVAC and conservation industries. On the same note, one item that is missing from the article is the importance of environmental monitoring. Although this Brief mentions that monitoring should occur for a year before an HVAC system is designed in planning step three, continual environmental monitoring after the system is installed is not stressed enough. The article mentions regular monitoring schedules for temperature and humidity, but does not go into great detail. Perhaps, the National Park Service could write another Brief about interior and exterior environmental monitoring. Now that we are starting to see some of the long-term effects of air-conditioning historic buildings, a new Brief could discuss the importance of monitoring the interior and exterior environments to ensure appropriate temperature and humidity levels are maintained to minimize damage to the building and collections. The new museum environmental standards could be included in the discussion to help raise awareness in the preservation community about wider acceptable ranges of temperature and relative humidity. Lastly, a new Brief could discuss the period it takes for buildings to acclimate to new HVAC equipment, in which time the interior conditions should be closely monitored and refinements made to operating procedures.

**Preservation Brief 39**

*Preservation Brief 39* is an informative resource for controlling moisture intrusion problems. This article was useful during the building conditions assessment because it describes signs to look for when trying to identify visible and hidden moisture problems. In addition, the Brief provides valuable explanations of how moisture moves
in and out of buildings. These moisture movement patterns are important to understand when prescribing climate control systems. Finally, the article suggests surveying methods and tools to use when trying to diagnose moisture damage. Similar to *Preservation Brief 24*, this Brief could be deemed outdated because it is now over fifteen years old. It needs to be updated with new techniques or materials used to control moisture in historic buildings. Also, this article could stress the importance of monitoring unwanted moisture even more. While this may be true, *Preservation Brief 39* is an excellent resource for diagnosing and correcting moisture problems. It is recommended that historic properties incorporate this Brief into their best management practices and operations and maintenance procedures.

**Two Climate Control Options**

As explained in *Chapter 5 - Results*, the most practical level of climate control that the Aiken-Rhett House will be able to achieve without major alterations is Class “C” control. The Class “C” level of control (25-75% RH, temperatures usually between 59-77°F, rarely over 86°F) will be applied to the first, second and third floors of the main house, as well as the two rooms on the basement level that are unconditioned. The Art Gallery and staff-occupied areas of the basement will be held to Class “B” level of control (40-60% RH, temperatures between 59-77°F, never over 86°F). The reasoning for having a different level of control in these two zones of the house is because they are already climate controlled and the finishes in both spaces have been updated with the Art Gallery restoration in 2004 and the basement renovation in 1996.
The final recommendations for the Aiken-Rhett House consist of two options for climate control. The first option requires less intrusion on historic building fabric, has lower capital and operating costs, and is also the most historically relevant. The second option for the Aiken-Rhett House is provided in case option one is not successful at achieving the desired Class “C” level of control in the main house. It is always recommended to start with the least expensive, least intrusive option first. If these recommendations do not produce the desired results, then further action can be taken.

Option 1: Increase Passive Methods

The first recommendation for climate control at the Aiken-Rhett House is to increase the use of the original passive methods of ventilation and air circulation. Namely, this option requires the use of the windows and shutters on third floor of the house, which are not currently utilized. Because hot air naturally rises, the third floor of the building is normally the warmest. Since the windows and shutters on this floor are not used, a very hot and humid stagnant environment is created during the summer. The thought is that utilizing the windows on the third floor would create more air circulation throughout the entire house and that the warm air on the third floor could escape from the building, thus creating a more ideal environment on the lower floors as well. In order to do this, the collections storage on the third floor should be relocated to a fully climate controlled facility that is capable of providing the environment that these collections need. If removal of all of the collections stored on the third floor is not a realistic option; perhaps only the highly sensitive objects can be relocated. Of course,
the relocation of collections will require a planned transition period when moved from the unconditioned house to a fully climate controlled facility. Care should be taken not to shock the objects, so that they can gradually acclimate to a controlled environment.

From discussion with the Foundation staff, there is concern about insects and birds coming into the house through the windows openings on the third floor. If this concern still remains after collections storage are removed from the third floor, then window screens can be used. Manufacturers create portable, adjustable windows screens that could be installed in the third floor windows to keep out birds and insects. Furthermore, there are adjustable windows screens on the market that filter out air particulates, such as dirt and pollen, and prevent rain from entering the building.²⁴⁴ Because the third floor of the Aiken-Rhett House is rarely frequented, the use of these types of window screens would provide ease of mind for house museum staff. If the Foundation did not want visitors to see window screens from the exterior of the building, the louvered shutters could be closed which would still allow for air circulation and ventilation on the third floor. In addition, these windows screens could be utilized during unoccupied hours because they provide an added amount of protection from rain, air particulates and insects. Therefore, the third floor windows could be used for nighttime ventilation during the height of the summer. Leaving the windows open at

²⁴⁴ One manufacturer that produces these types of window screens is MicroAirScreen ®. Their products can be found at http://www.allergystore.com/microairscreen.htm or http://groupweston.com/airfilter.asp.
night, but closing the louvered shutters would still allow for nighttime ventilation to alleviate the buildup of heat in the house during the daytime.

Next, this option for climate control will keep all of the existing HVAC systems at the Aiken-Rhett House in operation. This includes the Art Gallery climate control system, the packaged system for the basement and the forced air heating system for the top three floors of the main house. Because these systems currently function as designed and they are less than ten years old, it would be wasteful to remove them from the building. With this in mind, continual environmental monitoring should be employed in all areas of the house, including the Gallery and the basement. By monitoring the basement level and Art Gallery, it can be determined if the Class “B” levels of control are actually being met by HVAC systems. If not, equipment and controls adjustments will need to be made.

Currently, Historic Charleston Foundation monitors the west side of the first, second and third floors of the building. Continual monitoring of rooms on the north, south or east side of the Aiken-Rhett House is highly recommended in order to determine areas of the house that are consistently outside of the Class “C” temperature and humidity levels. Once these rooms are determined, then the causes of the problem occurrences can be singled out. As discussed in Chapter 5, high levels of humidity usually result from a rain or fog event or when dry-bulb temperatures are very close to the dew point temperature. Incidences of low humidity levels in the house occurred in the winter
when there were no rain events or when dew point temperatures were much lower than dry-bulb temperatures. In addition to documenting interior air properties, the exterior climate conditions around the Aiken-Rhett will also need to be monitored to help inform staff members at the museum that an incidence may occur. Both of these goals can be accomplished by using wireless data loggers and an on-site weather station that are connected to a local computer onsite. This will provide real-time climate information for the staff members. In order for the environmental monitoring to be a success at the Aiken-Rhett House, some of the staff members (property manager, museum director, senior docents) must be trained to use and interpret data collected by the monitors. Included in this training should be how and when to make adjustments to the passive climate control systems and emergency preparedness.

To address incidences when temperature or relative humidity levels are outside of the Class “C” control in the main house the use of off-the-shelf portable fans, heaters, dehumidifiers, and humidifiers will be needed. It should be noted that the use of portable equipment is supplemental and temporary and it can be removed after Class “C” environmental conditions are maintained. Equipment with programmable setpoints should be selected so that they automatically shut off after the temperature or relative humidity setpoints are satisfied. In areas where temperature levels are too high (over 86°F), electric fans can be used for added air circulation. In locations where humidity levels are too high (over 75% RH), heaters or dehumidifiers can be implemented. Portable heaters can be used to raise the temperature of the space, which in turn will
lower the relative humidity. Or, portable dehumidifiers can be used to directly remove moisture from the air. Because of the forced air heating system in the main house, temperatures and humidity levels rarely fall more than a couple degrees or percentage points below the Class “C” level of control (25% RH, 59°F). In the winter, if temperatures get too low in some rooms, the portable heaters can be used to elevate the temperature a few degrees. Similarly, if the relative humidity levels are too low, then humidifiers can be used to raise the humidity back within the Class “C” standards. Of course, the use of these portable pieces of equipment will require alterations to the operating procedures for the house museum.

Undoubtedly, the house museum operating procedures will need to be changed to include the opening and closing of the third floor windows and shutters. In addition to the exterior openings on the third floor, the periodic emptying of the dehumidifiers will need to be incorporated into the operational procedures. For example, when the dehumidifiers are being used, the entire staff should be made aware and one staff member should be in charge of checking the water collection trays and emptying them twice a day. It is recommended that dehumidifiers not be run during unoccupied hours to minimize the risk of the machine overflowing. Also, the filling of the portable humidifiers with water will need to be incorporated into the operating procedures of the Aiken-Rhett House. One staff member should be responsible for maintaining proper water levels in the humidifiers. Additionally, care should be taken to place the humidifiers in locations that are appropriate distances away from any building finishes.
or collections. Lastly, it is also suggested that the operating procedures of the house museum incorporate the proper shutdown of all of the portable equipment at the end of each business day.

Selection of the types of portable equipment will ultimately be up to Historic Charleston Foundation. If the Foundation wanted the equipment to blend in with the historic house, antique electric fans are available for purchase. Heaters, dehumidifiers and humidifiers also come in many styles and finishes, some that are more appropriate for the house museum than others. Because the same family live in the Aiken-Rhett House until the late 1960s, and there are multiple generations of finishes throughout the house, early twentieth century appliances would be appropriate for use in the house. Since the house museum may not want to unintentionally confuse visitors by using equipment that looks historic, the museum may want to use modern, sleekly designed equipment so that there is no confusion over the fact that it is a new addition to the historic space.

The selection of the portable equipment brings up the issue of it not distracting from the visitors' experience. One suggestion would be to locate the equipment in areas that are hidden from the visitors’ view, as well as out of hearing distance. Also, manufacturers make “ultra-quiet” types of heaters, dehumidifiers, fans and humidifiers that can be selected to minimize noise. Another suggestion would be to explain the climate control philosophy of the house museum to visitors. This would create an
opportunity to educate visitors about passive climate control methods and the supplemental use of portable devices to help maintain an interior environment that benefits the historic building and its finishes.

Even though this climate control option requires the purchasing of additional environmental monitors and portable equipment, the total capital cost would be significantly less than a typical conventional HVAC system. During the building conditions assessment results section it was mentioned that the historic paint and wallpaper finishes in the Aiken-Rhett House are in need of stabilization. The costs saved from the installation, operation and maintenance of a new HVAC system could be put towards a stabilization campaign for these important historic finishes. In the meantime, paint and wallpaper samples should be archived for future reference.

Option 1 will require the Aiken-Rhett House staff to be more involved in the management of the climate control system. But, this is viewed as a positive outcome because the staff will become more aware of what the building needs. They will realize that buildings are “alive” and that they learn over time and that “what makes a building learn is its physical connection to the people within.”\textsuperscript{245} If staff members working at the house museum are more involved with its climate control management program, then the Aiken-Rhett House will continue to learn and will continue to have a long, healthy existence. The ideas laid out in Option 1 may not be fully developed at present and they

\textsuperscript{245} Brand, How Buildings Learn, 209.
may involve trial and error; but “the point is to make adjustments to a building in a way that is always future-responsible...the process embraces error; it is eager to find things that don’t work and to try things that might not work. By failing small, early, and often, it can succeed long and large. And it turns its occupants into active learners and shapers rather than passive victims.”

Option 2: Implement Technologically Simple Mechanical Systems

The second option for a climate control system at the Aiken-Rhett House is the implementation of alternative “technologically simple” and “economically sustainable” strategy similar to the systems used in the case studies conducted by the Getty Conservation Institute in hot, humid climates. Again, this option should be implemented only if Option 1 does not succeed at maintaining the interior environment within Class “C” levels of control. Similar to Option 1, a stabilization campaign for the historic finishes in the house is recommended. Also advocated is the relocation of collections storage from third floor of the house to a fully climate controlled facility (or only the highly sensitive objects). Continual environmental monitoring should also be used with Option 2. It is important to ensure that Class “C” environmental standards are met in order to keep the building and its finishes out of high risk situations. Once again, certain staff members should be trained to be able to collect and interpret interior air property data, as well as make adjustments to the climate control system.

\[246\] Brand, How Buildings Learn, 209.
For Option 2, the Foundation can choose one of the two Getty Conservation Institute case studies reviewed in the Chapter 5, the Hollybourne Cottage system or the Barbosa Museum system. Certainly, both systems have their advantages and disadvantages. The Hollybourne Cottage system would be the one to select if lower installation, operating, and maintenance costs are desired. Because off-the-shelf residential convection heaters, dehumidifiers and ventilators are used, this system is more technologically simple than the Barbosa Museum system. Even though visitor comfort is a secondary priority of the Aiken-Rhett study, the use of the Hollybourne Cottage system would require some type of ventilation for staff health and comfort. It is envisioned that passive cooling methods (operable windows) would be utilized during the daytime when the Aiken-Rhett House is occupied. Therefore, mechanical nighttime ventilation would be required when the building is unoccupied to bring the relative humidity levels back below 70%. If the Hollybourne Cottage system was installed at the Aiken-Rhett, then the equipment would likely be installed in the basement and attic spaces to create the buffer zone for the floor levels in between. Again, this type of system is custom-designed for the specific needs of the building and each floor level, so variations from the Hollybourne Cottage design are probable. Even so, the lower levels of the Aiken-Rhett House will require more dehumidification and the upper levels will require more ventilation, similar to Hollybourne Cottage. In addition, this solution would keep the existing Aiken-Rhett House Art Gallery HVAC system in operation until it reaches the end of its useful life. At that time, the decision would be made to replace
the HVAC system in kind or to incorporate them into the heating, ventilating and dehumidification system. The forced-air heating system for the main house and the air-conditioning system for the basement may need to be removed to provide space for the new heating, ventilation and dehumidification equipment. Perhaps, the existing mechanical equipment can be reconfigured and incorporated into the new system. The reuse of the existing equipment is ideal because it could help lower capital costs for the new system.

The second choice for Option 2 is to provide a system similar to the Casa de Rui Barbosa Museum in Brazil. In addition to providing a slightly more stable environment for the building and collections (below 65% RH compared to below 75% RH), the Barbosa Museum system also provides human comfort. The main goal of the Barbosa Museum system was to maintain relative humidity levels below 65%, while allowing the temperature levels to fluctuate between 71.6-82.4°F (22-28°C). The system is able to provide cooling comfort for occupants by using a split direct-refrigerant air-conditioning unit and a downstream reheat coil (similar to what is used for the Aiken-Rhett Art Gallery). Contrary to the Hollybourne Cottage system, the Barbosa system has a more complex control system and requires less staff involvement. Along this same note, the Barbosa Museum system requires windows and doors to be closed at all times to prevent infiltration of outside air. If the Barbosa Museum system is implemented at the Aiken-Rhett, it is recommended that the existing Art Gallery system remain in operation until it reaches the end of its useful life. When the time comes to replace the Art Gallery
system, it will either be replaced in kind or incorporated into the Barbosa system that also has the ability to cool and dehumidify. Unfortunately, the existing furnaces for the forced-air heating system will likely need to be removed to provide adequate space to install the equipment for the new system. Even though collections and human comfort are secondary to this study, these factors may be considered primary priorities by Historic Charleston Foundation. On the other hand, to completely eliminate the use of passive cooling methods does not seem like an appropriate solution because it may take away from the sustainable goals and historic interpretation of the site.

Although the idea of removing the collections from the museum does not follow the current interpretation of the house, it may be beneficial for both the collections and the building. By not having to maintain an appropriate interior climate for multiple priorities, the stewards of the property can focus solely on the building and its finishes. Changing the interpretation philosophy of the house museum may help with the implementation of a new climate management system. Part of the goal for the new system is to respect all of the periods of significance in the house. Perhaps the Foundation could maintain a conservation philosophy for the majority of the house, but interpret the building for the entire period of when the Aiken and Rhett family lived there. This means that any changes to the house that occurred up until the late 1960s could be left in place and that all of these layers could be interpreted as significant to the property. In the end, the ultimate decision of which type of climate control system
to employ at the Aiken-Rhett House lies with the Foundation and the goals of the museum interpretation.

**Limitations of Study**

The greatest constraint on the Aiken-Rhett House study was the limited amount of time available to conduct the research. Because of the time frame of the study, less than a year’s worth of interior air property data was collected. The industry standard is to monitor environmental data for at least one year to effectively assess the interior and exterior climates. If air property data had been collected for one year, the results could have been different. The number of incidences when the temperature or relative humidity levels are outside of the recommended Class “C” ranges of control could increase with a whole year of data. For instance, no data was collected during the spring season, when the daily weather in Charleston is changing from cool and less humid to warm and more humid. Including this time of year in the air property monitoring would most certainly change the data results. Furthermore, the east side of the Aiken-Rhett House was monitored for only three months, during the change from fall to winter seasons. During the times that air properties were measured on both the east and west sides of the building, the west side was typically warmer. Therefore, it was assumed that during the summer months, the west side would still be warmer than the east. Still, this was an assumption included in the study, and if data was collected on the east side of the house during the summer, there is a possibility that the actual results could differ.
Another limitation on the Aiken-Rhett House climate control study was the available number of electronic data loggers (HOBO devices). Because there were only six data loggers available, they were placed on the first, second and third floors of the house on the east and west sides. Monitoring of the basement level, attic spaces and Art Gallery were not included in this study. Ideally, there would be enough electronic data loggers to produce a more-inclusive environmental monitoring program. This would include locating loggers on all floors, and on the north and south sides of the house in addition to the east and west sides. If possible, environmental monitoring of the basement and Art Gallery would have been included to determine if the existing HVAC system set points are being met. Lastly, it should be noted that there was a data logger placed on the exterior of the building in varying locations throughout the study. These exterior monitors provide better micro-climate information to assess external localized factors that might be influencing the structure. Unfortunately, the data logger was moved around by staff members and contractors conducting maintenance work on the building and even brought inside the house at some points. Therefore, the data collected from this logger was dismissed because the exact timing of when the logger was moved and where it was moved to could not be determined.

Even though data was collected on both sides of the Aiken-Rhett during the winter, Charleston has an unusually warm winter this year (2011-12). As a result, the air properties measurements are not providing an accurate representation of typical winter climate conditions inside the house. If Charleston had had a typical winter this year, the
data collected may have resulted in more occurrences of low temperatures and low humidity inside the Aiken-Rhett House.

The final limitation in the Aiken-Rhett House climate control study was the inability to access wall cavities to examine their physical conditions. Destructive testing on the historic building fabric was not an option; so, the building conditions assessment was limited to visual surface inspection. A tool such as a borescope would have been useful to examine the conditions inside the wall cavities, especially in the Art Gallery and basement levels where HVAC systems are currently operating. Then, it could be determined if the HVAC systems were causing any mold, mildew or rot problems inside the walls as a result of condensation from vapor diffusion. If so, more explicit recommendations could be made for the airconditioned Art Gallery and basement areas of the Aiken-Rhett House.

**Recommendations for Future Research**

During the Aiken-Rhett House climate control study, some ideas for future research developed from reviewing existing literature on alternative climate control for buildings in hot, humid climates. One idea, is to conduct more climate control case studies on “conserved,” unrestored buildings in warm and humid climates. Another recommendation would be to conduct research on historic house museums that successfully use a combination of passive methods and mechanical systems to control their interior environment. On the other hand, additional studies are necessary on the
best method to change a building from using HVAC systems back to more passive means of climate control. Also, factors such as energy efficiency, indoor air quality and local building codes were not specifically addressed in this study. While the final recommendations for climate control at the Aiken-Rhett House are inherently sustainable, an energy audit was not conducted and recommendations were not based on efficiency, rather historical appropriateness. In the future, specific energy saving measures at the Aiken-Rhett House could be incorporated into the climate control strategy and the National Park Service’s “Preservation Brief 3: Improving Energy Efficiency in Historic Buildings” could be utilized as a best practices guideline. Indoor air quality (IAQ) is also major concern for the curatorial staff at the Aiken-Rhett House. IAQ is a broad and complicated subject matter and methods of control at the Aiken-Rhett House in and of itself could be a standalone research project. Similarly, the last suggestion for future research could be addressing the local building codes in regards to climate control in historic buildings. Again, this subject could be a standalone research project, but a couple of questions to ask would be the following: how do current building codes address the capacity of historic buildings to provide natural ventilation, and do they enforce realistic HVAC system requirements on historic buildings that do not have the capability to produce the required results.

**Summary of Final Recommendations**

The chart below is a summary of the final climate control recommendations provided earlier in this chapter.
<table>
<thead>
<tr>
<th>Aiken-Rhett House Climate Control Recommendations</th>
<th>Option 1</th>
<th>Option 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Increase Passive Methods (Minimal Intervention)</strong></td>
<td><strong>Implement Technologically Simple Mechanical Systems (Moderate Intervention)</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Goals:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>1st, 2nd &amp; 3rd Floors</strong></td>
<td>Achieve Class “C” Control for the 1&lt;sup&gt;st&lt;/sup&gt;, 2&lt;sup&gt;nd&lt;/sup&gt; and 3&lt;sup&gt;rd&lt;/sup&gt; floors of the main house (25-75% RH, temperatures usually between 59-77°F, rarely over 86°F)</td>
<td>Achieve Class “C” Control for the 1&lt;sup&gt;st&lt;/sup&gt;, 2&lt;sup&gt;nd&lt;/sup&gt; and 3&lt;sup&gt;rd&lt;/sup&gt; floors of the main house (25-75% RH, temperatures usually between 59-77°F, rarely over 86°F)</td>
</tr>
<tr>
<td><strong>Art Gallery &amp; Staff-occupied areas of basement</strong></td>
<td>Achieve Class “B” Control for the Art Gallery and staff-occupied areas of the basement (40-60% RH, temperatures between 59-77°F, never over 86°F)</td>
<td>Achieve Class “B” Control for the Art Gallery and staff-occupied areas of the basement (40-60% RH, temperatures between 59-77°F, never over 86°F)</td>
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<td><strong>Recommended Tasks:</strong></td>
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<tr>
<td><strong>Collections Storage</strong></td>
<td>Remove collections storage from 3rd Floor and relocate to a fully climate-controlled facility (or only highly sensitive objects)</td>
<td>Remove collections storage from 3rd Floor and relocate to a fully climate-controlled facility (or only highly sensitive objects)</td>
</tr>
<tr>
<td><strong>Climate Control Methods</strong></td>
<td>Utilize windows and shutters on 3rd Floor to increase air circulation throughout building</td>
<td>Implement one of the mechanical systems designed by the Getty Conservation Institute (either the Hollybourne Cottage system or the Casa de Rui Barbosa Museum system)</td>
</tr>
<tr>
<td><strong>Special Ventilation Needs</strong></td>
<td>Use nighttime ventilation during summer (if needed)</td>
<td>Address visitor and staff health and safety by using passive daytime methods and mechanical nighttime dehumidification (Hollybourne Cottage system only)</td>
</tr>
<tr>
<td><strong>Existing HVAC Systems</strong></td>
<td>Keep current HVAC systems in operation</td>
<td>Keep current HVAC systems in operation OR incorporate into new systems</td>
</tr>
<tr>
<td><strong>Environmental monitoring</strong></td>
<td>Continual interior and exterior monitoring</td>
<td>Continual interior and exterior monitoring</td>
</tr>
<tr>
<td><strong>Portable Equipment Use</strong></td>
<td>Use portable dehumidifiers, heaters, fans and humidifiers in spot locations</td>
<td>X</td>
</tr>
<tr>
<td><strong>Operational Procedures</strong></td>
<td>Modify museum operational procedures to incorporate 3&lt;sup&gt;rd&lt;/sup&gt; floor, portable equipment and nighttime ventilation</td>
<td>Modify museum operational procedures depending on which system is selected</td>
</tr>
<tr>
<td><strong>Optional:</strong></td>
<td></td>
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<tr>
<td><strong>Window Accessories</strong></td>
<td>Use window screens on 3rd floor</td>
<td>X</td>
</tr>
<tr>
<td><strong>Archives</strong></td>
<td>Archive wallpaper and paint samples for future reference</td>
<td>Archive wallpaper and paint samples for future reference</td>
</tr>
<tr>
<td><strong>Stabilization Campaigns</strong></td>
<td>Stabilize historic paint and wallpaper finishes</td>
<td>Stabilize historic paint and wallpaper finishes</td>
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</tbody>
</table>
The final recommendations for the Aiken-Rhett House hold true to the current conservation philosophy and interpretation of the house museum. By keeping the building and its finishes as first priorities, the recommendations seek to increase the use of original architectural features of the building and any mechanical interventions are portable or removable. The suggestions also necessitate hands-on climate management from staff members involved with daily operation of the museum. Both options will require staff training for environmental monitoring, but funds saved on mechanical systems could be invested in people. Spending time and money educating employees is a worthwhile investment -- not only will it promote a feeling of community among staff, but it also increases their personal knowledge and skill set that can be applied in different applications, like their own home. Furthermore, investing in people will make them informed participants in the climate management of a historic structure which they undoubtedly already hold in high regard. The collection and interpretation of environmental monitoring data seems to be a very important component of climate management that is lacking from most operational procedures of historic house museums; yet, it provides practical and useful information about specific climate control needs. Hopefully, this observational approach to climate management in historic buildings will increase in popularity in the near future.
Afterword

Honestly, when I first started this project, I thought at the end of it all, I would be suggesting some type of high-tech mechanical climate control system. My opinion about the use of HVAC systems in historic buildings has changed significantly since I began. This being said, I do believe high-tech, complex HVAC systems have their place and are needed in certain applications, but not when it comes to historic house museums in hot and humid climates. Increasing use of passive methods of climate control (that are tried and true) and supplementing those with simple and sustainable mechanical equipment can produce a result that is better for the historic building, its finishes AND collections. While my passive recommendations require the building occupants to be more involved in climate management, I view this as a positive thing. This will allow the building users to become more in tune with the interior and exterior environment and their effects on the building itself. They will become more aware of what the building needs, and become active learners and shapers of the building’s future. As responsible stewards of historic house museums, we should remember that mechanical air-conditioning is a relatively new invention and was not widely used in Southern residences until the 1970s. The real long-term effects of HVAC systems on historic buildings have yet to be seen.

My conclusions reflect the movement of conservation practices in hot and humid climates towards more simple, sustainable climate control systems used in conjunction with passive methods. As mentioned in my Chapter 6, the idea that mechanical systems
are harmful for historic buildings and that we should look to passive methods of climate control could be considered a “change-back phenomenon.” This idea presented by Stewart Brand in his book *How Buildings Learn*, is directly applicable to HVAC systems. He explains that “change is often followed by reversal of the change,” and that “most change is undertaken as a trial, no matter what people say at the time. And [that] most trials are errors.”

Essentially, the implementation of high-tech HVAC systems in historic buildings could be considered a “trial,” that we as preservationists and conservationists may eventually deem inappropriate. Re-utilization of passive methods at this point in time is actually innovative. We need to keep focused on the conservation issues and less distracted by new technologies: *We need to be problem-centered, not technology-driven*. The evolving philosophy of environmental management for historic house museums is looking more carefully at being sustainable, while also being mindful of historic methods of climate control.

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Appendices
Appendix A: Modern Heating, Ventilating & Air Conditioning (HVAC) Systems and Definitions

Modern heating, ventilating and air conditioning (HVAC) systems can be classified in two different ways. The first classification discussed is based on zones and air volume controlled by supply fans. The second classification is based on the media used in the thermal distribution system. For definitions of words in bold text refer to the Definitions section at the end of this Appendix.

Zone & Air Volume Classifications

HVAC systems serve a single thermal zone or multiple thermal zones. This simply describes whether the supply fan in the system delivers air to a single zone or several different zones in a building. A zone is defined as “a single conditioned space, or a group of spaces that react thermally in a similar manner over time and which is governed by a single thermostat.”\(^1\) In example, a zone may be comprised of several offices on the same side of a building or a zone may be a single room like a laboratory. For the purposes of this discussion, an HVAC system will either be a single zone system or a multiple zone system.

Single zone and multiple zone systems can further be categorized as either constant volume or variable volume. A supply fan can deliver a constant amount of air or it can vary the amount of air it delivers to a thermal zone. Therefore, HVAC systems

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\(^1\) The Trane Company, *Air Conditioning Clinic: Introduction to HVAC Systems* (La Crosse, WI: American Standard, 2006), 44.
are described as one of the following: Single Zone, Constant Volume; Single Zone, Variable Volume; Multiple Zone, Constant Volume; and Multiple Zone, Variable Volume. A single zone, constant volume system supplies a constant amount of variable temperature air to single zone controlled by one thermostat. Likewise, a multiple zone, constant volume system delivers a constant volume of variable temperature air to multiple different zones, each controlled by its own thermostat. A single zone, variable volume system delivers a variable amount of constant temperature air to a zone controlled by one thermostat. Lastly, a multiple zone, variable volume system provides variable quantities of constant temperature air to several individually controlled zones.

**Thermal Distribution Media Classifications**

HVAC systems can also be categorized based on the type of media (air, water or refrigerant) that each system uses to heat or cool the conditioned spaces. Most large centralized systems are either all-air, all-water or air-water systems; while smaller applications are generally direct refrigerant systems.

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2 Trane, *Introduction to HVAC Systems*, 45.
3 Ibid., 57.
4 Ibid., 56.
5 Ibid., 61.
**All-Air Systems**

In all-air systems, the media used to heat and cool the conditioned spaces is air. Because air is the heating and cooling medium, these types of systems require large amounts of ductwork to deliver the air to the conditioned spaces. In a typical application, an all-air system will include a **boiler** and **chiller** located in a central plant where water is heated or cooled to be distributed to the **air handler units** in unoccupied spaces. The air handlers run the hot or cold water through a coil to heat or cool the air to the temperature and humidity setpoints in each thermal zone. Once the air handler treats the air, it is delivered to each zone through terminal outlets, such as **grilles**, **diffusers** and **registers**. Air from the conditioned spaces can then be returned (return air) to the air handler to be reintroduced into the system. All-air systems are very suitable for applications in which individual control of multiple spaces is desired, like office buildings or hospitals. They are also used in applications like clean rooms and research facilities, where close and accurate control of the indoor environment is needed.\(^7\)

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Figure A.2: Schematic of a single duct (constant temperature, variable volume) type of all-air HVAC system. Source: Image from Carrier Air Conditioning, *The ABCs of Air Conditioning* (Syracuse, NY: Carrier, 1989), 5.

Figure A.3: Schematic of a double duct (constant volume, variable temperature) type of all-air HVAC system. Source: Image from Carrier Air Conditioning, *The ABCs of Air Conditioning* (Syracuse, NY: Carrier, 1989), 5.

Figure A.4: Schematic of a multi-zone (constant volume, variable temperature) type of all-air HVAC system. Source: Image from Carrier Air Conditioning, *The ABCs of Air Conditioning* (Syracuse, NY: Carrier, 1989), 5.
All-Water Systems

All-water, or hydronic, systems use water as the medium to heat and cool the conditioned spaces. Like the all-air system, hot and cold water is created in a central plant, but then it is transported from the plant to terminal units, typically fan coil units, located in or adjacent to the conditioned space. The fan coil units then run the hot or cold water though coils to treat air from the conditioned space and recirculate it into the space. All-water systems can be categorized as 2-pipe systems or 4-pipe systems. A 2-pipe system has one supply and one return line in which hot or cold water flows through both. In a 4-pipe system, there are two supply lines and two return lines, one set for cold water and the other set for hot water. All-water systems are ductless and very rare, most likely because they provide no means for humidity control or outside air ventilation. In order to have ventilation in conjunction with an all-water system, a separate ventilation system would need to be installed or exterior openings would need to be used.\(^8\)

Figure A.5: Schematic of the 2-pipe all-water HVAC system. Source: Image from Carrier Air Conditioning, The ABCs of Air Conditioning (Syracuse, NY: Carrier, 1989), 9.

Figure A.6: Schematic of the 4-pipe all-water HVAC system. Source: Image from Carrier Air Conditioning, The ABCs of Air Conditioning (Syracuse, NY: Carrier, 1989), 9.
Air-Water Systems

Air-water systems use both air and water as the media to heat and cool conditioned spaces, utilizing the benefits of both the all-air and all-water systems. Just like both of the systems discussed before, water is heated and cooled at a central plant and transported to the building through a piping system. On the air side of the system, the hot or cold water is sent to an air handler unit where its treats 100% outside air without any recirculation. The main objective of the air side of an air-water system is to satisfy the ventilation requirements, filter and dehumidify the outside air and pressurize the conditioned space.9 On the water side of the system, the hot or cold water is distributed to the terminal units inside the conditioned space to help balance the cooling or heating requirements in each space. The terminal units are 100% recirculation units, using no outside air, and are typically fan coil units, induction units or radiant heat panels. Some of the advantages of air-water systems include minimal space requirements for the distribution systems, positive ventilation and lower operating costs. Disadvantages include complex control systems, frequent maintenance and loose humidity control. These systems are not recommended if close humidity control is desired, but can be used in applications such as schools, office buildings and apartments.10

10 Ibid., 31-33.
Figure A.7: Schematic of the induction type of air-water HVAC system. *Source:* Image from Carrier Air Conditioning, *The ABCs of Air Conditioning* (Syracuse, NY: Carrier, 1989), 7.

Figure A.8: Schematic of a fan coil unit (with a supplementary outside air unit for ventilation) type of air-water HVAC system. *Source:* Image from Carrier Air Conditioning, *The ABCs of Air Conditioning* (Syracuse, NY: Carrier, 1989), 7.
**Direct Refrigerant Systems**

As the name implies, direct refrigerant systems use refrigerant as the media for heating or cooling the conditioned space. Instead of using a chilled water loop to distribute cold water through a cooling coil, a direct refrigerant system has liquid refrigerant flowing through the cooling coil. Thus, the heat is transferred directly from the airside of the system to the refrigeration loop. These systems are commonly referred to as direct expansion or DX systems because the refrigerant enters an expansion device before it enters the cooling coil (or evaporator).\(^{11}\) DX systems are typically factory-assembled and come in packaged or split installation options. Examples of types of DX systems include: packaged terminal air conditioners (PTAC) commonly used in hotels, dorms and apartments; split DX systems commonly installed in single family homes; and packaged DX rooftop systems used for low-rise buildings. The heat pump system is a variation of the direct expansion system, where the cooling mode of the refrigeration loop can be reversed to provide heating to a conditioned space. The two types of heat pumps are the air-to-air and water source. Air-to-air heat pumps use air as the heat source and heat sink and they are the most common types and very widely used in residential and some commercial applications. Depending on the mode of operation, water source heat pumps use both air and water as the heat source or heat sink, reversing the refrigeration cycle when the operation is switched from heating to

\(^{11}\) Trane, *Introduction to HVAC Systems*, 30.
cooling, and vice-versa. A variation of the water source heat pump is the ground source heat pump (geothermal) that uses the relatively constant temperature of the earth as a heat exchanger.

Control Systems

HVAC automatic control systems ensure that desired interior conditions are provided, maintained and managed efficiently and economically. First, the basic control system will be explained and then the three different levels of HVAC control systems will be summarized.

Basic control systems include five elements: the controlled variable, the sensor, the controller, the controlled device, and the controlled agent. For the purpose of explanation, a chilled water cooling coil will be used as an example (see figure A.9). The controlled variable is “the parameter being measured and controlled” and in the example it is the “dry-bulb temperature of the air leaving the

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13 Trane, Introduction to HVAC Systems, 55.
cooling coil.” In the cooling coil example, the dry-bulb temperature sensor in the airflow leaving the coil is the “sensor” and it “measures the condition of the controlled variable and sends an input signal to the controller.” The controller is the “brain” of the basic control system and it “compares the measured condition of the controlled variable to the desired condition (setpoint), and transmits a corrective output signal to the controlled device.” The controlled device in this example is the chilled water valve and it “reacts to the output signal from the controller and takes action to vary the controlled agent.” The last component of a basic control system is the controlled agent which is the chilled water in the example. The chilled water is the “medium that is manipulated by the controlled device,” so that when the valve operates, more or less chilled water flows through the cooling coil and changes the cooling capacity of the coil.

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15 Ibid.
16 Ibid.
17 Ibid.
18 Ibid.
HVAC control loop systems are categorized as closed or open. An open control loop measures an external condition that has a relationship with the controlled variable, while a closed control loop measures the actual controlled variable. Closed loop control systems are usually preferred because they are more energy efficient and allow better control.¹⁹ There are three types of controllers in HVAC systems which are named based on their different power sources: pneumatic, analog-electric, and direct digital control (DDC). A pneumatic type control system uses compressed air to operate the controlled devices. The pneumatic controller is connected to a compressed air system and can signal a controlled device to operate by changing the air pressure in their connection line.²⁰ Pneumatic control systems are perceived as having a low first cost and easy installation, but they require much more maintenance than the other control systems and installation cost increases significantly if complex control systems are required.²¹

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¹⁹ Trane, HVAC System Control, 2-3.
²⁰ Ibid., 14.
²¹ Ibid., 20.
An analog-electric control system uses electric current or voltage to operate the controlled devices. A sensor will send a signal to the electronic controller, and in turn the controller will send a signal to the controlled device to produce the desired output. Due to a lower maintenance requirement, analog-electric control systems tend to be more energy efficient and provide better climate control than pneumatic systems.  

Lastly, a direct digital control system uses electric current or voltage and digital software programs to operate controlled devices. Direct digital control systems are similar to analog-electronic systems because the controlled devices and sensors are usually the same; however, the direct digital control system uses digital software programs to receive the sensor signal and send an output signal to the controlled device. This is a microprocessor-based control system that communicates directly with the building automation system that is monitored from a central location. This type of control provides more flexibility and the implementation of complex control strategies; thus, allowing the building HVAC system to be controlled in a more intelligent manner.

HVAC automatic control systems can be divided into three different levels: unit-level control, system-level control, and building management. Unit-level control provides control and protection for individual pieces of HVAC equipment, like chillers, boilers, fan coil units or VAV boxes. System-level control is utilized to coordinate the operation of several pieces of HVAC equipment to work together as an efficient system.

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22 Trane, *HVAC System Control*, 16-17.
23 Ibid., 18.
24 Ibid., 21-23.
Usually, a separate system-level controller is used to monitor all of the equipment in one system; however, in simpler systems a unit-level controller on one of the pieces of equipment in the system can be used to provide the same system-level functions.\(^{25}\) Moreover, unit-level controllers can conduct their operational duties even if a system-level controller is not connected to them.

The third type of control system, called building management or automation systems (BMS or BAS), are used when building operators want to integrate all of the HVAC systems with other systems (lighting, emergency power, fire alarm, security) in a building and monitor them from one central location. The building automation system is operated from a central computer that communicates digitally with the different systems in the building (figure 2.8).

Because all of the different systems are connected, the BAS can provide the operators with diagnostic reports and alarms if any components are not performing as designed. Integration of different building systems can allow them to assist one another. In example, if the fire alarm is

\(^{25}\) Trane, HVAC System Control, 31.
activated when connected to a building automation system, the BAS will signal the HVAC systems to shutdown to prevent the spread of fire and smoke. Building management systems have the capability to produce a number of different reports that are valuable tools for building operation staff. These reports include alarm activity logs, after-hours tenant occupancy, building energy use, trend logs, equipment performance and system commissioning.\textsuperscript{26} Another benefit of building management systems is the ability to connect multiple buildings in different locations and control them from one single location.

A major trend in the building management industry is the move towards interoperability between pieces of equipment manufactured by different companies. This means that different manufacturers of control systems and HVAC equipment are designing their products with a standard open communications protocol.\textsuperscript{27} BACnet and LonTalk are two of the most commonly used open, standard protocol used in the HVAC industry today. Both of these protocols are similar, but they each have unique characteristics that may make one superior over the other for certain types of control systems. For instance, BACnet tends to be better suited for providing central control of multiple stand-alone buildings and communication between system-level controllers.

\textsuperscript{26} Trane, \textit{HVAC System Control}, 54.
\textsuperscript{27} Ibid., 64.
On the other hand, LonTalk is thought to be better for communication with unit-level controllers.\footnote{Ibid., 67-68.}
Equipment & Systems Definitions:
Below are definitions of some different types of heating, ventilating and air conditioning (HVAC) equipment and systems:

THE REFRIGERATION LOOP/ SYSTEM COMPONENTS:

![Diagram of a simple refrigeration system showing the four major components: evaporator, compressor, condenser and expansion device (valve). Source: Image from The Trane Company, Air Conditioning Manual (La Crosse, WI: American Standard, 1996), Figure 6-B.]

**Evaporator:** a heat exchanger in the refrigeration system in which water (air in a DX system) rejects heat to the refrigerant. The water (air) transfers heat to the cool, liquid refrigerant which causes it to boil and turn into a vapor. After the refrigerant changes into vapor inside the evaporator, it leaves and enters the compressor.

**Compressor:** a mechanical device in the refrigeration system used to increase the temperature and pressure of the vapor refrigerant. When the vapor refrigerant enters the compressor, it is “compressed” to a higher pressure, which in turn increases its temperature. The hot, high pressure refrigerant gas leaves the compressor and is

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29 Trane, *Introduction to HVAC Systems*, 16-17.
transported through the hot gas line to the condenser. Common types of compressors include centrifugal, helical-rotary (screw), reciprocating and scroll.\textsuperscript{30}

\textbf{Condenser}: a heat exchanger in the refrigeration system in which refrigerant rejects heat to air or water (air-cooled condenser or water-cooled condenser). The hot refrigerant gas transfers some of its heat to the cooler air or water which “condenses” the refrigerant from a vapor into a liquid.\textsuperscript{31} After the refrigerant leaves the condenser, it is transported through the liquid line to the expansion device.

\textbf{Expansion device}: device in the refrigeration system that decreases the pressure and temperature of the refrigerant. When the hot liquid refrigerant leaves the condenser, it needs to be cooled down to be able to absorb heat inside the evaporator. The expansion device creates a pressure drop that allows the hot liquid refrigerant to decrease in pressure and cool down. Once the cooled liquid refrigerant leaves the expansion device, it returns to the evaporator to begin the cycle over again.\textsuperscript{32}

\textbf{CHILLED / HOT WATER SYSTEM COMPONENTS:}

\textbf{Chiller}: produces cold water that is used to cool the air in a large capacity air conditioning system. HVAC systems that use water chillers are generally called chilled water systems. The cold water is transported throughout a building by pumps and piping to the terminal units near the conditioned spaces. The chilled water travels through the cooling coil in the terminal unit, removes heat from the supply air, and then returns back to the chiller. Chillers are comprised of a condenser, evaporator and a compressor. The different types of chillers are named based on the type of compressor or the type of refrigeration cycle they use.\textsuperscript{33}

\textsuperscript{30} Trane, \textit{Introduction to HVAC Systems}, 17.
\textsuperscript{31} Ibid., 18.
\textsuperscript{32} Ibid., 19.
\textsuperscript{33} Trane, \textit{Chilled-Water Systems}, 1-2.
Boiler: produces hot water or steam that is used to heat the air in a large capacity air conditioning system. The hot water is transported throughout a building by pumps and piping to the terminal units near the conditioned spaces. The hot water or steam travels through the heating coil in the terminal unit, adds heat to the supply air, and then returns back to the boiler to be reheated.\(^{34}\)

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\(^{34}\) Trane, *Introduction to HVAC Systems*, 50.


**AIRSIDE SYSTEM COMPONENTS:**

*Supply fan*: a fan that delivers the supply air to the conditioned space. Often times, the supply fan is also used to draw the return air back out of the conditioned space.

*Air handler unit*: a piece of equipment installed on the airside loop of a HVAC system that is comprised of filters, a supply fan and a cooling coil. An air handler mixes return air and outside air and passes it through the filters, the supply fan and then the cooling coil before delivering the supply air to the conditioned space. These units are typically installed outside of the conditioned space, in a mechanical room, basement or roof. Because of the location, a supply-air distribution system made of sheet metal ductwork is used to transport the supply air from the air handler to the conditioned spaces.  

![Figure A.14: Example of an air handling unit. Source: Image from Trane, Air Conditioning Clinic: Introduction to HVAC Systems (La Crosse, WI: American Standard, 2006), Figure 13.](image)

**Fan coil unit**: a factory-assembled terminal unit installed on the airside loop of a HVAC system comprised of a filter, a supply fan and a cooling and/or heating coil in a common casing. A fan coil unit draws return air from the conditioned space into the unit, passes it through the filter, the supply fan and the cooling coil before delivering the supply air to the conditioned space. These units are typically installed in the conditioned space or in a wall or ceiling adjacent to the space. Fan coil units can be vertical or horizontal in configuration and can be wall or floor mounted or hung from a ceiling.

![Fan Coil Unit Diagram](image)


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**Induction units**: a terminal unit that is very similar to a fan coil unit; however it is only used with “air-water” systems. It uses high velocity airflow from a primary air source (air handling unit) to induce the flow of air from the conditioned space into the induction unit. In the induction unit, the air from the conditioned space is heated or cooled and then mixed with air from the primary source before it is delivered back into the space. These types of terminal units are intended for use in the perimeter rooms of a multi-story building.\(^\text{37}\)

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**Radiant heat panels**: a terminal unit that is located in either a wall of ceiling and provides radiant heating or cooling to the conditioned space. Supplementary constant volume air is also supplied to the conditioned space to provide the required amount of ventilation and dehumidification.  

**Radiator**: a unit that emits heat through radiation and natural convection. Radiators are usually comprised of metal tubes, blades or panels. Hot water or steam produced by a boiler is transported through piping to the radiator terminal unit where it exchanges heat with the air in the conditioned space and then is returned to the boiler. These terminal units are the most common type of heating system used in residential and commercial buildings.

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**VAV terminal unit**: a variable air volume (VAV) unit is a sheet metal assembly that varies the amount of air that is delivered to the conditioned space. It is installed upstream of the supply air diffusers and uses an airflow modulation device, like a rotating blade damper, to change the size of the air passage to the conditioned space. Control hardware installed on the VAV terminal unit adjusts the air modulation device based on the thermostat readings in each individually controlled space. There are several types of VAV terminal units for different types of applications and different levels of temperature control.

![VAV Terminal Units](image)

Figure A.18: Examples of four different types of VAV terminal units used in variable air volume HVAC systems. *Source: Image from Trane, Air Conditioning Clinic: VAV Systems (La Crosse, WI: American Standard, 2001), Figure 79.*

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**DIRECT REFRIGERANT (STAND-ALONE) SYSTEMS:**

*Packaged terminal air conditioner (PTAC)*: a piece of equipment that contains all of the components of the refrigeration loop (evaporator coil, compressor, air-cooled condenser coil, condenser fan, expansion device), several components of the airside loop (supply fan, filter), and all of the controls in one factory-assembled unit. These units are typically installed in perimeter walls of a building to be able to reject the heat directly to the outdoors. 41

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Figure A.19: Example of a typical through-wall packaged terminal air conditioner. *Source: Image from Trane, Air Conditioning Clinic: HVAC System Control* (La Crosse, WI: American Standard, 2002), Figure 62.
Packaged DX rooftop air conditioner: a factory assembled, packaged piece of HVAC equipment that includes all of the refrigeration system components and several airside system components (supply fan and filters). This piece of equipment is typically mounted on a roof where it can combine outside air with return air from the conditioned space to provide the adequate amount of ventilation and pressurization required for the interior spaces. Packaged DX rooftop air conditioners are generally used for low-rise buildings with large floor areas, such as offices, schools, and stores.

Figure A.20: Typical configuration of a packaged DX rooftop air conditioner. Source: Image from Trane, Air Conditioning Clinic: Introduction to HVAC Systems (La Crosse, WI: American Standard, 2006), Figure 30.

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42 Trane, Introduction to HVAC Systems, 86.
**Split DX systems:** a direct refrigerant stand-alone system that has its components split apart into two different units with refrigerant piping field-installed between the two units. The packaged air-cooled condensing unit is located outside and includes the compressor and the condenser. The air handler is located inside the building and contains the evaporator and the expansion device, as well as the supply fan and filters. This type of DX systems allows greater flexibility with the design because the components are split apart. It is very common in residential and light commercial applications for the air-cooled condensing unit to be an air-to-air heat pump, providing both the heating and cooling requirements for the building.

![Split DX System](image)

*Figure A.21: Example of a typical Split DX System configuration. Source: Image from Trane, *Air Conditioning Clinic: Introduction to HVAC Systems* (La Crosse, WI: American Standard, 2006), Figure 44.*

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HEAT PUMPS:

Heat pump: a packaged or split piece of HVAC equipment that can provide both heating and cooling. A valve installed in the refrigerant piping allows the refrigeration cycle to be reversed so the system can switch back and forth between heating and cooling modes. In the heating mode, the roles of the condenser and evaporator are reversed so that the condenser functions as the “evaporator” and the evaporator functions as the “condenser.” Heat pumps are typically classified based on their heat source (what heat is taken from) and heat sink (what heat is transferred to) media.45

Air-to-air heat pump: uses air as the heat source and heat sink in both operating modes. Air-to-air heat pumps are not able to maintain setpoints if the exterior air temperatures are extremely high or low. These are the most common type of heat pumps and are used in many different light commercial and residential applications.46

Water source heat pump: uses water and air as the heat source and heat sink. In the cooling mode, water is used as the heat sink in the “condenser” to change the refrigerant into liquid. The air is the heat source in the “evaporator” transferring heat from the air to the refrigerant to cool the supply air. In the heating mode, water is used as the heat source in the “evaporator” to change the refrigerant from liquid to vapor. The air is used as the heat sink when heat is transferred from the refrigerant to the air to provide heated supply air to the conditioned space. Typically, all of the water source heat pumps in a system are connected to one common water loop with a cooling tower and boiler to maintain the temperature of the water.47

46 Ibid.
47 Trane, Introduction to HVAC Systems, 52-53.
Figure A.22: Diagram of a standard water source heat pump system with a cooling tower and hot water boiler. 
Source: Image from The Trane Company, *Air Conditioning Manual* (La Crosse, WI: American Standard, 1996), Figure 7-K(b).
**Ground source heat pump system (geothermal):** a variation of the water source heat pump where the relatively constant temperature of the earth is used as the heat exchanger instead of a cooling tower and boiler. A common water loop system is installed underground and the water is circulated throughout the system by pumps located in an equipment room close to the conditioned spaces. The same pumps then move water to the water source heat pumps that are installed adjacent to the conditioned spaces. The water is then returned back to the pumps to be recirculated through the geothermal heat exchanger.\(^{48}\)

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\(^{48}\) Trane, *Introduction to HVAC Systems*, 55.
**TERMINAL OUTLETS / DELIVERY ITEMS:**

**Diffuser:** a type of supply air delivery device that is usually mounted on the ceiling of a conditioned space. Blades in the diffuser direct airflow into different directions. Ductwork transporting the supply air is connected to the diffuser above the finished ceiling. Diffusers are manufactured in many different shapes, sizes, styles and finishes.

![Diffuser Diagram](image)

**Register:** an air delivery device that is similar to a diffuser except that it is typically installed in a floor or wall. Registers typically have adjustable blades that can control the airflow in different directions. 49

**Grille:** a device used to cover return air intakes. Grilles typically have non-movable linear blades that serve to obstruct the view of the inside of the return air intake. 50

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50 Ibid.
Appendix B: Building & HVAC Systems Conditions Assessment

Key for the Moisture Intrusion & Air Infiltration Interior Inspection Forms:

**Heating Systems:**
- **Forced-air** = the room is heated directly or indirectly by the gas-fired furnaces located either under the piazza, the Art Gallery, or in the attic spaces.
- **Packaged** = the room is heated by the gas/electric packaged system for the staff-occupied areas of the basement.
- **Heat Pump** = the Art Gallery is the only room in the house provided heating by the fan coil unit and heat pump located in between the Gallery and the stable building.

**Cooling Systems:**
- **Packaged** = the room is cooled by the gas/electric packaged system for the staff-occupied areas of the basement.
- **Fan coil unit** = the Art Gallery is the only room in the house that is provided cooling by the fan coil unit and condenser unit (heat pump) located under the Gallery.

**Effects of Air & Moisture Intrusion:**
- **Ef** = Efflorescence is present on plaster or exposed brick surfaces
- **Mo** = Mold is present on an interior surface
- **Mi** = Mildew is present on an interior surface
- **ML** = Mortar loss; exposed brick walls have mortar loss in the masonry joints
- **PL** = Plaster loss; interior walls or ceilings have plaster loss, may result in exposed wood lath
- **PP** = Peeling paint; paint finishes are peeling, cracking, or alligatoring
- **PW** = Peeling wallpaper; wallpaper finishes are peeling off the walls or ceilings
- **Ro** = Rot; signs of wood rot on interior surfaces
- **RD** = Rising damp; signs of rising damp (horizontal tide marks) are present on interior walls
- **WD** = Water damage; interior surface shows signs of past water damage usually in the form of staining

**Sources of Infiltration:**
- **ED** = air leakage or infiltration at an exterior door; air can enter or escape from the building at holes around the door frame or because the door does not fit properly within the frame
- **WS** = air leakage or infiltration at a window because the sash does not fit properly within the window frame, could also be caused by damaged window frame or deformation of the wood frame or sash components
CC = crack(s) in the plaster ceiling, outside air can infiltrate the interior space if the room is on the top level of the structure or below the attic space
WC = crack(s) in the plaster wall, allows outside air to infiltrate the interior space through the wall cavity
Fl = cracks or holes within the floor system that allow for air to infiltrate the interior space

Figure B.1: Basement (cellar) level floor plan showing room names and numbers. Source: Image from Willie Graham, Carl Lounsbury, and Orlando Ridout V, *Architectural Investigations of the Aiken-Rhett House, 48 Elizabeth Street, Charleston, South Carolina* (Charleston: Historic Charleston Foundation, 2005).
Figure B.2: Current first floor plan showing room names and numbers. Source: Image from Willie Graham, Carl Lounsbury, and Orlando Ridout V, *Architectural Investigations of the Aiken-Rhett House, 48 Elizabeth Street, Charleston, South Carolina* (Charleston: Historic Charleston Foundation, 2005).
Figure B.3: Current second floor plan showing room names and numbers. Source: Image from Willie Graham, Carl Lounsbury, and Orlando Ridout V, *Architectural Investigations of the Aiken-Rhett House, 48 Elizabeth Street, Charleston, South Carolina* (Charleston: Historic Charleston Foundation, 2005).
Figure B.4: Current third floor plan showing room names and numbers. Source: Image from Willie Graham, Carl Lounsbury, and Orlando Ridout V, Architectural Investigations of the Aiken-Rhett House, 48 Elizabeth Street, Charleston, South Carolina (Charleston: Historic Charleston Foundation, 2005).
# Moisture Intrusion & Air Infiltration

## Interior Inspection

<table>
<thead>
<tr>
<th>Floor #</th>
<th>Ground / Basement</th>
<th>Date:</th>
<th>11/22/2011</th>
</tr>
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<tbody>
<tr>
<td>Room #</td>
<td>G01</td>
<td>Time:</td>
<td>10:30 AM</td>
</tr>
<tr>
<td>Room Name</td>
<td>Entry Foyer</td>
<td>Temp. (Avg, Max, Min):</td>
<td>67°F, 77°F, 57°F</td>
</tr>
<tr>
<td>Heating System</td>
<td>Y (Forced-air)</td>
<td>RH (Avg, Max, Min):</td>
<td>84%, 100%, 65%</td>
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<tr>
<td>Cooling System</td>
<td>N</td>
<td>Dew Point:</td>
<td>62°F</td>
</tr>
</tbody>
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## Building Component

<table>
<thead>
<tr>
<th>Building Component</th>
<th>Effects</th>
<th>Sources</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>North</td>
<td>PP</td>
<td></td>
<td>Faux marble paint peeling</td>
</tr>
<tr>
<td>East</td>
<td>PP</td>
<td></td>
<td>Faux marble paint peeling; interior door to air-conditioned basement areas on this wall</td>
</tr>
<tr>
<td>South</td>
<td>PP</td>
<td></td>
<td>Faux marble paint peeling</td>
</tr>
<tr>
<td>West</td>
<td>PP, PL</td>
<td>ED, EW</td>
<td>plaster loss on knee wall and on sides of stairs; faux marble paint peeling</td>
</tr>
<tr>
<td>Ceiling</td>
<td>PP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Doors</td>
<td>ED</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frames</td>
<td>PP</td>
<td>ED</td>
<td>paint peeling on door frame</td>
</tr>
<tr>
<td>Windows</td>
<td>PP</td>
<td>EW</td>
<td>windows are sidelights for front door</td>
</tr>
<tr>
<td>Frames</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Floors</td>
<td></td>
<td>*</td>
<td>*Marble stone deterioration</td>
</tr>
</tbody>
</table>

## Other notes:
The west wall on the basement level of the foyer is a knee wall. The finishes in the foyer were restored in the 1980s by the Charleston Museum.

## Key:
- **Effects of Air & Moisture Intrusion:**
  - Ef = Efflorescence, Mo = Mold, Mi = Mildew, ML = Mortar loss, PL = Plaster loss, PP = Peeling paint, PW = Peeling wallpaper, Ro = rot, RD = Rising damp, WD = Water damage
- **Sources of Infiltration:**
  - ED = Exterior door, EW = Exterior window, CC = Plaster ceiling cracks, WC = Plaster wall cracks, Fl = Holes/cracks in floor
Figure G01.1: Plaster and paint loss on west knee wall at the small set of stairs.

Figure G01.2: Faux marble paint peeling on the east wall of the entry foyer on the ground level.
Moisture Intrusion & Air Infiltration
Interior Inspection

<table>
<thead>
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<td>Time:</td>
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<td>RH (Avg, Max, Min):</td>
<td>50%, 71%, 33%</td>
</tr>
<tr>
<td>Cooling System:</td>
<td>Y (Packaged)</td>
<td>Dew Point:</td>
<td>30°F</td>
</tr>
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</table>

### Building Component Effects Sources Notes

<table>
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<tr>
<th>Walls North</th>
<th>Ef, ML</th>
<th>Limewash in good condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>East</td>
<td>Ef, ML</td>
<td>Limewash in good condition</td>
</tr>
<tr>
<td>South</td>
<td>Ef, ML</td>
<td>Limewash in good condition</td>
</tr>
<tr>
<td>West</td>
<td>Ef, ML</td>
<td>ED</td>
</tr>
<tr>
<td>Ceiling</td>
<td>PP</td>
<td>whitewash peeling on joists; minor rot where gas piping rises up to 1st floor on east side of chimney</td>
</tr>
<tr>
<td>Doors</td>
<td>R</td>
<td>ED</td>
</tr>
<tr>
<td>Frames</td>
<td>PP, R</td>
<td>bottom of interior door frame has been spliced for rot repair</td>
</tr>
<tr>
<td>Windows</td>
<td></td>
<td>EW</td>
</tr>
<tr>
<td>Frames</td>
<td>PP</td>
<td></td>
</tr>
<tr>
<td>Floors</td>
<td>ML, RD</td>
<td>Fi</td>
</tr>
</tbody>
</table>

Other notes:
Moisture Content (MC) of brick floor is 15%, MC of exterior wood door is over 20%. Mortar loss and efflorescence on brick walls is minor.

Key:
Effects of Air & Moisture Intrusion:
Ef = Efflorescence, Mo = Mold, Mi = Mildew, ML = Mortar loss, PL = plaster loss, PP = Peeling paint, PW = Peeling wallpaper, Ro = rot, RD = rising damp, WD = water damage

Sources of Infiltration:
ED = exterior door, EW = exterior window, CC = plaster ceiling cracks, WC = plaster wall cracks, Fl = holes/cracks in floor
Figure G02.1: Wood rot at the bottom of the exterior door on the west wall.

Figure G02.2: Bottom of interior door frame has been spliced to repair wood rot.
**Moisture Intrusion & Air Infiltration**

**Interior Inspection**

<table>
<thead>
<tr>
<th>Building Component</th>
<th>Effects</th>
<th>Sources</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walls</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North</td>
<td>RD, PL, ML</td>
<td>ED, WC</td>
<td>plaster separating from brick wall, crack on left side of door frame</td>
</tr>
<tr>
<td>East</td>
<td>RD, PL, Ef, ML</td>
<td></td>
<td></td>
</tr>
<tr>
<td>South</td>
<td>RD, PL, ML</td>
<td></td>
<td>plaster separating from brick wall</td>
</tr>
<tr>
<td>West</td>
<td>Rd, PL, ML</td>
<td></td>
<td>plaster separating from brick wall</td>
</tr>
<tr>
<td>Ceiling</td>
<td></td>
<td></td>
<td>good condition</td>
</tr>
<tr>
<td>Doors</td>
<td>R</td>
<td>ED</td>
<td></td>
</tr>
<tr>
<td>Frames</td>
<td>PP, R</td>
<td></td>
<td>rot in door headers on north wall, bottom of frame on east wall spliced for repair, cracks all around door frame on north wall</td>
</tr>
<tr>
<td>Windows</td>
<td>n/a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frames</td>
<td>n/a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Floors</td>
<td>RD</td>
<td>Fl</td>
<td>fair condition; floor comprised of brick on grade</td>
</tr>
</tbody>
</table>

Other notes:
- Mortar sacrificing on bottom of wall faster than upper parts of wall --> rising damp
- Bead board and new doors (1996) in good condition

Key:
**Effects of Air & Moisture Intrusion:**
- Ef = Efflorescence, Mo = Mold, Mi = Mildew, ML = Mortar loss, PL = plaster loss, PP = Peeling paint, PW = Peeling wallpaper, Ro = rot, RD = rising damp, WD = water damage

**Sources of Infiltration:**
- ED = exterior door, EW = exterior window, CC = plaster ceiling cracks, WC = plaster wall cracks, Fl = holes/cracks in floor
Figure G03.1: Plaster finish coat separating from walls.

Figure G03.2: Mortar loss is greater at the bottom of the walls, than at the top. This is most likely caused by rising damp.
# Moisture Intrusion & Air Infiltration
## Interior Inspection

<table>
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<th>Ground</th>
<th>Room #:</th>
<th>G04</th>
<th>Date:</th>
<th>11/21/2011</th>
<th>Time:</th>
<th>10:30 AM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room Name:</td>
<td>Ticket Office</td>
<td>Temp. (Avg, Max, Min):</td>
<td>68°F, 78°F, 57°F</td>
<td>RH (Avg, Max, Min):</td>
<td>84%, 100%, 57%</td>
<td>Dew Point:</td>
<td>61°F</td>
</tr>
<tr>
<td>Heating System:</td>
<td>Y (Packaged)</td>
<td>Cooling System:</td>
<td>Y (Packaged)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Building Component</th>
<th>Effects</th>
<th>Sources</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walls</td>
<td>North</td>
<td>PL, ML</td>
<td>plaster separating from brick wall</td>
</tr>
<tr>
<td></td>
<td>East</td>
<td>PL, Ef, ML</td>
<td>plaster separating from brick wall</td>
</tr>
<tr>
<td></td>
<td>South</td>
<td>PL, ML</td>
<td>ED; plaster separating from brick wall</td>
</tr>
<tr>
<td></td>
<td>West</td>
<td>PL, ML</td>
<td>plaster separating from brick wall</td>
</tr>
<tr>
<td>Ceiling</td>
<td></td>
<td></td>
<td>good condition</td>
</tr>
<tr>
<td>Doors</td>
<td></td>
<td>ED</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Frames</td>
<td>PP, R</td>
<td>rot in door headers on south wall, bottom of frame on east and south walls spliced for repair</td>
</tr>
<tr>
<td>Windows</td>
<td></td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Frames</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td>Floors</td>
<td>RD</td>
<td>Fi</td>
<td>fair condition; floor comprised of brick on grade</td>
</tr>
</tbody>
</table>

**Other notes:**
Mortar sacrificing on bottom of wall faster than upper parts of wall --> rising damp

**Key:**

**Effects of Air & Moisture Intrusion:**
Ef = Efflorescence, Mo = Mold, Mi = Mildew, ML = Mortar loss, PL = plaster loss, PP = Peeling paint, PW = Peeling wallpaper, Ro = rot, RD = rising damp, WD = water damage

**Sources of Infiltration:**
ED = exterior door, EW = exterior window, CC = plaster ceiling cracks, WC = plaster wall cracks, Fl = holes/cracks in floor
Figure G04.1: Mortar loss is greater at the bottom of the walls, than at the top. This is likely caused by rising damp.
**Moisture Intrusion & Air Infiltration**

**Interior Inspection**

<table>
<thead>
<tr>
<th>Building Component</th>
<th>Effects</th>
<th>Sources</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walls</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North</td>
<td>PL, ML</td>
<td>ED</td>
<td>plaster separating from brick wall</td>
</tr>
<tr>
<td>East</td>
<td>PL, Ef, ML</td>
<td></td>
<td>plaster separating from brick wall</td>
</tr>
<tr>
<td>South</td>
<td>PL, ML</td>
<td></td>
<td>plaster separating from brick wall</td>
</tr>
<tr>
<td>West</td>
<td>PL, Ef, ML</td>
<td></td>
<td>plaster separating from brick wall, efflorescence in NW corner</td>
</tr>
<tr>
<td>Ceiling</td>
<td>PL</td>
<td>CC</td>
<td>hole in plaster at SE corner</td>
</tr>
<tr>
<td>Doors</td>
<td>R</td>
<td>ED</td>
<td>rot at bottom of exterior door on north wall</td>
</tr>
<tr>
<td>Frames</td>
<td>PP, R</td>
<td>ED</td>
<td>rot in door header and bottom of frame on north wall</td>
</tr>
<tr>
<td>Windows</td>
<td>n/a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frames</td>
<td>n/a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Floors</td>
<td>RD</td>
<td>Fl</td>
<td>Holes in stone that show brick beneath</td>
</tr>
</tbody>
</table>

**Other notes:**
Mortar sacrificing on bottom of wall faster than upper parts of wall --> rising damp
Hole in relieving arch stuffed with paper, need better seal.

**Key:**

**Effects of Air & Moisture Intrusion:**
Ef = Efflorescence, Mo = Mold, Mi = Mildew, ML = Mortar loss, PL = plaster loss, PP = Peeling paint, PW = Peeling wallpaper, Ro = rot, RD = rising damp, WD = water damage

**Sources of Infiltration:**
ED = exterior door, EW = exterior window, CC = plaster ceiling cracks, WC = plaster wall cracks, Fl = holes/cracks in floor
Figure G05.1: Efflorescence on west wall in northwest corner of room.

Figure G05.2: Wood rot in door header on north wall.
Moisture Intrusion & Air Infiltration
Interior Inspection

<table>
<thead>
<tr>
<th>Building Component</th>
<th>Effects</th>
<th>Sources</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walls</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North</td>
<td>Ef, ML</td>
<td></td>
<td>whitewash in good condition</td>
</tr>
<tr>
<td>East</td>
<td>Ef, ML</td>
<td>EW</td>
<td>whitewash in good condition</td>
</tr>
<tr>
<td>South</td>
<td>Ef, ML</td>
<td>EW</td>
<td>whitewash in good condition</td>
</tr>
<tr>
<td>West</td>
<td>Ef, ML</td>
<td>EW</td>
<td>whitewash in good condition</td>
</tr>
<tr>
<td>Ceiling</td>
<td>PP</td>
<td></td>
<td>whitewash peeling on joists</td>
</tr>
<tr>
<td>Doors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frames</td>
<td>PP, R</td>
<td></td>
<td>bottom of interior door frame has been spliced for rot repair</td>
</tr>
<tr>
<td>Windows</td>
<td>PP</td>
<td>EW</td>
<td>major paint loss; cracks/ holes around exterior window frames</td>
</tr>
<tr>
<td>Frames</td>
<td>PP</td>
<td>EW</td>
<td></td>
</tr>
<tr>
<td>Floors</td>
<td>ML</td>
<td>Fl</td>
<td>Minor mortar loss between bricks on floor, some damaged bricks</td>
</tr>
</tbody>
</table>

Other notes:
Mortar loss and efflorescence on brick walls is minor.
Moisture Content (MC) of brick floor is 15%, MC of window frames is 18-20%.

Key:
Effects of Air & Moisture Intrusion:
Ef = Efflorescence, Mo = Mold, Mi = Mildew, ML = Mortar loss, PL = plaster loss, PP = Peeling paint, PW = Peeling wallpaper, Ro = rot, RD = rising damp, WD = water damage

Sources of Infiltration:
ED = exterior door, EW = exterior window, CC = plaster ceiling cracks, WC = plaster wall cracks, Fl = holes/cracks in floor
Figure G06.1: Damaged bricks and minor mortar loss on floor.

Figure G06.2: Whitewash peeling on ceiling (floor joists for 1st floor).
### Moisture Intrusion & Air Infiltration

#### Interior Inspection

<table>
<thead>
<tr>
<th>Building Component</th>
<th>Effects</th>
<th>Sources</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walls</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North</td>
<td>PL, ML, RD, Ef</td>
<td>ED, WC</td>
<td>plaster in poor condition</td>
</tr>
<tr>
<td>East</td>
<td>PL, ML, RD, Ef</td>
<td>WC</td>
<td>95% plaster loss, moderate mortar loss</td>
</tr>
<tr>
<td>South</td>
<td>PL, ML, RD</td>
<td>WC</td>
<td>Patches at top of wall, hole to right of door</td>
</tr>
<tr>
<td>West</td>
<td>PL, ML, RD, Ef</td>
<td>EW, WC</td>
<td>plaster separating from brick wall, efflorescence in NW corner</td>
</tr>
<tr>
<td>Ceiling</td>
<td>PP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Doors</td>
<td>PP</td>
<td>ED</td>
<td>rot at bottom of exterior door on north wall</td>
</tr>
<tr>
<td>Frames</td>
<td>PP</td>
<td></td>
<td>rot in door header and bottom of frame on north wall</td>
</tr>
<tr>
<td>Windows</td>
<td>PP</td>
<td>EW</td>
<td></td>
</tr>
<tr>
<td>Frames</td>
<td>PP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Floors</td>
<td>RD, R</td>
<td>Fl</td>
<td>rot at baseboard on north wall</td>
</tr>
</tbody>
</table>

Other notes:

- Rising damp causing significant plaster loss on west wall. Limewash peeling on all walls.
- Ductwork run through closet on south wall, from furnace on exterior of south wall up to 1st floor.

**Key:**

**Effects of Air & Moisture Intrusion:**

- Ef = Efflorescence, Mo = Mold, Mi = Mildew, ML = Mortar loss, PL = plaster loss, PP = Peeling paint, PW = Peeling wallpaper, Ro = rot, RD = rising damp, WD = water damage

**Sources of Infiltration:**

- ED = exterior door, EW = exterior window, CC = plaster ceiling cracks, WC = plaster wall cracks, Fl = holes/cracks in floor

<table>
<thead>
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<th>Floor #:</th>
<th>Ground</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Room #:</td>
<td>G07</td>
<td>Time:</td>
<td>10:30 AM</td>
</tr>
<tr>
<td>Room Name:</td>
<td>Back Stair Hall</td>
<td>Temp. (Avg, Max, Min):</td>
<td>68°F, 78°F, 57°F</td>
</tr>
<tr>
<td>Heating System:</td>
<td>N</td>
<td>RH (Avg, Max, Min):</td>
<td>84%, 100%, 57%</td>
</tr>
<tr>
<td>Cooling System:</td>
<td>N</td>
<td>Dew Point:</td>
<td>61°F</td>
</tr>
</tbody>
</table>
Figure G07.1: Efflorescence and plaster loss on west wall south of staircase.

Figure G07.2: Back stair hall looking west. Plaster loss on west wall and peeling paint on staircase.
## Moisture Intrusion & Air Infiltration

### Interior Inspection

<table>
<thead>
<tr>
<th>Floor #</th>
<th>Room #</th>
<th>Room Name</th>
<th>Date</th>
<th>Time</th>
<th>Temp. (Avg, Max, Min)</th>
<th>RH (Avg, Max, Min)</th>
<th>Dew Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground</td>
<td>G08</td>
<td>Warming Kitchen</td>
<td>11/21/2011</td>
<td>10:30 AM</td>
<td>68°F, 78°F, 57°F</td>
<td>84%, 100%, 57%</td>
<td>61°F</td>
</tr>
</tbody>
</table>

### Building Component

<table>
<thead>
<tr>
<th>Building Component</th>
<th>Effects</th>
<th>Sources</th>
<th>Notes</th>
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<tbody>
<tr>
<td>Walls</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North</td>
<td>PL, Ef</td>
<td>ED, EW, WC</td>
<td>plaster in poor condition</td>
</tr>
<tr>
<td>East</td>
<td>PL, Ef</td>
<td>EW, WC</td>
<td>95% plaster loss, moderate mortar loss</td>
</tr>
<tr>
<td>South</td>
<td>PL, Ef</td>
<td>EW, WC</td>
<td>Patches at top of wall, hole to right of door</td>
</tr>
<tr>
<td>West</td>
<td>PL, Ef</td>
<td>WC</td>
<td>plaster separating from brick wall, efflorescence in NW corner</td>
</tr>
<tr>
<td>Ceiling</td>
<td></td>
<td></td>
<td>good condition; gas piping on ceiling rusting</td>
</tr>
<tr>
<td>Doors</td>
<td>R, WD, PP</td>
<td>ED</td>
<td>rot on door on north wall</td>
</tr>
<tr>
<td>Frames</td>
<td>R, WD, PP</td>
<td></td>
<td>rot on frame on north wall</td>
</tr>
<tr>
<td>Windows</td>
<td>PP</td>
<td>EW</td>
<td>frame separating from walls</td>
</tr>
<tr>
<td>Frames</td>
<td>R, WD, PP</td>
<td></td>
<td>rot on all frames and window sills on exterior walls</td>
</tr>
<tr>
<td>Floors</td>
<td>RD</td>
<td>FI</td>
<td>brownstone on grade</td>
</tr>
</tbody>
</table>

**Other notes:**
Firebox flue is open, which is a source of air infiltration. Efflorescence is present on bottom half of walls due to rising damp. Large holes is plaster behind built-in pie safes and shelves.

**Key:**

**Effects of Air & Moisture Intrusion:**
Ef = Efflorescence, Mo = Mold, Mi = Mildew, ML = Mortar loss, PL = plaster loss, PP = Peeling paint, PW = Peeling wallpaper, Ro = rot, RD = rising damp, WD = water damage

**Sources of Infiltration:**
ED = exterior door, EW = exterior window, CC = plaster ceiling cracks, WC = plaster wall cracks, Fl = holes/cracks in floor
Figure G08.1: Wood rot on window sill and frame. East wall, north window.

Figure G08.2: Large holes in plaster behind built in shelves.
# Moisture Intrusion & Air Infiltration

## Interior Inspection

<table>
<thead>
<tr>
<th>Building Component</th>
<th>Effects</th>
<th>Sources</th>
<th>Notes</th>
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</thead>
<tbody>
<tr>
<td><strong>Walls</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North</td>
<td>PP</td>
<td>WC</td>
<td>Faux marble paint peeling</td>
</tr>
<tr>
<td>East</td>
<td>PP</td>
<td>WC</td>
<td>Faux marble paint peeling</td>
</tr>
<tr>
<td>South</td>
<td>PP, PL</td>
<td>WC</td>
<td>plaster loss on curved wall south of door, paint peeling</td>
</tr>
<tr>
<td>West</td>
<td>PP</td>
<td>ED, EW, WC</td>
<td>Faux marble paint peeling</td>
</tr>
<tr>
<td>Ceiling</td>
<td>PP</td>
<td>CC</td>
<td></td>
</tr>
<tr>
<td>Doors</td>
<td>Ro</td>
<td>ED</td>
<td>rot at bottom of door</td>
</tr>
<tr>
<td>Frames</td>
<td>Ro</td>
<td>ED</td>
<td>rot at bottom of frame</td>
</tr>
<tr>
<td>Windows</td>
<td></td>
<td>EW</td>
<td>casement sidelight windows at front door</td>
</tr>
<tr>
<td>Frames</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Floors</td>
<td>*</td>
<td></td>
<td>*Marble stone deterioration</td>
</tr>
</tbody>
</table>

**Other notes:**
The faux marble paint was restored in the 1980s by the Charleston Museum. It is peeling badly on the west and north walls and is especially bad near the front door.

**Key:**

**Effects of Air & Moisture Intrusion:**

Ef = Efflorescence, Mo = Mold, Mi = Mildew, ML = Mortar loss, PL = plaster loss, PP = Peeling paint, PW = Peeling wallpaper, Ro = rot, RD = rising damp, WD = water damage

**Sources of Infiltration:**

ED = exterior door, EW = exterior window, CC = plaster ceiling cracks, WC = plaster wall cracks, FI = holes/cracks in floor
Figure 101.1: Rot at door frame on west wall.

Figure 101.2: Faux marble paint peeling on the south wall of the entry foyer. There is also plaster loss at the bottom of the wall near the floor.
Moisture Intrusion & Air Infiltration
Interior Inspection

<table>
<thead>
<tr>
<th>Building Component</th>
<th>Effects</th>
<th>Sources</th>
<th>Notes</th>
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<td>Walls</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>North</td>
<td>PW, PP</td>
<td>WC</td>
<td>wallpaper borders ok, panels are in poor condition</td>
</tr>
<tr>
<td>East</td>
<td>PW, PP</td>
<td>WC</td>
<td>wallpaper borders ok, panels are in poor condition</td>
</tr>
<tr>
<td>South</td>
<td>PW, PP</td>
<td>ED, EW,WC</td>
<td>wallpaper borders ok, panels are in poor condition</td>
</tr>
<tr>
<td>West</td>
<td>PW, PP</td>
<td>EW, WC</td>
<td>wallpaper borders ok, panels are in poor condition</td>
</tr>
<tr>
<td>Ceiling</td>
<td>PP</td>
<td>CC</td>
<td>paint peeling worst in NE corner, SW corner &amp; left of chimney</td>
</tr>
<tr>
<td>Doors</td>
<td>PP</td>
<td>ED</td>
<td></td>
</tr>
<tr>
<td>Frames</td>
<td>PP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Windows</td>
<td></td>
<td>EW</td>
<td>Large cracks where windows meet floor</td>
</tr>
<tr>
<td>Frames</td>
<td>PP, WD</td>
<td></td>
<td>signs of water damage/rot at windows</td>
</tr>
<tr>
<td>Floors</td>
<td>FL</td>
<td></td>
<td>Large cracks where windows meet floor</td>
</tr>
</tbody>
</table>

Other notes:
Dark stains on wood baseboards, might be from cleaning floors. Moisture Content (MC) of wood baseboards are 18%.

Key:
Effects of Air & Moisture Intrusion:
Ef = Efflorescence, Mo = Mold, Mi = Mildew, ML = Mortar loss, PL = plaster loss, PP = Peeling paint, PW = Peeling wallpaper, Ro = rot, RD = rising damp, WD = water damage

Sources of Infiltration:
ED = exterior door, EW = exterior window, CC = plaster ceiling cracks, WC = plaster wall cracks, FL = holes/cracks in floor
Figure 102.1: Crack in plaster ceiling and pink spots evident of water damage in southwest corner of room.

Figure 102.2: Wallpaper peeling in northeast corner of west drawing room.
### Moisture Intrusion & Air Infiltration

#### Interior Inspection

| Floor #: | 1 | Date: | 11/18/2011 |
| Room #: | 103 | Time: | 1:30 PM |
| Room Name: | Main Stair Hall | Temp. (Avg, Max, Min): | 48°F, 55°F, 42°F |
| Heating System: | Y (Forced Air) | RH (Avg, Max, Min): | 50%, 71%, 33% |
| Cooling System: | N | Dew Point: | 30°F |

<table>
<thead>
<tr>
<th>Building Component</th>
<th>Effects</th>
<th>Sources</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walls</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North</td>
<td>PP</td>
<td>ED, EW, WC</td>
<td>paint in poor condition</td>
</tr>
<tr>
<td>East</td>
<td>PP</td>
<td>WC</td>
<td>paint in poor condition</td>
</tr>
<tr>
<td>South</td>
<td>PP</td>
<td>WC</td>
<td>paint in poor condition</td>
</tr>
<tr>
<td>West</td>
<td>PP</td>
<td>WC</td>
<td>paint in poor condition</td>
</tr>
<tr>
<td>Ceiling</td>
<td>PP</td>
<td>CC</td>
<td>paint in poor condition</td>
</tr>
<tr>
<td>Doors</td>
<td>PP</td>
<td>ED</td>
<td>severe paint peeling, cracking, chipping</td>
</tr>
<tr>
<td>Frames</td>
<td>PP</td>
<td></td>
<td>severe paint peeling, cracking, chipping</td>
</tr>
<tr>
<td>Windows</td>
<td>PP</td>
<td>EW</td>
<td>severe paint peeling, cracking, chipping</td>
</tr>
<tr>
<td>Frames</td>
<td>PP</td>
<td></td>
<td>severe paint peeling, cracking, chipping</td>
</tr>
<tr>
<td>Floors</td>
<td></td>
<td>Fl</td>
<td></td>
</tr>
</tbody>
</table>

**Other notes:**
Severe paint loss (peeling, cracking, chipping, alligatoring) on wood frames, doors, and baseboards. Paint is in poor condition on walls, ceilings, and bottom of staircase.

**Key:**

Effects of Air & Moisture Intrusion:
Ef = Efflorescence, Mo = Mold, Mi = Mildew, ML = Mortar loss, PL = plaster loss, PP = Peeling paint, PW = Peeling wallpaper, Ro = rot, RD = rising damp, WD = water damage

Sources of Infiltration:
ED = exterior door, EW = exterior window, CC = plaster ceiling cracks, WC = plaster wall cracks, Fl = holes/cracks in floor
Figure 103.1: Paint cracking and peeling underneath staircase in main hall.

Figure 103.2: Paint loss is severe on wood door frame on north wall.
Mositure Intrusion & Air Infiltration

### Interior Inspection

<table>
<thead>
<tr>
<th>Building Component</th>
<th>Effects</th>
<th>Sources</th>
<th>Notes</th>
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</thead>
<tbody>
<tr>
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<td></td>
<td></td>
</tr>
<tr>
<td>North</td>
<td>PP, WD</td>
<td>EW, WC</td>
<td>signs of water damage above windows</td>
</tr>
<tr>
<td>East</td>
<td>PP</td>
<td>WC</td>
<td></td>
</tr>
<tr>
<td>South</td>
<td>PP</td>
<td>WC</td>
<td></td>
</tr>
<tr>
<td>West</td>
<td>PP</td>
<td>WC</td>
<td></td>
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<td>Ceiling</td>
<td>PP</td>
<td>CC</td>
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<tr>
<td>Doors</td>
<td>PP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frames</td>
<td>PP</td>
<td></td>
<td>paint on door frames in severe condition</td>
</tr>
<tr>
<td>Windows</td>
<td></td>
<td>EW</td>
<td></td>
</tr>
<tr>
<td>Frames</td>
<td>PP, Ro</td>
<td></td>
<td>signs of rot on window sill; paint in severe condition</td>
</tr>
<tr>
<td>Floors</td>
<td></td>
<td>Fl</td>
<td></td>
</tr>
</tbody>
</table>

**Other notes:**

Paint on the walls is in moderate condition; however paint on cornices and wood frames is in poor to severe condition. Above the window on the north wall there is a crack in the plaster with what appears to be water damage. Thermostat for forced-air heating system on north wall to left of window.

**Key:**

**Effects of Air & Moisture Intrusion:**

Ef = Efflorescence, Mo = Mold, Mi = Mildew, ML = Mortar loss, PL = plaster loss, PP = Peeling paint, PW = Peeling wallpaper, Ro = rot, RD = rising damp, WD = water damage

**Sources of Infiltration:**

ED = exterior door, EW = exterior window, CC = plaster ceiling cracks, WC = plaster wall cracks, Fl = holes/cracks in floor
Figure 105.1: Signs of wood rot on window sill at north wall.

Figure 105.2: Large crack at top right corner of window frame on north wall.
### Moisture Intrusion & Air Infiltration
#### Interior Inspection

<table>
<thead>
<tr>
<th>Floor #</th>
<th>1</th>
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</thead>
<tbody>
<tr>
<td>Room #</td>
<td>106</td>
</tr>
<tr>
<td>Room Name</td>
<td>East Parlor</td>
</tr>
<tr>
<td>Heating System</td>
<td>Y (Forced-air)</td>
</tr>
<tr>
<td>Cooling System</td>
<td>N</td>
</tr>
<tr>
<td>Date</td>
<td>11/18/2011</td>
</tr>
<tr>
<td>Time</td>
<td>1:30 PM</td>
</tr>
<tr>
<td>Temp. (Avg, Max, Min)</td>
<td>48°F, 55°F, 42°F</td>
</tr>
<tr>
<td>RH (Avg, Max, Min)</td>
<td>50%, 71%, 33%</td>
</tr>
<tr>
<td>Dew Point</td>
<td>30°F</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Building Component</th>
<th>Effects</th>
<th>Sources</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walls</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North</td>
<td>PW, PP</td>
<td>WC</td>
<td>wallpaper borders still intact, panels are almost all missing</td>
</tr>
<tr>
<td>East</td>
<td>PW, PP</td>
<td>EW, WC</td>
<td>wallpaper borders still intact, panels are almost all missing</td>
</tr>
<tr>
<td>South</td>
<td>PW, PP</td>
<td>ED, EW, WC</td>
<td>wallpaper borders still intact, panels are almost all missing</td>
</tr>
<tr>
<td>West</td>
<td>PW, PP</td>
<td>WC</td>
<td>wallpaper borders still intact, panels are almost all missing</td>
</tr>
<tr>
<td>Ceiling</td>
<td></td>
<td>PP</td>
<td>CC</td>
</tr>
<tr>
<td>Doors</td>
<td></td>
<td>PP</td>
<td>ED</td>
</tr>
<tr>
<td>Frames</td>
<td></td>
<td>PP</td>
<td></td>
</tr>
<tr>
<td>Windows</td>
<td></td>
<td>EW</td>
<td>Large cracks where windows meet floor</td>
</tr>
<tr>
<td>Frames</td>
<td>PP, WD</td>
<td></td>
<td>signs of water damage/rot at windows</td>
</tr>
<tr>
<td>Floors</td>
<td></td>
<td>Fl</td>
<td>Large cracks where windows meet floor</td>
</tr>
</tbody>
</table>

**Other notes:**
Dark stains on wood baseboards, might be from cleaning floors. Moisture Content (MC) of wood baseboards are 18%.

**Key:**
- **Effects of Air & Moisture Intrusion:**
  - Ef = Efflorescence, Mo = Mold, Mi = Mildew, ML = Mortar loss, PL = plaster loss, PP = Peeling paint, PW = Peeling wallpaper, Ro = rot, RD = rising damp, WD = water damage

**Sources of Infiltration:**
- ED = exterior door, EW = exterior window, CC = plaster ceiling cracks, WC = plaster wall cracks, Fl = holes/cracks in floor
Figure 106.1: Paint chipping and dark stains on baseboards. Crack in wall where baseboard meets marble firebox surround.

Figure 106.2: Signs of water damage and rot at bottom of windows on east wall.
### Moisture Intrusion & Air Infiltration

#### Interior Inspection

<table>
<thead>
<tr>
<th>Building Component</th>
<th>Effects</th>
<th>Sources</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walls</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North</td>
<td>PP</td>
<td>EW, WC</td>
<td>paint in poor condition</td>
</tr>
<tr>
<td>East</td>
<td>PP</td>
<td>WC</td>
<td></td>
</tr>
<tr>
<td>South</td>
<td>PP, PW</td>
<td>WC</td>
<td>remnants of wallpaper on south wall</td>
</tr>
<tr>
<td>West</td>
<td>PP</td>
<td>WC</td>
<td></td>
</tr>
<tr>
<td>Ceiling</td>
<td>PP</td>
<td>CC</td>
<td>new paint in staircase, peeling in hall</td>
</tr>
<tr>
<td>Doors</td>
<td>PP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frames</td>
<td>PP</td>
<td></td>
<td>bottom of interior door frame has been spliced for rot repair</td>
</tr>
<tr>
<td>Windows</td>
<td>PP</td>
<td>EW</td>
<td>new window on north wall</td>
</tr>
<tr>
<td>Frames</td>
<td>PP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Floors</td>
<td></td>
<td>Fl</td>
<td>hole in floor south of stair case</td>
</tr>
</tbody>
</table>

**Other notes:**
Ductwork run up from ground level through toilet room at south end of hall to supply heated air to this part of 1st Floor.

**Key:**
**Effects of Air & Moisture Intrusion:**
Ef = Efflorescence, Mo = Mold, Mi = Mildew, ML = Mortar loss, PL = plaster loss, PP = Peeling paint, PW = Peeling wallpaper, Ro = rot, RD = rising damp, WD = water damage

**Sources of Infiltration:**
ED = exterior door, EW = exterior window, CC = plaster ceiling cracks, WC = plaster wall cracks, Fl = holes/cracks in floor
Figure 107.1: Peeling paint and limewash on east wall. Also paint chipping off of door frame.

Figure 107.2: Heating system ductwork run up from basement in toilet room.
# Moisture Intrusion & Air Infiltration

## Interior Inspection

<table>
<thead>
<tr>
<th>Building Component</th>
<th>Effects</th>
<th>Sources</th>
<th>Notes</th>
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<td>Walls</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North</td>
<td>PP</td>
<td>EW, WC</td>
<td>wallpaper exists on north part of wall, plaster loss at corners of chimney</td>
</tr>
<tr>
<td>East</td>
<td>PP, PW, PL</td>
<td>WC</td>
<td></td>
</tr>
<tr>
<td>South</td>
<td>PP</td>
<td>ED, EW, WC</td>
<td></td>
</tr>
<tr>
<td>West</td>
<td>PP</td>
<td>WC</td>
<td></td>
</tr>
<tr>
<td>Ceiling</td>
<td>PP</td>
<td>CC</td>
<td>paint in poor condition; misc. patches on ceiling &amp; cornice</td>
</tr>
<tr>
<td>Doors</td>
<td>PP</td>
<td>ED</td>
<td>rot at bottom of exterior door on north wall</td>
</tr>
<tr>
<td>Frames</td>
<td>PP</td>
<td></td>
<td>rot in door header and bottom of frame on north wall</td>
</tr>
<tr>
<td>Windows</td>
<td>PP</td>
<td>EW</td>
<td></td>
</tr>
<tr>
<td>Frames</td>
<td>PP, Ro</td>
<td></td>
<td>rot on frame &amp; paneling</td>
</tr>
<tr>
<td>Finishes</td>
<td>PP, PW</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Floors</td>
<td></td>
<td>FI</td>
<td></td>
</tr>
</tbody>
</table>

**Other notes:**
Large cracks in plaster at corners of room and at window and door frames.

**Key:**

**Effects of Air & Moisture Intrusion:**
EF = Efflorescence, Mo = Mold, Mi = Mildew, ML = Mortar loss, PL = plaster loss, PP = Peeling paint, PW = Peeling wallpaper, Ro = rot, RD = rising damp, WD = water damage

**Sources of Infiltration:**
ED = exterior door, EW = exterior window, CC = plaster ceiling cracks, WC = plaster wall cracks, FI = holes/cracks in floor
Figure 108.1: Plaster loss at the corner of the north side of the chimney located on the east wall, looking south.

Figure 108.2: Wood rot at window frame and paneling on north wall.
## Moisture Intrusion & Air Infiltration

### Interior Inspection

<table>
<thead>
<tr>
<th>Building Component</th>
<th>Effects</th>
<th>Sources</th>
<th>Notes</th>
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<tbody>
<tr>
<td>Walls</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>North</td>
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<td></td>
<td>OK</td>
</tr>
<tr>
<td>East</td>
<td></td>
<td>EW</td>
<td>OK</td>
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<td>South</td>
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<td></td>
<td>OK</td>
</tr>
<tr>
<td>West</td>
<td></td>
<td>EW</td>
<td>OK</td>
</tr>
<tr>
<td>Ceiling</td>
<td>WD, PP</td>
<td></td>
<td>Water spot in vestibule and two spots on cornice at east wall</td>
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<tr>
<td>Doors</td>
<td></td>
<td>ED</td>
<td>exterior door on east wall in vestibule</td>
</tr>
<tr>
<td>Frames</td>
<td></td>
<td></td>
<td>OK</td>
</tr>
<tr>
<td>Windows</td>
<td></td>
<td>WS</td>
<td>condensation forms on windows during warm periods</td>
</tr>
<tr>
<td>Frames</td>
<td></td>
<td>PP</td>
<td>minor paint cracking</td>
</tr>
<tr>
<td>Floors</td>
<td></td>
<td>Fl</td>
<td>floor boards separating, can see holes btwn boards</td>
</tr>
</tbody>
</table>

**Other notes:**

Water damage is visible on the plaster cornice at the south corner of the chimney and above the north window, both at the east wall. Paint peeling on the ceiling near the skylight opening and inside the skylight. There is a bad water spot with mildew on the ceiling of the vestibule.

**Key:**

**Effects of Air & Moisture Intrusion:**

Ef = Efflorescence, Mo = Mold, Mi = Mildew, ML = Mortar loss, PL = plaster loss, PP = Peeling paint, PW = Peeling wallpaper, Ro = rot, RD = rising damp, WD = water damage

**Sources of Infiltration:**

ED = exterior door, EW = exterior window, CC = plaster ceiling cracks, WC = plaster wall cracks, Fl = holes/cracks in floor
Figure 109.1: Water damage on plaster cornice at south corner of the chimney on the east wall.

Figure 109.2: Water spot with mildew on the ceiling at the east wall of the vestibule.
## Moisture Intrusion & Air Infiltration
### Interior Inspection

<table>
<thead>
<tr>
<th>Building Component</th>
<th>Effects</th>
<th>Sources</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walls</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North</td>
<td>PW, Mi</td>
<td>EW, WC</td>
<td></td>
</tr>
<tr>
<td>East</td>
<td>PW, Mi</td>
<td>WC</td>
<td></td>
</tr>
<tr>
<td>South</td>
<td>PW, Mi</td>
<td>WC</td>
<td></td>
</tr>
<tr>
<td>West</td>
<td>PW, Mi</td>
<td>EW, WC</td>
<td></td>
</tr>
<tr>
<td>Ceiling</td>
<td>PP</td>
<td>CC</td>
<td></td>
</tr>
<tr>
<td>Doors</td>
<td>PP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frames</td>
<td>PP</td>
<td></td>
<td>paint alligatoring</td>
</tr>
<tr>
<td>Windows</td>
<td>PP</td>
<td>EW</td>
<td></td>
</tr>
<tr>
<td>Frames</td>
<td>PP</td>
<td></td>
<td>paint alligatoring</td>
</tr>
<tr>
<td>Floors</td>
<td></td>
<td></td>
<td>OK</td>
</tr>
</tbody>
</table>

Other notes:
Wallpaper has significant amount of mildew on surface. Plaster wall surfaces are also covered in mildew where wallpaper has peeled off. Wood frame moisture content 18-20%.

### Key:

**Effects of Air & Moisture Intrusion:**
Ef = Efflorescence, Mo = Mold, Mi = Mildew, ML = Mortar loss, PL = plaster loss, PP = Peeling paint, PW = Peeling wallpaper, Ro = rot, RD = rising damp, WD = water damage

**Sources of Infiltration:**
ED = exterior door, EW = exterior window, CC = plaster ceiling cracks, WC = plaster wall cracks, Fl = holes/cracks in floor
Figure 201.1: Paint alligating on window, frame and sill on the north wall.

Figure 201.2: Visible mildew and/or water stains on wallpaper and plaster wall surfaces, looking northeast.
### Moisture Intrusion & Air Infiltration

**Interior Inspection**

<table>
<thead>
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<th>2</th>
<th>Date:</th>
<th>10/27/2011</th>
</tr>
</thead>
<tbody>
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<td>Room #:</td>
<td>202</td>
<td>Time:</td>
<td>10:15 AM</td>
</tr>
<tr>
<td>Room Name:</td>
<td>Southwest Bedroom</td>
<td>Temp. (Avg, Max, Min):</td>
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</tr>
<tr>
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<td>Y (Forced-air)</td>
<td>RH (Avg, Max, Min):</td>
<td>69%, 94%, 37%</td>
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<tr>
<td>Cooling System:</td>
<td>N</td>
<td>Dew Point:</td>
<td>59°F</td>
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</table>

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<th>Building Component</th>
<th>Effects</th>
<th>Sources</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
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<td>Walls</td>
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<tr>
<td>North</td>
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<td>WC</td>
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</tr>
<tr>
<td>East</td>
<td>PW</td>
<td>WC</td>
<td></td>
</tr>
<tr>
<td>South</td>
<td>PW</td>
<td>EW, WC</td>
<td>large cracks in wood paneling &amp; trim at window</td>
</tr>
<tr>
<td>West</td>
<td>PW, PL</td>
<td>EW, WC</td>
<td>Large hole in plaster @ top left corner of center window</td>
</tr>
<tr>
<td>Ceiling</td>
<td>PP, PL</td>
<td>CC</td>
<td>severe paint peeling, holes in closet ceiling</td>
</tr>
<tr>
<td>Doors</td>
<td>PP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frames</td>
<td>PP</td>
<td></td>
<td>severe paint loss</td>
</tr>
<tr>
<td>Windows</td>
<td></td>
<td>EW</td>
<td>large cracks where windows meet plaster walls</td>
</tr>
<tr>
<td>Frames</td>
<td>PP, WD</td>
<td></td>
<td>severe paint loss, piece of trim missing (air leak)</td>
</tr>
<tr>
<td>Floors</td>
<td></td>
<td>Fi</td>
<td></td>
</tr>
</tbody>
</table>

**Other notes:**

Wallpaper approximately 50% missing on all walls. Large cracks in walls and ceilings. Wood paneling on west wall is in poor condition. Piece of wood trim missing on southern most window on the west wall (air leakage potential).

**Key:**

**Effects of Air & Moisture Intrusion:**

Ef = Efflorescence, Mo = Mold, Mi = Mildew, ML = Mortar loss, PL = plaster loss, PP = Peeling paint, PW = Peeling wallpaper, Ro = rot, RD = rising damp, WD = water damage

**Sources of Infiltration:**

ED = exterior door, EW = exterior window, CC = plaster ceiling cracks, WC = plaster wall cracks, Fl = holes/cracks in floor
Figure 202.1: Severe paint loss on ceiling, large cracks in ceiling and wall, hole in plaster at top left corner of center window on west wall.

Figure 202.2: Significant paint loss on wood trim and paneling throughout room. Cracks in center of wood paneling.
**Moisture Intrusion & Air Infiltration**

**Interior Inspection**

- **Floor #:** 2  
- **Room #:** 203  
- **Room Name:** Main stair  
- **Date:** 10/27/2011  
- **Time:** 10:15 AM  
- **Heating System:** Y (Forced Air)  
- **Cooling System:** N  
- **Temp. (Avg, Max, Min):** 70°F, 60°F, 50°F  
- **RH (Avg, Max, Min):** 69%, 94%, 37%  
- **Dew Point:** 59°F

<table>
<thead>
<tr>
<th>Building Component</th>
<th>Effects</th>
<th>Sources</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Walls</td>
<td>PP</td>
<td>EW, WC</td>
<td>significant peeling &amp; cracking</td>
</tr>
<tr>
<td>East Walls</td>
<td>PP</td>
<td>WC</td>
<td>significant peeling &amp; cracking</td>
</tr>
<tr>
<td>South Walls</td>
<td>PP, PL</td>
<td>WC</td>
<td>significant peeling &amp; cracking</td>
</tr>
<tr>
<td>West Walls</td>
<td>PP</td>
<td>WC</td>
<td>significant peeling &amp; cracking</td>
</tr>
<tr>
<td>Ceiling</td>
<td>PP</td>
<td>CC</td>
<td>significant peeling, ceiling medallion is OK</td>
</tr>
<tr>
<td>Doors</td>
<td>n/a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frames</td>
<td>PP</td>
<td></td>
<td>severe paint loss on arch opening into stair</td>
</tr>
<tr>
<td>Windows</td>
<td>PP</td>
<td>EW</td>
<td></td>
</tr>
<tr>
<td>Frames</td>
<td>PP</td>
<td></td>
<td>severe paint loss on tripartite window</td>
</tr>
<tr>
<td>Floors</td>
<td></td>
<td>OK</td>
<td></td>
</tr>
</tbody>
</table>

**Other notes:**
Wood paneling on arched opening leading to staircase has cracking.

**Key:**
- **Effects of Air & Moisture Intrusion:**
  - Ef = Efflorescence, Mo = Mold, Mi = Mildew, ML = Mortar loss, PL = plaster loss, PP = Peeling paint, PW = Peeling wallpaper, Ro = rot, RD = rising damp, WD = water damage
- **Sources of Infiltration:**
  - ED = exterior door, EW = exterior window, CC = plaster ceiling cracks, WC = plaster wall cracks, Fl = holes/cracks in floor
Figure 203.1: Paint chipping off window frame on north wall of stair landing between 1st and 2nd floor.

Figure 203.2: Significant paint loss on wood components of the arch leading into the staircase.

Figure 203.3: Paint loss at tripartite window at landing between 1st and 2nd floors.
## Moisture Intrusion & Air Infiltration

### Interior Inspection

<table>
<thead>
<tr>
<th>Floor #:</th>
<th>2</th>
<th>Date:</th>
<th>10/27/2011</th>
<th>Room #:</th>
<th>204</th>
<th>Time:</th>
<th>10:15 AM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room Name:</td>
<td>Main hall</td>
<td>Temp. (Avg, Max, Min):</td>
<td>70°F, 60°F, 50°F</td>
<td>Heating System:</td>
<td>Y (Forced Air)</td>
<td>RH (Avg, Max, Min):</td>
<td>69%, 94%, 37%</td>
</tr>
</tbody>
</table>

### Building Component | Effects | Sources | Notes |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Walls</td>
<td>North</td>
<td>PP</td>
<td>WC</td>
</tr>
<tr>
<td>East</td>
<td>PP</td>
<td>WC</td>
<td>significant peeling &amp; cracking</td>
</tr>
<tr>
<td>South</td>
<td>PP, PL</td>
<td>ED, EW, WC</td>
<td>large cracks &amp; hole in plaster over door to piazza</td>
</tr>
<tr>
<td>West</td>
<td>PP</td>
<td>WC</td>
<td>significant peeling &amp; cracking</td>
</tr>
<tr>
<td>Ceiling</td>
<td>PP</td>
<td>CC</td>
<td>significant peeling</td>
</tr>
<tr>
<td>Doors</td>
<td>PP</td>
<td>ED</td>
<td>severe paint peeling, cracking, chipping</td>
</tr>
<tr>
<td>Frames</td>
<td>PP</td>
<td></td>
<td>severe paint peeling, cracking, chipping</td>
</tr>
<tr>
<td>Windows</td>
<td>PP</td>
<td>EW</td>
<td>severe paint peeling, cracking, chipping</td>
</tr>
<tr>
<td>Frames</td>
<td>PP</td>
<td></td>
<td>significant paint loss</td>
</tr>
<tr>
<td>Floors</td>
<td></td>
<td>OK</td>
<td></td>
</tr>
</tbody>
</table>

**Other notes:**
Large cracks and hole in plaster at the arch over the door to the piazza on the south wall. Some cracks in wood wainscot throughout room.

**Key:**
- Effects of Air & Moisture Intrusion:
  - Ef = Efflorescence, Mo = Mold, Mi = Mildew, ML = Mortar loss, PL = plaster loss, PP = Peeling paint, PW = Peeling wallpaper, Ro = rot, RD = rising damp, WD = water damage

- Sources of Infiltration:
  - ED = exterior door, EW = exterior window, CC = plaster ceiling cracks, WC = plaster wall cracks, Fl = holes/cracks in floor
Figure 204.1: Large cracks and hole in plaster at south wall over the door to the piazza.

Figure 204.2: Paint peeling on west wall of main hall.
# Moisture Intrusion & Air Infiltration

## Interior Inspection

<table>
<thead>
<tr>
<th>Floor #:</th>
<th>2</th>
<th>Date:</th>
<th>11/8/2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room #:</td>
<td>205</td>
<td>Time:</td>
<td>2:45 PM</td>
</tr>
<tr>
<td><strong>Room Name:</strong></td>
<td>NE Dressing Room</td>
<td><strong>Temp. (Avg, Max, Min):</strong></td>
<td>64°F, 73°F, 55°F</td>
</tr>
<tr>
<td><strong>Heating System:</strong></td>
<td>Y (Forced Air)</td>
<td><strong>RH (Avg, Max, Min):</strong></td>
<td>74%, 94%, 50%</td>
</tr>
<tr>
<td><strong>Cooling System:</strong></td>
<td>N</td>
<td><strong>Dew Point:</strong></td>
<td>55°F</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Building Component</th>
<th>Effects</th>
<th>Sources</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Walls</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North</td>
<td>PW, PL</td>
<td>EW, WC</td>
<td>hole in wall near tub</td>
</tr>
<tr>
<td>East</td>
<td>PW</td>
<td>WC</td>
<td></td>
</tr>
<tr>
<td>South</td>
<td>PW, PL</td>
<td>WC</td>
<td>holes around firebox</td>
</tr>
<tr>
<td>West</td>
<td>PW</td>
<td>WC</td>
<td></td>
</tr>
<tr>
<td><strong>Ceiling</strong></td>
<td>PL</td>
<td>CC</td>
<td>plaster missing from ceiling, lath only</td>
</tr>
<tr>
<td><strong>Doors</strong></td>
<td>PP</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Frames</strong></td>
<td>PP</td>
<td></td>
<td>paint on door frames in severe condition</td>
</tr>
<tr>
<td><strong>Windows</strong></td>
<td>n/a</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Frames</strong></td>
<td>PP, Ro</td>
<td></td>
<td>crack in wood panel below window</td>
</tr>
<tr>
<td><strong>Floors</strong></td>
<td>Fl</td>
<td>3/4&quot; crack at transition to SE bedroom</td>
<td></td>
</tr>
</tbody>
</table>

**Other notes:**
Plaster is missing from the entire ceiling and there are holes in the lath in the northwest corner of the ceiling. Moisture content of wood frames, doors, and paneling is 18%.

**Key:**
- Ef = Efflorescence, Mo = Mold, Mi = Mildew, ML = Mortar loss, PL = plaster loss, PP = Peeling paint, PW = Peeling wallpaper, Ro = rot, RD = rising damp, WD = water damage

**Sources of Infiltration:**
- ED = exterior door, EW = exterior window, CC = plaster ceiling cracks, WC = plaster wall cracks, Fl = holes/cracks in floor
Figure 205.1: Plaster missing on ceiling, wallpaper peeling off walls. View of southwest corner above door.

Figure 205.2: Holes in plaster near wall around firebox on south wall.
Moisture Intrusion & Air Infiltration
Interior Inspection

<table>
<thead>
<tr>
<th>Floor #:</th>
<th>2</th>
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</thead>
<tbody>
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<td>Date:</td>
<td>10/27/2011</td>
</tr>
<tr>
<td>Room #:</td>
<td>206</td>
</tr>
<tr>
<td>Time:</td>
<td>10:15 AM</td>
</tr>
<tr>
<td>Room Name:</td>
<td>SE Bedroom</td>
</tr>
<tr>
<td>Temp. (Avg, Max, Min):</td>
<td>70°F, 60°F, 50°F</td>
</tr>
<tr>
<td>Heating System:</td>
<td>Y (Forced Air)</td>
</tr>
<tr>
<td>RH (Avg, Max, Min):</td>
<td>69%, 94%, 37%</td>
</tr>
<tr>
<td>Cooling System:</td>
<td>N</td>
</tr>
<tr>
<td>Dew Point:</td>
<td>59°F</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Building Component</th>
<th>Effects</th>
<th>Sources</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walls</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North</td>
<td>PW</td>
<td>WC</td>
<td></td>
</tr>
<tr>
<td>East</td>
<td>PW</td>
<td>EW, WC</td>
<td></td>
</tr>
<tr>
<td>South</td>
<td>PW</td>
<td>EW, WC</td>
<td></td>
</tr>
<tr>
<td>West</td>
<td>PW</td>
<td>WC</td>
<td></td>
</tr>
<tr>
<td>Ceiling</td>
<td>PW, PP</td>
<td>CC</td>
<td>severe paint loss on cornice, wallpaper approx. 30% gone</td>
</tr>
<tr>
<td>Doors</td>
<td>PP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frames</td>
<td>PP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Windows</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PP</td>
<td>EW</td>
<td>Large cracks where window frames meet plaster walls</td>
<td></td>
</tr>
<tr>
<td>Frames</td>
<td>PP, WD</td>
<td></td>
<td>piece of trim missing on right side of west window on south wall</td>
</tr>
<tr>
<td>Floors</td>
<td>FI</td>
<td></td>
<td>holes @ baseboard and window boxes</td>
</tr>
</tbody>
</table>

Other notes:
Hole in the ceiling in the closet on the north wall. Wallpaper in decent condition, wood paneling cracking

Key:

Effects of Air & Moisture Intrusion:
Ef = Efflorescence, Mo = Mold, Mi = Mildew, ML = Mortar loss, PL = plaster loss, PP = Peeling paint, PW = Peeling wallpaper, Ro = rot, RD = rising damp, WD = water damage

Sources of Infiltration:
ED = exterior door, EW = exterior window, CC = plaster ceiling cracks, WC = plaster wall cracks, Fl = holes/cracks in floor
Figure 206.1: Wallpaper peeling off the ceiling, looking south.

Figure 206.2: Cracks at joints of wood paneling in window boxes.
**Moisture Intrusion & Air Infiltration**
**Interior Inspection**

<table>
<thead>
<tr>
<th>Building Component</th>
<th>Effects</th>
<th>Sources</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walls</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North</td>
<td>PP</td>
<td>EW, WC</td>
<td>paint in fair to poor condition</td>
</tr>
<tr>
<td>East</td>
<td>PP</td>
<td>WC</td>
<td>paint in fair to poor condition</td>
</tr>
<tr>
<td>South</td>
<td>PP, PW</td>
<td>WC</td>
<td>paint in fair to poor condition</td>
</tr>
<tr>
<td>West</td>
<td>PP</td>
<td>WC</td>
<td>paint in fair to poor condition</td>
</tr>
<tr>
<td>Ceiling</td>
<td>PP</td>
<td>CC</td>
<td>piece of cornice missing on east wall</td>
</tr>
<tr>
<td>Doors</td>
<td>PP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frames</td>
<td>PP</td>
<td></td>
<td>paint cracking, peeling &amp; alligatoring</td>
</tr>
<tr>
<td>Windows</td>
<td>PP</td>
<td>EW</td>
<td>new window on north wall</td>
</tr>
<tr>
<td>Frames</td>
<td>PP</td>
<td></td>
<td>paint cracking, peeling &amp; alligatoring</td>
</tr>
<tr>
<td>Floors</td>
<td>FI</td>
<td></td>
<td>hole in floor under sink to south of staircase</td>
</tr>
</tbody>
</table>

**Other notes:**
Ductwork run up from ground level through toilet room at south end of hall to supply heated air to 3rd Floor. Paint in poor condition in the toilet room. Possible paint damage on the ceiling and cornice at the glass divider between the hall and the stairwell.

**Key:**
**Effects of Air & Moisture Intrusion:**
Ef = Efflorescence, Mo = Mold, Mi = Mildew, ML = Mortar loss, PL = plaster loss, PP = Peeling paint, PW = Peeling wallpaper, Ro = rot, RD = rising damp, WD = water damage

**Sources of Infiltration:**
ED = exterior door, EW = exterior window, CC = plaster ceiling cracks, WC = plaster wall cracks, Fl = holes/cracks in floor
Figure 207.1: Paint and plaster damage at glass divider between stairwell and hall, looking south.

Figure 207.2: Hole in floor under the sink to the south of the staircase.
## Moisture Intrusion & Air Infiltration

### Interior Inspection

<table>
<thead>
<tr>
<th>Building Component</th>
<th>Effects</th>
<th>Sources</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walls</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North</td>
<td>PW, WD</td>
<td>EW, WC</td>
<td>water damage @ NE corner of cornice</td>
</tr>
<tr>
<td>East</td>
<td>PW, WD</td>
<td>WC</td>
<td>water damage @ corners where chimney meets cornice</td>
</tr>
<tr>
<td>South</td>
<td>PW, PL</td>
<td>ED, EW, WC</td>
<td>hole in plaster below cornice</td>
</tr>
<tr>
<td>West</td>
<td>PW, WD</td>
<td>WC</td>
<td>water damage at cornice</td>
</tr>
<tr>
<td>Ceiling</td>
<td>PP</td>
<td>CC</td>
<td>paint in poor condition; misc. patches on ceiling &amp; cornice</td>
</tr>
<tr>
<td>Doors</td>
<td>PP</td>
<td>ED</td>
<td>paint in severe condition on SW door, exterior door on S. wall does not shut properly</td>
</tr>
<tr>
<td>Frames</td>
<td>PP</td>
<td></td>
<td>large cracks where frames meet walls</td>
</tr>
<tr>
<td>Windows</td>
<td>PP</td>
<td>EW</td>
<td></td>
</tr>
<tr>
<td>Frames</td>
<td>PP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Floors</td>
<td></td>
<td>Fi</td>
<td></td>
</tr>
</tbody>
</table>

### Other notes:
Large cracks in plaster at corners of room and at window and door frames. Wallpaper failing at cracks in plaster. Moisture content of wood components between 18-20%.

### Key:

**Effects of Air & Moisture Intrusion:**
- Ef = Efflorescence, Mo = Mold, Mi = Mildew, ML = Mortar loss, PL = plaster loss, PP = Peeling paint, PW = Peeling wallpaper, Ro = rot, RD = rising damp, WD = water damage

**Air Infiltration:**
- ED = exterior door, WS = window sash, CC = ceiling cracks, WC = wall cracks, Fl = Floor cracks/holes
Figure 208.1: Wallpaper peeling off east wall of withdrawing room.

Figure 208.2: Large hole in plaster below cornice on south wall. Plaster failure is causing wallpaper to peel.
### Moisture Intrusion & Air Infiltration
#### Interior Inspection

<table>
<thead>
<tr>
<th>Building Component</th>
<th>Effects</th>
<th>Sources</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Walls</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North</td>
<td>PP, Mi, Mo</td>
<td>EW, WC</td>
<td>green stain in NE corner coming from ceiling, no longer active</td>
</tr>
<tr>
<td>East</td>
<td>PP</td>
<td>WC</td>
<td></td>
</tr>
<tr>
<td>South</td>
<td>PP</td>
<td>WC</td>
<td></td>
</tr>
<tr>
<td>West</td>
<td>PP</td>
<td>EW, WC</td>
<td></td>
</tr>
<tr>
<td><strong>Ceiling</strong></td>
<td>PP, PL</td>
<td>CC</td>
<td>surface bubbling &amp; peeling, large holes in plaster</td>
</tr>
<tr>
<td><strong>Doors</strong></td>
<td>PP</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Frames</strong></td>
<td>PP</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Windows</strong></td>
<td>PP</td>
<td>EW</td>
<td></td>
</tr>
<tr>
<td><strong>Frames</strong></td>
<td>PP</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Floors</strong></td>
<td></td>
<td>OK</td>
<td></td>
</tr>
</tbody>
</table>

**Other notes:**
Green mild or mold on north wall in northeast corner, looks to be coming from the ceiling. Moisture content of door frame is 18%, window frames +20%, and floor +20%.

**Key:**
- **Effects of Air & Moisture Intrusion:**
  - Ef = Efflorescence, Mo = Mold, Mi = Mildew, ML = Mortar loss, PL = plaster loss, PP = Peeling paint, PW = Peeling wallpaper, Ro = rot, RD = rising damp, WD = water damage
- **Sources of Infiltration:**
  - ED = exterior door, EW = exterior window, CC = plaster ceiling cracks, WC = plaster wall cracks, FI = holes/cracks in floor
Figure 301.2: Green stain in northeast corner coming from ceiling. Large hole in plaster ceiling.

Figure 301.2: Paint peeling and bubbling on the ceiling near a large hole in the plaster ceiling.
Moisture Intrusion & Air Infiltration
Interior Inspection

Floor #: 3  Date: 10/7/2011
Room #: 302  Time: 10:00 AM
Room Name: SW Bedroom  Temp. (Avg, Max, Min): 72°F, 80°F, 64°F
Heating System: Y (Forced-air)  RH (Avg, Max, Min): 69%, 83%, 47%
Cooling System: N  Dew Point: 61°F

<table>
<thead>
<tr>
<th>Building Component</th>
<th>Effects</th>
<th>Sources</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walls</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North</td>
<td>PP, WD</td>
<td>WC</td>
<td>signs of water damage near cornice above fireplace</td>
</tr>
<tr>
<td>East</td>
<td>PP</td>
<td>WC</td>
<td></td>
</tr>
<tr>
<td>South</td>
<td>PP</td>
<td>EW, WC</td>
<td></td>
</tr>
<tr>
<td>West</td>
<td>PP</td>
<td>EW, WC</td>
<td></td>
</tr>
<tr>
<td>Ceiling</td>
<td>PP, PL</td>
<td>CC</td>
<td>paint peeling mostly in middle near diffuser</td>
</tr>
<tr>
<td>Doors</td>
<td>PP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frames</td>
<td>PP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Windows</td>
<td>PP</td>
<td>EW</td>
<td></td>
</tr>
<tr>
<td>Frames</td>
<td>PP, WD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Floors</td>
<td>Fl</td>
<td>OK</td>
<td></td>
</tr>
</tbody>
</table>

Other notes:
Moisture content of window frames is 16-20%, wood door is 16%.

Key:
Effects of Air & Moisture Intrusion:
Ef = Efflorescence, Mo = Mold, Mi = Mildew, ML = Mortar loss, PL = plaster loss, PP = Peeling paint, PW = Peeling wallpaper, Ro = rot, RD = rising damp, WD = water damage

Sources of Infiltration:
ED = exterior door, EW = exterior window, CC = plaster ceiling cracks, WC = plaster wall cracks, Fl = holes/cracks in floor
Figure 302.1: View of the water damage on the north wall above the fireplace.

Figure 302.2: Close-up of water damage on north wall above the fireplace.
**Moisture Intrusion & Air Infiltration**

**Interior Inspection**

<table>
<thead>
<tr>
<th>Building Component</th>
<th>Effects</th>
<th>Sources</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Walls</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North</td>
<td>PP</td>
<td>EW, WC</td>
<td>severe paint cracking &amp; peeling</td>
</tr>
<tr>
<td>East</td>
<td>PP</td>
<td>WC</td>
<td>severe paint cracking &amp; peeling</td>
</tr>
<tr>
<td>South</td>
<td>n/a</td>
<td></td>
<td>no south wall</td>
</tr>
<tr>
<td>West</td>
<td>PP</td>
<td>WC</td>
<td>severe paint cracking &amp; peeling</td>
</tr>
<tr>
<td>Ceiling</td>
<td>PP</td>
<td>CC</td>
<td>moderate paint peeling</td>
</tr>
<tr>
<td>Doors</td>
<td>n/a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frames</td>
<td>PP</td>
<td></td>
<td>severe paint loss on arch opening into stair</td>
</tr>
<tr>
<td>Windows</td>
<td>PP</td>
<td>EW</td>
<td></td>
</tr>
<tr>
<td>Frames</td>
<td>PP</td>
<td></td>
<td>severe paint loss on tripartite window</td>
</tr>
<tr>
<td>Floors</td>
<td></td>
<td></td>
<td>OK</td>
</tr>
</tbody>
</table>

**Other notes:**

Wood paneling on arched opening leading to staircase has cracking.

**Key:**

**Effects of Air & Moisture Intrusion:**

Ef = Efflorescence, Mo = Mold, Mi = Mildew, ML = Mortar loss, PL = plaster loss, PP = Peeling paint, PW = Peeling wallpaper, Ro = rot, RD = rising damp, WD = water damage

**Sources of Infiltration:**

ED = exterior door, EW = exterior window, CC = plaster ceiling cracks, WC = plaster wall cracks, Fl = holes/cracks in floor
Figure 303.1: Severe paint peeling and cracking visible on north, west and east walls. View looking north.

Figure 303.2: Paint peeling on the ceiling around the decorative plaster medallion.
## Moisture Intrusion & Air Infiltration

### Interior Inspection

<table>
<thead>
<tr>
<th>Floor #:</th>
<th>3</th>
<th>Date:</th>
<th>10/14/2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room #:</td>
<td>304</td>
<td>Time:</td>
<td>10:30 AM</td>
</tr>
<tr>
<td>Room Name:</td>
<td>Main hall</td>
<td>Temp. (Avg, Max, Min):</td>
<td>69°F, 78°F, 60°F</td>
</tr>
<tr>
<td>Heating System:</td>
<td>Y (Forced-air)</td>
<td>RH (Avg, Max, Min):</td>
<td>68%, 100%, 30%</td>
</tr>
<tr>
<td>Cooling System:</td>
<td>N</td>
<td>Dew Point:</td>
<td>55°F</td>
</tr>
</tbody>
</table>

### Building Component

<table>
<thead>
<tr>
<th>Building Component</th>
<th>Effects</th>
<th>Sources</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walls</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North</td>
<td>PP</td>
<td>WC</td>
<td>severe paint cracking, peeling &amp; alligatoring</td>
</tr>
<tr>
<td>East</td>
<td>PP</td>
<td>WC</td>
<td>severe paint cracking, peeling &amp; alligatoring</td>
</tr>
<tr>
<td>South</td>
<td>PP</td>
<td>EW, WC</td>
<td>severe paint cracking, peeling &amp; alligatoring</td>
</tr>
<tr>
<td>West</td>
<td>PP</td>
<td>WC</td>
<td>severe paint cracking, peeling &amp; alligatoring</td>
</tr>
<tr>
<td>Ceiling</td>
<td>PP</td>
<td>CC</td>
<td>significant peeling</td>
</tr>
<tr>
<td>Doors</td>
<td>PP</td>
<td>ED</td>
<td>severe paint peeling, cracking, chipping</td>
</tr>
<tr>
<td>Frames</td>
<td>PP</td>
<td></td>
<td>severe paint peeling, cracking, chipping</td>
</tr>
<tr>
<td>Windows</td>
<td>PP</td>
<td>EW</td>
<td>severe paint peeling, cracking, chipping</td>
</tr>
<tr>
<td>Frames</td>
<td>PP</td>
<td></td>
<td>significant paint loss</td>
</tr>
<tr>
<td>Floors</td>
<td></td>
<td>OK</td>
<td></td>
</tr>
</tbody>
</table>

### Other notes:

**Key:**

**Effects of Air & Moisture Intrusion:**

Ef = Efflorescence, Mo = Mold, Mi = Mildew, ML = Mortar loss, PL = plaster loss, PP = Peeling paint, PW = Peeling wallpaper, Ro = rot, RD = rising damp, WD = water damage

**Sources of Infiltration:**

ED = exterior door, EW = exterior window, CC = plaster ceiling cracks, WC = plaster wall cracks, Fl = holes/cracks in floor
Figure 304.1: Paint peeling on ceiling of main hall.

Figure 304.2: Cracks in wood paneling.
**Moisture Intrusion & Air Infiltration**

**Interior Inspection**

<table>
<thead>
<tr>
<th>Floor #:</th>
<th>3</th>
<th>Date:</th>
<th>10/14/2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room #:</td>
<td>305</td>
<td>Time:</td>
<td>10:30 AM</td>
</tr>
<tr>
<td>Room Name:</td>
<td>NE Dressing Room</td>
<td>Temp. (Avg, Max, Min):</td>
<td>69°F, 78°F, 60°F</td>
</tr>
<tr>
<td>Heating System:</td>
<td>Y (Forced-air)</td>
<td>RH (Avg, Max, Min):</td>
<td>68%, 100%, 30%</td>
</tr>
<tr>
<td>Cooling System:</td>
<td>N</td>
<td>Dew Point:</td>
<td>55°F</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Building Component</th>
<th>Effects</th>
<th>Sources</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walls</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North</td>
<td>PW, Mi</td>
<td>EW, WC</td>
<td>mildew @ NW &amp; NE corners</td>
</tr>
<tr>
<td>East</td>
<td>PW, Mi</td>
<td>WC</td>
<td>mildew @ NE &amp; SE corners</td>
</tr>
<tr>
<td>South</td>
<td>PW, Mi</td>
<td>WC</td>
<td>mildew @ SE &amp; SW corners</td>
</tr>
<tr>
<td>West</td>
<td>PW, Mi</td>
<td>WC</td>
<td>mildew @ SW &amp; NW corners</td>
</tr>
<tr>
<td>Ceiling</td>
<td>PL, PW, WD</td>
<td>CC</td>
<td>areas plaster loss, wallpaper peeling</td>
</tr>
<tr>
<td>Doors</td>
<td>PP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frames</td>
<td>PP</td>
<td></td>
<td>paint on door frames in severe condition</td>
</tr>
<tr>
<td>Windows</td>
<td></td>
<td>EW</td>
<td></td>
</tr>
<tr>
<td>Frames</td>
<td>PP , Ro</td>
<td></td>
<td>crack in wood panel below window</td>
</tr>
<tr>
<td>Floors</td>
<td></td>
<td>Fl</td>
<td>linoleum flooring in poor condition</td>
</tr>
</tbody>
</table>

**Other notes:**
The there is a boxed out hole to the attic on the south side of the ceiling. Large crack in southeast corner of room and large hole (1-1/2"x4") at the bottom left side of the door frame on the south wall. Water damage at southeast corner of ceiling at cornice.

**Key:**

**Effects of Air & Moisture Intrusion:**

Ef = Efflorescence, Mo = Mold, Mi = Mildew, ML = Mortar loss, PL = plaster loss, PP = Peeling paint, PW = Peeling wallpaper, Ro = rot, RD = rising damp, WD = water damage

**Sources of Infiltration:**

ED = exterior door, EW = exterior window, CC = plaster ceiling cracks, WC = plaster wall cracks, Fl = holes/cracks in floor
Figure 305.1: Wallpaper peeling in northwest corner of room. Possible mildew visible.

Figure 305.2: Wallpaper peeling on south wall. Large crack in southeast corner visible. Large area of plaster loss on the ceiling to the right of the framed out hole to the attic.
# Moisture Intrusion & Air Infiltration

## Interior Inspection

<table>
<thead>
<tr>
<th>Floor #:</th>
<th>3</th>
<th>Date:</th>
<th>10/14/2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room #:</td>
<td>306</td>
<td>Time:</td>
<td>10:30 AM</td>
</tr>
<tr>
<td>Room Name:</td>
<td>SE Bedroom</td>
<td>Temp. (Avg, Max, Min):</td>
<td>69°F, 78°F, 60°F</td>
</tr>
<tr>
<td>Heating System:</td>
<td>Y (Forced-air)</td>
<td>RH (Avg, Max, Min):</td>
<td>68%, 100%, 30%</td>
</tr>
<tr>
<td>Cooling System:</td>
<td>N</td>
<td>Dew Point:</td>
<td>55°F</td>
</tr>
</tbody>
</table>

### Building Component

<table>
<thead>
<tr>
<th>Walls</th>
<th>Effects</th>
<th>Sources</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>North</td>
<td>PW</td>
<td>WC</td>
<td>wallpaper in poor condition</td>
</tr>
<tr>
<td>East</td>
<td>PW</td>
<td>EW, WC</td>
<td>wallpaper in poor condition</td>
</tr>
<tr>
<td>South</td>
<td>PW, WD</td>
<td>EW, WC</td>
<td>wallpaper in worst condition</td>
</tr>
<tr>
<td>West</td>
<td>PW</td>
<td>WC</td>
<td>wallpaper in poor condition</td>
</tr>
<tr>
<td>Ceiling</td>
<td>PW, PP, WD</td>
<td>CC</td>
<td>south part of ceiling in worst condition, paint peeling @ cornices</td>
</tr>
<tr>
<td>Doors</td>
<td>PP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frames</td>
<td>PP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Windows</td>
<td>PP</td>
<td>EW</td>
<td>Large cracks where window frames meet plaster walls</td>
</tr>
<tr>
<td>Frames</td>
<td>PP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Floors</td>
<td>Fl</td>
<td></td>
<td>OK</td>
</tr>
</tbody>
</table>

### Other notes:
Possible water damage at the cornice on the south wall above west window.

### Key:

**Effects of Air & Moisture Intrusion:**
Ef = Efflorescence, Mo = Mold, Mi = Mildew, ML = Mortar loss, PL = plaster loss, PP = Peeling paint, PW = Peeling wallpaper, Ro = rot, RD = rising damp, WD = water damage

**Sources of Infiltration:**
ED = exterior door, EW = exterior window, CC = plaster ceiling cracks, WC = plaster wall cracks, Fl = holes/cracks in floor
Figure 306.1: Wallpaper peeling off the ceiling, looking southwest.

Figure 306.2: Possible water damage at the cornice above the west window on the south wall.
### Moisture Intrusion & Air Infiltration
#### Interior Inspection

<table>
<thead>
<tr>
<th>Floor #:</th>
<th>3</th>
<th>Date:</th>
<th>10/14/2011</th>
<th>Room #:</th>
<th>307</th>
<th>Time:</th>
<th>10:30 AM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room Name:</td>
<td>Back stair hall</td>
<td>Temp. (Avg, Max, Min):</td>
<td>69°F, 78°F, 60°F</td>
<td>Heating System:</td>
<td>Y (Forced-air)</td>
<td>RH (Avg, Max, Min):</td>
<td>68%, 100%, 30%</td>
</tr>
<tr>
<td>Cooling System:</td>
<td>N</td>
<td>Dew Point:</td>
<td>55°F</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Building Component</th>
<th>Effects</th>
<th>Sources</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walls</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North</td>
<td>PP</td>
<td>EW, WC</td>
<td></td>
</tr>
<tr>
<td>East</td>
<td>PP</td>
<td>WC</td>
<td></td>
</tr>
<tr>
<td>South</td>
<td>PP, PL</td>
<td>WC</td>
<td>plaster damage above door</td>
</tr>
<tr>
<td>West</td>
<td>PP</td>
<td>EW, WC</td>
<td></td>
</tr>
<tr>
<td>Ceiling</td>
<td>PP, PL</td>
<td>CC</td>
<td>plaster loss near framed out hole to attic &amp; near south wall</td>
</tr>
<tr>
<td>Doors</td>
<td>PP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frames</td>
<td>PP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Windows</td>
<td>PP</td>
<td>EW</td>
<td></td>
</tr>
<tr>
<td>Frames</td>
<td>PP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Floors</td>
<td>Fl</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Other notes:**
Ductwork runs down from attic space above East Wing through the toilet room at south end of hall to supply heated air to 2nd Floor Dining Room.

**Key:**

**Effects of Air & Moisture Intrusion:**
- Ef = Efflorescence, Mo = Mold, Mi = Mildew, ML = Mortar loss, PL = Plaster loss, PP = Peeling paint, PW = Peeling wallpaper, Ro = Rot, RD = Rising damp, WD = Water damage

**Sources of Infiltration:**
- ED = Exterior door, EW = Exterior window, CC = Plaster ceiling cracks, WC = Plaster wall cracks, FI = Holes/cracks in floor
Figure 307.1: Plaster loss near framed out hole to attic near north door on east wall.

Figure 307.2: View of south wall showing hole in plaster ceiling and damaged plaster above door.
**Moisture Intrusion & Air Infiltration**

**Interior Inspection**

<table>
<thead>
<tr>
<th>Floor #</th>
<th>3</th>
<th>Date:</th>
<th>10/14/2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room #</td>
<td>308</td>
<td>Time:</td>
<td>10:30 AM</td>
</tr>
<tr>
<td>Room Name</td>
<td>Bath &amp; Linens</td>
<td>Temp. (Avg, Max, Min):</td>
<td>69°F, 78°F, 60°F</td>
</tr>
<tr>
<td>Heating System</td>
<td>Y (Forced-air)</td>
<td>RH (Avg, Max, Min):</td>
<td>68%, 100%, 30%</td>
</tr>
<tr>
<td>Cooling System</td>
<td>N</td>
<td>Dew Point:</td>
<td>55°F</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Building Component</th>
<th>Effects</th>
<th>Sources</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walls</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North</td>
<td>PW, WD</td>
<td>EW, WC</td>
<td>water damage @ NE corner of cornice</td>
</tr>
<tr>
<td>East</td>
<td>PW, WD</td>
<td>WC</td>
<td>water damage where chimney meets cornice</td>
</tr>
<tr>
<td>South</td>
<td>PW, PL</td>
<td>WC</td>
<td>water damage @ SW corner</td>
</tr>
<tr>
<td>West</td>
<td>PW</td>
<td>WC</td>
<td>water damage @ SW corner</td>
</tr>
<tr>
<td>Ceiling</td>
<td>PP, PL</td>
<td>CC</td>
<td>supported by wood 2x4 members, areas of plaster loss, water stains</td>
</tr>
<tr>
<td>Doors</td>
<td>PP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frames</td>
<td>PP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Windows</td>
<td>PP</td>
<td>EW</td>
<td></td>
</tr>
<tr>
<td>Frames</td>
<td>PP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Floors</td>
<td>Fl</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Other notes:**

The plaster ceiling is currently being supported by what appears to be 2x4 wood members. Areas of plaster loss and water stains on the ceiling.

**Key:**

**Effects of Air & Moisture Intrusion:**

Ef = Efflorescence, Mo = Mold, Mi = Mildew, ML = Mortar loss, PL = plaster loss, PP = Peeling paint, PW = Peeling wallpaper, Ro = rot, RD = rising damp, WD = water damage

**Sources of Infiltration:**

ED = exterior door, EW = exterior window, CC = plaster ceiling cracks, WC = plaster wall cracks, Fl = holes/cracks in floor
Figure 308.1: Water damage at cornice in northeast corner of the room.

Figure 308.2: Plaster loss and water stains above door on south wall.
**Moisture Intrusion & Air Infiltration**

**Interior Inspection**

<table>
<thead>
<tr>
<th>Floor #:</th>
<th>3</th>
<th>Date:</th>
<th>10/14/2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room #:</td>
<td>309</td>
<td>Time:</td>
<td>10:30 AM</td>
</tr>
<tr>
<td>Room Name:</td>
<td>Servant Quarters</td>
<td>Temp. (Avg, Max, Min):</td>
<td>69°F, 78°F, 60°F</td>
</tr>
<tr>
<td>Heating System:</td>
<td>Y (Forced-air)</td>
<td>RH (Avg, Max, Min):</td>
<td>68%, 100%, 30%</td>
</tr>
<tr>
<td>Cooling System:</td>
<td>N</td>
<td>Dew Point:</td>
<td>55°F</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Building Component</th>
<th>Effects</th>
<th>Sources</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walls</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North</td>
<td>PP</td>
<td>WC</td>
<td>paint peeling at NW corner</td>
</tr>
<tr>
<td>East</td>
<td>WD</td>
<td>WC</td>
<td>water damage on cornice @ chimney</td>
</tr>
<tr>
<td>South</td>
<td>PP</td>
<td>EW, WC</td>
<td></td>
</tr>
<tr>
<td>West</td>
<td>PP</td>
<td>WC</td>
<td>paint peeling at NW corner</td>
</tr>
<tr>
<td>Ceiling</td>
<td>PP, PL, WD</td>
<td>CC</td>
<td>water damage on cornice @ NE corner and NW corner</td>
</tr>
<tr>
<td>Doors</td>
<td>PP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frames</td>
<td>PP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Windows</td>
<td>PP</td>
<td>EW</td>
<td></td>
</tr>
<tr>
<td>Frames</td>
<td>PP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Floors</td>
<td></td>
<td>Fl</td>
<td></td>
</tr>
</tbody>
</table>

**Other notes:**
Large hole in plaster ceiling with adjacent peeling paint. Paint on walls is in moderate condition.

**Key:**

**Effects of Air & Moisture Intrusion:**

Ef = Efflorescence, Mo = Mold, Mi = Mildew, ML = Mortar loss, PL = plaster loss, PP = Peeling paint, PW = Peeling wallpaper, Ro = rot, RD = rising damp, WD = water damage

**Sources of Infiltration:**

ED = exterior door, EW = exterior window, CC = plaster ceiling cracks, WC = plaster wall cracks, Fl = holes/cracks in floor
Figure 309.1: Large hole in plaster ceiling with adjacent peeling paint, looking north.

Figure 309.2: Water damage near the cornice above the firebox on the east wall.
Examples of Historic Photograph Comparision


Figure B.6: Same wall in the Withdrawing Room in Fall 2011. Photograph by author.

Figure B.8: West wall of the Withdrawing Room in Fall 2011. Photograph by author.

Figure B.10: Ceiling medallion of the main stair hall in Fall 2011. Photograph by author.

Figure B.12: Back stairs on the north elevation in January 2012. Exterior coatings were restored in the mid-2000s. Photograph by author.
**Mechanical System Inspection**

<table>
<thead>
<tr>
<th>Equipment / System:</th>
<th>Forced-air, fan coil unit, heat pump &amp; make-up air</th>
<th>Date: 11/17/2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor #:</td>
<td>Ground</td>
<td>Time: 2:30 PM</td>
</tr>
<tr>
<td>Room Name:</td>
<td>Art Gallery Basement / Cistern</td>
<td>Temp. (Avg, Max, Min): 65°F, 77°F, 53°F</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RH (Avg, Max, Min): 75%, 94%, 47%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dew Point: 59°F</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Manuf.</th>
<th>Model #</th>
<th>Serial #</th>
<th>Date of Mfg. / Install</th>
<th>Visual Inspection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fan Coil Unit</td>
<td>Carrier</td>
<td>FC4CNF042</td>
<td>4303A70359</td>
<td>2003 / 2004</td>
<td>Capacitor and fan motor replaced in June 2009; Bolts on FCU rusted; corrosion on copper piping near condensate line, maintenance records on file, equipment operating properly at this time; filters do not fit properly</td>
</tr>
<tr>
<td>Split DX System Heat Pump</td>
<td>Carrier</td>
<td>38BYC036350</td>
<td>4103E09161</td>
<td>2003 / 2004</td>
<td>Located outside in alley between Gallery &amp; Stable; fan motor and capacitor replaced in April 2009; maintenance records on file, equipment operating properly at this time</td>
</tr>
<tr>
<td>Indirect Gas-Fired Make-Up Air Furnace</td>
<td>Greenheck</td>
<td>IGX-108-H12-HZ</td>
<td>03L09943</td>
<td>2003 / 2004</td>
<td>Copper tubing from FCU to condenser unit is corroded, possible leak from condensate line causing issue; maintenance records on file, equipment operating properly</td>
</tr>
<tr>
<td>Make-up Air Unit (Positive Pressure)</td>
<td>Ultra-Aire</td>
<td>UA-150H</td>
<td>B0648934</td>
<td>2006</td>
<td>Ultra-Aire unit replaced original Drykor unit in 2006, Quarterly maintenance reports on file, equipment operating properly at this time</td>
</tr>
<tr>
<td>Reheat Coil</td>
<td>Heatrix</td>
<td>M1-1414</td>
<td>n/a</td>
<td>2003 / 2004</td>
<td>Quarterly maintenance reports on file, equipment operating properly</td>
</tr>
<tr>
<td>Motorized Damper</td>
<td>Famco</td>
<td>ADC W/24 Volt</td>
<td>n/a</td>
<td>2003 / 2004</td>
<td>Quarterly maintenance reports on file, equipment operating properly</td>
</tr>
</tbody>
</table>
### Tear in Insulation
- **Ductwork:** n/a
- **Diffusers & Grilles:** n/a

<table>
<thead>
<tr>
<th></th>
<th>n/a</th>
<th>n/a</th>
<th>n/a</th>
<th>2003 / 2004</th>
<th>Tears in insulation need to be repaired</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Diffusers &amp; Grilles</strong></td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>2003 / 2004</td>
<td>Good condition</td>
</tr>
</tbody>
</table>

**Other notes:**
- Do not store items on top of equipment.
- Exposed control wiring to be covered.
- Insulation on bottom of Art Gallery floor system (basement ceiling) in good condition.
- Small tears in insulation on round ducts need repair.
- Condensation on FCU and ductwork in summer, not present today.
- No condensate present in drain pan.
- Three (3) separate controls for the Art Gallery system: one (1) Carrier thermostat for the FCU set at 68°F, one (1) Honeywell humidity control for FCU set at 53%, one (1) controller for the Ultra-Aire make-up air unit.
Figure AG.1: Carrier Fan coil unit (FCU) located under the Art Gallery, elevated off ground per code requirements.

Figure AG.2: Bolts on fan coil unit rusted.
Figure AG.3: Ultra-Aire dehumidifier located on the north wall of the Art Gallery, elevated per code requirements.

Figure AG.4: Heatrix reheat coil installed on supply ductwork from FCU.

Figure AG.5: Exposed control wiring.

Figure AG.6: Tears in duct insulation.
Figure AG.7: Corrosion on copper piping under condensate line.

Figure AG.8: Possible leak from condensate line causing corrosion of copper.

Figure AG.9: Gas-fired furnace for the forced-air heating system located under the Art Gallery.

Figure AG.10: Improperly sized air filters in the fan coil unit.
## Mechanical System Inspection

**Date:** 11/17/2011  
**Time:** 2:30 PM  
**Temp. (Avg, Max, Min):** 65°F, 77°F, 53°F  
**RH (Avg, Max, Min):** 75%, 94%, 47%  
**Dew Point:** 59°F

<table>
<thead>
<tr>
<th>System Component</th>
<th>Manuf.</th>
<th>Model #</th>
<th>Serial #</th>
<th>Date of Mfg. / Install</th>
<th>Visual Inspection</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-way Multi-poise Induced - Combustion Gas Furnace</td>
<td>Carrier</td>
<td>58STA070---101112</td>
<td>4203A28856</td>
<td>2003 / 2004</td>
<td>Quarterly maintenance reports on file, equipment operating properly at this time</td>
</tr>
<tr>
<td>Indirect Gas-Fired Make-Up Air Furnace</td>
<td>Greenheck</td>
<td>IGX-109-H12-HZ</td>
<td>03L09942</td>
<td>2003 / 2004</td>
<td>Recently replaced in 2009, quarterly maintenance reports on file, equipment operating properly at this time</td>
</tr>
<tr>
<td>Gas / Electric Packaged System</td>
<td>Trane</td>
<td>4YCX3030A1075AA</td>
<td>9055H959H</td>
<td>Jan. 2009 / May 2010</td>
<td>Entire unit replaced in 2009, quarterly maintenance reports on file, equipment operating properly at this time</td>
</tr>
<tr>
<td>Ductwork</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>2003</td>
<td>Sheetmetal ductwork is in good condition; round duct insulation in attic needs one tear to be fixed</td>
</tr>
<tr>
<td>Diffusers &amp; Grilles</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>2003</td>
<td>Good condition</td>
</tr>
</tbody>
</table>

**Other notes:**

There were a couple discrepancies between the actual installation of the forced-air heating system and the construction documents. Instead of air being delivered to the 1st floor Library, it is delivered to the Back Stair Hall via the water closet chase. Also, only one thermostat for heating system could be located on the first floor (in the Library).
Figure MH.1: Greenheck furnace located under the first floor piazza, south of the East Wing addition.

Figure MH.2: Trane packaged heat pump, sits west of the Greenheck furnace under the piazza.
Figure MH.3: Carrier furnace located in the attic of the main house, looking east.

Figure MH.4: Round ductwork in the attic from the Carrier furnace, looking east. Tear in insulation needs to be repaired.
Appendix C – Interior Environmental Monitoring Data

During the Aiken-Rhett House study, several thousand interior air property measurements were recorded from each HOBO data logger. Because of the large amount of data collected, a representative sample set was selected for inclusion in this Appendix. For each HOBO data logger, one line graph is presented showing all of the measurements collected during the study. After this graph, examples are shown of days when there was an occurrence where the temperature (DB) or relative humidity levels were out of the Class “C” level of control. On these graphs, the temperature (DB) and dew point temperature (DP) are plotted as lines and the relative humidity percentage is plotted as bar charts to help make the graphs more readable.
Figure C.1: Results from monitoring the interior air properties in the first floor West Parlor. Graph by author.
Figure C. 2: On July 27, 2011, the relative humidity levels in the first floor West Parlor exceeded the Class “C” upper limit of 75% RH, reaching as high as 83.5% RH at 12:00 PM. Graph by author.

Figure C.3: On January 3, 2012, the relative humidity levels in the first floor West Parlor dropped below the Class “C” lower limit of 25% RH, reaching 23.4% RH at 2:00 PM. Graph by author.
Figure C.4: Results from monitoring the interior air properties in the first floor dining room in the East Wing. Graph by author.
Figure C.5: On October 31, 2011, the temperature fell below the Class “C” lower limit of 59°F, falling to 58.04°F at 9:00 AM. Graph by author.

Figure C.6: On January 26, 2012, the relative humidity levels in the first floor Dining Room exceeded the Class “C” upper limit of 75% RH, reaching as high as 80.8% RH at 11:00 AM. Graph by author.
Figure C.7: Results from monitoring the interior air properties in the second floor Southwest Bedroom. Graph by author.
Figure C.8: On January 3, 2012, the temperature and relative humidity levels in the second floor Southwest Bedroom fell below the lower limits of the Class “C” level of control, 59°F and 25% RH, respectively. At 10:00 AM, the temperature fell to 57.35°F and the humidity fell to 23.6% RH.
Figure C.9: Results from monitoring the interior air properties in the second floor Withdrawing Room in the East Wing. Graph by author.
Figure C.10: On November 15, 2011, the relative humidity in the second floor Withdrawing Room exceeded the Class “C” upper limit of 75% RH, reaching as high as 82.0% RH at 3:00 PM. Graph by author.

Figure C.11: On December 27, 2011, the relative humidity in the second floor Withdrawing Room exceeded the Class “C” upper limit of 75% RH, reaching as high as 89.2% RH at 12:00 PM. Graph by author.
Figure C.12: Results from monitoring the interior air properties in the third floor Southwest Bedroom. Graph by author.
Figure C. 13: On November 11, 2011, the temperature in the third floor Southwest Bedroom exceeded the Class “C” upper limit of 86°F, reaching as high as 96.26°F at 4:00 PM. This spike in temperature is attributed to the data logger being located under the supply diffuser for the forced-air heating system. On this same date, the relative humidity level fell below the Class “C” level of control, reaching as low as 23.6% RH at 3:00 PM. Graph by author.
Figure C.14: Results from monitoring the interior air properties in the third floor North Room in the East Wing.

Aiken-Rhett House Air Properties:
3rd Floor East Wing North Room 10/27/11 to 2/3/12

Graph by author.
Figure C.15: On December 27, 2011, the relative humidity in the third floor East Wing North Room exceeded the Class “C” upper limit of 75% RH, reaching as high as 80.7% RH at 12:00 PM. Graph by author.

Figure C.16: On January 3, 2012, the relative humidity in the third floor East Wing North Room fell below the Class “C” lower limit of 25% RH, falling as low as 23.5% RH at 11:00 AM. The temperature also fell to 58.73°F at 3:00 AM. Graph by author.
The four case study sites are presented in the following order:

1. Drayton Hall
2. Joseph Manigault House
3. Heyward-Washington House
4. Nathaniel Russell House
1. **House Museum:**
   a. **Name:** Drayton Hall
   b. **Address:**
   c. **Year built:** 1738-1742
   d. **Size (square footage):** 10,920 square feet (includes basement)
   e. **Stories:** Three (3) stories with an attic, (two finished floors and a full basement level)
   f. **Materials:** Brick masonry, metal roof
   g. **Major restoration dates:** N/A
   h. **Visitors per year:** 55,000

2. **Interview Information:**
   a. **Date:** 12/13/2011
   b. **Time:** 10:30 am
   c. **Interviewee:**
      i. **Name:** Patricia Smith
      ii. **Title:** Preservation Technician
      iii. **Role & Responsibilities:** manages the historic architecture, maintains the preservation archives, electronic drafting (AutoCAD and GIS)
      iv. **Length of employment:** 2 years

3. **What types of mechanical system(s) are currently installed on site (chilled water, geothermal, etc.)?**
   No mechanical systems are installed, but there is limited electricity.

4. **Do you know why the decision was made to install this type of system?**
   - The electricity is used in the summer to run box fans if the temperature gets above 80°F. The house will be shut down to visitors when the heat index gets to 115°F. The windows are opened in the house when the temperature exceeds 75°. The fans are generally brought in when the temperature regularly exceeds 80°. When the heat index reaches 115° we close the house to the public to ensure their safety, but no further measures are taken.
5. Were there problems inside the house museum that needed to be corrected by a climate control system?

- I do not know what started the CAP (Conditions Assessment Program) grant monitoring, but perhaps the staff was curious about the effects of condensation and temperature and relative humidity fluctuations. I do not know if there was a major event that influenced the desire to monitor environmental conditions.

6. What are the priorities of the current mechanical systems installed? (i.e. visitor comfort or protecting the collections)

- The structure and the finishes have priority. There are no collections stored in the house because it is not climate controlled. Our collections are stored in a climate controlled facility onsite. There are a few architectural fragments stored on the second floor, in a room visitors do not access. If a new visitor center is built, then it is likely that some of the collections would be displayed in this new climate controlled facility.

7. Are there any current issues (that are public record) that have developed since the existing system has been installed?

- There are not current issues; but the climate monitoring system was a failure because it never functioned like it was designed to operate. The staff finally removed the wires from the system out of house last year (2010), most of the equipment was already gone by that time.

8. What types of control systems, if any, are installed?

- N/A

9. In your opinion, how effective are these systems at controlling the climate to the desired parameters within the house museum?

- Though limited, our passive systems do have a positive impact on visitor comfort. By opening and closing doors and windows and using light and shade to help heat or cool a room, we are able to extend the amount of
time that visitors can comfortably tour the house. That being said, because there are no mechanical systems installed in the house, the interior of the house feels very similar to the conditions outside. We can only do so much when the temperature goes to extremes of heat or cold.

10. Ventilation systems within the house museum?

- Use of box fans and operation of windows.

11. Weatherization methods installed?

- Window weather stripping or seals - No
- Door weather stripping or seals - No
- Insulation - No
- Radiant barrier – No
- UV film - On windows in the first floor withdrawing room, the stair hall, and the great halls on both floors

12. Natural or passive ventilation systems installed?

- Open/close windows (when & why): windows are opened in the morning at 9am and closed when the house is shut down for the day at 4:30pm
- Use of shutters (when & why): Shutters are used every day. Ideally, throughout each day, the shutters are opened or shut depending on how the sun moves. This does not happen because it is not feasible with just the guides going in and out of the house periodically for tours. The shutters are opened at 9am and closed at 4:30pm, just like the windows. The staff is also concerned about light in the house, so unless it is really cloudy, only enough shutters are opened so visitors can see.

13. Do you have a service / maintenance agreement with a mechanical contractor?

- N/A

14. Cost of operation and maintenance?

- N/A
15. Are there any general maintenance issues with the finishes in the house (wallpaper, paint, wood trim or paneling, plaster)?

- Sometimes condensation forms on the walls when there are rapid changes in temperature (from hot to cold or cold to hot). The mahogany wood panels in the stair hall look like they are leeching out water when these rapid changes in temperature occur. The other wood paneling in the house fairs OK with the interior conditions.
- The paint was stabilized with Aquazol a couple years ago by Kristine Thompson, which has slowed the peeling, but the paint is still fading (probably due to light and heat). The paint is in much better condition in rooms that the windows and shutters stayed closed.
- The walls in basement become damp with rapid changes in temperature, as well. It is especially bad during this time of year with repeated cycles of hot and cold, when the temperature is not consistent.

16. Are you aware of any mildew or mold problems within the house?

- I am not aware of any mold or mildew problems on the interior of the house; but on the exterior there are a lot of issues. Rising damp has caused a lot of biological growth, especially on the underside of the river front steps.

17. Are there any new mechanical system technologies that you have heard of that you are interested in using at your house museum?

- No, because of the interpretation of house museum. The house is a good teaching tool for passive methods of heating and cooling. I don’t know of any seminars Drayton Hall has had on this topic, but other museums have called and asked us questions.

18. Is there anything you would change about the current mechanical system installed?

- The current electrical system is not adequate for what it is being used for; the riser is located on the north side of the house, so it’s easy to plug in fans on that side of the building. On the south side of the house
we have to run extension cords for the fans. Also, the receptacles are not grounded properly, and they are located on the exterior of the south side of the house, so when it’s raining, no fans can be used in that part of the house.

19. Pros & Cons of existing systems? Other thoughts?

- I like the fact that Drayton Hall is not climate controlled; it makes the house more authentic and I think it’s better for the house. Visitors don’t understand that one size does not fit all, so to speak, when it comes to climatizing historic house museums. Some visitors have been to many climate controlled museums and think that means it is best for the structure, but they do not realize that the finishes in house may not be original, whereas at Drayton Hall they are. If we installed a mechanical system at Drayton Hall there could be devastating effects to the structure and its finishes.

20. Other case study references you can recommend?

- In the Robert Mills House in Columbia, SC, ductwork was run through chimneys. In the winter time it is very hot inside the building (it felt like 90 degrees), which affected the wood floors and plaster. I worked there in 2007-2008, so changes may have been made to the system since then, but at the time it was a big problem.

21. Has a blower door test occurred to determine air leakage of the building? Has a duct blaster test occurred to determine air leakage of the ductwork system?

- No; N/A

22. Contact Information for follow-up:

- Information on file
**Historic House Museum HVAC Systems Site Visit Images**

**Case Studies for the Aiken-Rhett House Climate Control System Study**

**Thesis By:** Mariah Schwartz – Clemson University / College of Charleston

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Drayton Hall

Site Visit Images

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Case Studies for the Aiken-Rhett House Climate Control System Study

Thesis By: Mariah Schwartz – Clemson University / College of Charleston

Figure 8: Drayton Hall, 1st Floor, Great Hall (Room 101), northwest wall. Photo by author.

Figure 9: Drayton Hall, 1st Floor, Great Hall (101), northwest wall. Photo by author.
Historic House Museum HVAC Systems Site Visit Images

Case Studies for the Aiken-Rhett House Climate Control System Study

Thesis By: Mariah Schwartz – Clemson University / College of Charleston

Figure 10: Close-up view of deteriorated paint in the Great Hall (101). Photo by author.

Figure 11: Drayton Hall, 1st Floor, Ionic Room (102), northeast wall. Photo by author.
Historic House Museum HVAC Systems Site Visit Images

Case Studies for the Aiken-Rhett House Climate Control System Study

Thesis By: Mariah Schwartz – Clemson University / College of Charleston

Figure 12: Drayton Hall, 1st Floor, Ionic Room (102), southwest wall. Photo by author.

Figure 13: Drayton Hall, 2nd Floor, East Chamber (202), northeast wall. Interior shutters are kept closed in this room unless work is taking place. The paint is in much better condition in this room than in the Ionic Room directly below it. Photo by author.

Drayton Hall
Site Visit Images
Figure 14: 2nd Floor, East Chamber (202), northwest wall panels with paint in good condition. Photo by author.

Figure 15: Drayton Hall, 2nd Floor, Great Drawing Room (201), northwest wall. Photo by author.

Drayton Hall
Site Visit Images
Figure 16: Drayton Hall, Stairhall (109), near top of 2\textsuperscript{nd} Floor landing, view looking southwest. This is the mahogany wood paneling that sometimes appears to be leeching out water when rapid changes in temperature occur. Photo by author.

Figure 17: Close-up view of a typical hole that was drilled for the climate monitoring system wires. All of the system wires were removed from the building in 2010. Photo by author.
Historic House Museum HVAC Systems Site Visit Images

Case Studies for the Aiken-Rhett House Climate Control System Study

Thesis By: Mariah Schwartz – Clemson University / College of Charleston

Figure 18: Drayton Hall, Basement Level, Hall (001). Efflorescence is causing brick failure and stucco coating to spall. Photo by author.

Figure 19: Drayton Hall, Basement Level, Hall (001), southwest wall. Stains under the concrete repairs are from water intrusion caused by the settlement of the portico. Photo by author.
1. **House Museum:**
   a. **Name:** Joseph Manigault House
   b. **Address:** 350 Meeting Street, Charleston, SC, 29403
   c. **Year built:** 1803
   d. **Size (square footage):** 9,044 square feet (includes basement, not attic)
   e. **Stories:** Three (3) levels plus a full basement and an attic
   f. **Materials (walls & roof):** Brick with slate roof
   g. **Major restoration dates:** 1989 repainted after Hurricane Hugo
   h. **Visitors per year:** 31,000

2. **Interview Information:**
   a. **Date:** 12/14/2011
   b. **Time:** 10:45am
   c. **Interviewee:**
      i. **Name:** Melanie Wilson
      ii. **Title:** Chief Historic House Interpreter
      iii. **Role & Responsibilities:** Gives house tours, responsible for scheduling and maintaining the house
      iv. **Length of employment:** Four (4) years as of January 2012

3. **Weatherization methods installed?**
   a. **Window weather stripping / seals:** No
   b. **Door weather stripping/seals:** No
   c. **Insulation:** No
   d. **Radiant barrier:** No
   e. **UV film:** on each pane of glass on the 1st and 2nd floors; not on 3rd because shutters are not opened unless people are working up there and there is no furniture on the 3rd floor

4. **Natural or passive ventilation systems installed?**
   a. **Open/close windows (when & why):** During the summer, windows are opened in the morning and closed at night; if the weather is mild in the winter time, the staff will open a window on the 2nd floor to show how a jib door works, not meant for ventilation though; the house is opened around 9:30am and closed around 4:30pm each day.
   b. **Use of shutters (when & why):** Interior shutters are opened and closed everyday depending on sun location, regardless of weather. These are used for...
Historic House Museum HVAC Systems Questionnaire

Case Studies for the Aiken-Rhett House Climate Control System Study

Thesis By: Mariah Schwartz – Clemson University / College of Charleston

light, but the temperature does change once they are opened. Inside
temperature will get colder in winter time and warmer in summer once the
shutters are opened.

5. What types of mechanical system(s) are currently installed on site (chilled water,
geothermal, etc.)? During walk-thru look for manufacturer, model #s, serial #s, and
installation date when examining equipment.

- The boiler, fan coil unit (FCU) and associated ductwork are located in the
  basement. The condenser unit is located outside, on the east exterior basement
  wall. All of the equipment was installed during late 1990s. We are going to
  replace the condenser unit soon because the coils are deteriorating. Most likely
  an irrigation sprinkler was hitting the unit and caused it to rust.
- Heat is only provided on the 1st floor of the main house and the Dining Room is
  the only room conditioned by the FCU in the basement. The Dining Room is
  where the tour introductions occur, so the visitors stand in this room for about
  10 minutes at the start of each tour. Visitors are only allowed on the 1st and 2nd
  floors. Even though there may be warm days in the winter time, the air
  conditioning system is only used in the summer.
- The FCU is probably fairly new because it can be upgraded to the “new gas”
system when the condenser unit will be replaced soon. The FCU will be
  increased from a 1.5 ton unit to a 2 ton at that time. There is a ductless system
  in staff lounge that provides air conditioning, but no heat.

6. What are the operating times for the mechanical systems? Do they run constantly or
   only during business hours?

- The HVAC system starts at 8:00am and shuts off at 5:00pm everyday

7. Were there problems inside the house museum that needed a climate control system
to remedy? (i.e. condensation, mildew, mold, failure of finishes, etc.)

- Not that I am aware of.
8. Do you know why the decision was made to install this type of system?

- Visitor comfort and staff comfort were the concern when these systems were installed. The ductless system in the staff lounge was added a lot later, might have had a window unit in the lounge at one time.

9. What are the priorities of the current mechanical systems installed? (i.e. visitor comfort or protecting the collections)

- Visitor comfort

10. Are there any current issues (that are public record) that have developed since the existing system has been installed?

- The heating system dries out the furniture, so we have to put portable humidifiers in the Dining Room and Library / Office during the wintertime. We also cover the floor vents in Library / Office and Dining Room with Plexiglas while we run humidifiers. In the summertime, the biggest problem with mildew occurs in the Dining Room because the windows are not open and a lot of condensation forms around windows and on the shutters. No mildew has ever been found on the furniture.

11. Are there any general maintenance issues with the finishes in the house (wallpaper, paint, wood trim or paneling, plaster)?

- The paint is fifteen (15) years old, so it is chipping due to age, not any known moisture issues. There is also the typical expansion and contraction of building components in a historic house.

12. What types of control systems, if any, are installed?

- The thermostat for the Dining Room is located in the Staff Lounge, right under the vent for the ductless unit, by the door that joins both rooms. We are talking about getting a remote thermostat in the Dining Room because the thermostat in the Staff Lounge never reads the right temperature in the Dining Room due to its location. The thermostat for the Dining Room was installed before the Staff Lounge unit was installed.
Historic House Museum HVAC Systems Questionnaire

Case Studies for the Aiken-Rhett House Climate Control System Study

Thesis By: Mariah Schwartz – Clemson University / College of Charleston

- We have a hygrothermograph in the Dining Room to monitor the temperature and relative humidity. It is an older version that draws lines on graph paper.

13. In your opinion, how effective are these systems at controlling the indoor climate to the desired parameters within the house museum?

- I do not think there are any problems with the systems; they do their best for this house museum. However, the floor vents were installed along exterior walls near the windows and the heat seems to leak through the windows in the winter.

*Note: There is no protocol for shutting down the house in the summertime due to heat. A cooler of ice water is on porch every day for visitors.

14. Do you have a service / maintenance agreement with a mechanical contractor?

a. If so, do you think the maintenance agreement is beneficial to the house? Is the equipment operating as designed?

- We do not have a maintenance contract; if there is an issue we call Morelli Heating & Air Conditioning. They are the company that is going to put in the new condenser unit.

15. Do you know if a blower door test has been conducted on the house to test air leakage? Has a duct blaster test been conducted to test ductwork leakage?

- No

16. Are there any new mechanical system technologies that you have heard of that you are interested in using at your house museum?

- Only the remote thermostat in the Dining Room

17. Is there anything you would change about the current mechanical system installed?

- Adding the remote thermostat and upgrading to the 2 ton unit. It would also be nice to have a mechanism to humidify the rooms in the winter so we do not have to use the portable humidifiers in the rooms.
18. Last thoughts -- Pros & Cons of the existing mechanical systems?

- It is better for the structure and furniture to breathe; you should open up the house to let it breathe. This building has been operating in this manner for over 200 years. It is difficult to explain to the guests why we do not air condition the entire house. If you do condition a historic building, be prepared to fix the plaster work a lot for the first couple of years until the house adjusts to the new interior climate.

19. Are there any other case study references you can recommend?

- Thomas Jefferson’s Monticello (hidden ductwork in chimney flues), the Edmonston-Alston House, Middleton Plantation, and Magnolia Plantation (has a raised basement, smells of mildew)

20. Contact Information for follow-up:

- Contact information on file
Historic House Museum HVAC Systems Site Visit Images

Case Studies for the Aiken-Rhett House Climate Control System Study

Thesis By: Mariah Schwartz – Clemson University / College of Charleston

Figure 1: The Joseph Manigault House, south elevation. Photo by author.

Figure 2: Manigault House, Basement Level, boiler equipment, looking south. Photo by author.
Historic House Museum HVAC Systems Site Visit Images

Case Studies for the Aiken-Rhett House Climate Control System Study

Thesis By: Mariah Schwartz – Clemson University / College of Charleston

Figure 3: Manigault House, Basement Level, fan coil unit, looking west. Photo by author.

Figure 4: Manigault House, 1st Floor, Hall, looking south. Floor grille under main stairs provides heat during the cooler periods. Photo by author.
Figure 5: Manigault House, 1st Floor, Dining Room, looking east. Photo by author.

Figure 6: Manigault House, 1st Floor, Dining Room, floor grille below window on south wall. Photo by author.
Figure 7: Manigault House, 1st Floor, Dining Room, floor supply grille covered by Plexiglas on east wall. This is done in the winter to prevent heat from entering the room and drying out the furniture. Photo by author.

Figure 8: Manigault House, 1st Floor, Dining Room, hygrothermograph under the dining table. This instrument is used to record temperature and humidity. Photo by author.
Figure 9: Manigault House, 1st Floor, Staff Lounge, wall mounted split system air condition unit on east wall. Outdoor unit located at east exterior elevation next to the condenser unit for the fan coil unit in the basement. Photo by author.

Figure 10: The thermostat for the Dining Room is located inside the Staff Lounge near the door that joins the two spaces. The location of this thermostat is near the supply for the air conditioner unit in the Staff Lounge, which affects the thermostat readings. Photo by author.
Figure 11: Manigault House, 1st Floor, Library / Office, looking southwest. A supply grille is located below the window on the south wall to the left of the chair. The bookcase in the foreground is one of the pieces of furniture adversely affected by the heating system in the winter. Photo by author.

Figure 12: 1st Floor, Library / Office, supply grille covered by Plexiglas in the northwest corner of the room. Photo by author.
Figure 13: Manigault House, exterior, east elevation. Condenser units for the fan coil unit (rear) and the ductless split system (front) located outside on the east wall of the full basement. Photo by author.
1. **House Museum:**
   a. **Name:** Heyward-Washington House
   b. **Address:** 87 Church Street, Charleston, SC, 29403
   c. **Year built:** 1772
   d. **Size (square footage):** 6,776 square feet (includes basement, but not the attic or kitchen building; 7,499 square feet total including the kitchen building)
   e. **Stories:** 3 levels, plus a basement and attic
   f. **Materials (exterior walls & roof):** Brick, slate roof
   g. **Major restoration dates:** 1930s return to original floor plan & 1990s HVAC installation
   h. **Visitors per year:** 18,000

2. **Interview Information:**
   a. **Date:** 12/15/2011
   b. **Time:** 11:30am
   c. **Interviewee:**
      i. **Name:** Melanie Wilson
      ii. **Title:** Chief Historic House Interpreter
      iii. **Role & Responsibilities:** Gives house tours, responsible for scheduling and maintaining the house
      iv. **Length of employment:** Four (4) years as of January 2012

3. **Ventilation systems within the house museum?**
   a. **Use of outside air:** No outside air, except for mixing at AHUs

4. **Weatherization methods installed?**
   a. **Window weather stripping / seals:** Yes, we use interlocking metal weather strips (these windows are tighter than the Joseph Manigault House even though they are older)
   b. **Door weather seals:** Only on the front door, there is a door sweep and interlocking metal weather strips around front door
   c. **Insulation:** Blown insulation on the floor of attic (ceiling of 3rd floor) and batt insulation under the first floor in the basement (basement ceiling); no insulation in walls, just plaster and wood lath on solid brick, 3 courses deep (about 1.5 feet)
d. **Radiant barrier:** None

e. **UV film:** There is film on each individual glass window pane that was applied with Johnson & Johnson baby shampoo. The new film was installed on the 1st floor last year, and the 2nd floor was done 2 years ago. The window film does not harm the historic windows; for instance, the old film came off with ammonia.

5. **Natural or passive ventilation systems installed?**

   a. **Open/close windows (when & why):** No, because the interior is air-conditioned
   
   b. **Use of shutters (when & why):** All exterior shutters are kept open, except on the 3rd Floor, which are kept closed to keep out the light. We only close exterior shutters for hurricanes; one shutter on the east side of the 2nd floor is never opened because we want to keep light off of harpsichord (even though there is UV film on the window)

6. **What types of mechanical system(s) are currently installed on site (chilled water, geothermal, etc.)? During walk-thru look for manufacturer, model #s, serial #s, and installation date when examining equipment.**

   - Chilled water system [AHUs in basement and attic of main house, chiller (compressor and evaporator) and remote air-cooled condenser located on the 2nd Floor of the kitchen building]
   
   - Boiler system (runs on natural gas) located in hyphen between main house and kitchen building
   
   - We found an HVAC System Project Manual dated 1993, but we think the equipment was installed in 1995 (check model #s; photos on file of equipment model #s)

7. **What are the operating times for the mechanical systems? Do they run constantly or only during business hours?**

   - The HVAC system starts at 8:00am and shuts off at 5:00pm everyday

8. **Were there problems inside the house museum that needed to be addressed with a climate control system? (i.e. condensation, mildew, mold, failure of finishes, etc.)**
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- There was an existing HVAC system before this current system was put in; I am not sure what type of system the old one was, but the Project Manual called for the old system to be demolished during the project to install the new chilled water and boiler systems
- We can assume that the older HVAC system was not working correctly; perhaps it was just outdated and needed replacement
- People used to live on the 3rd floor, they acted as security/care givers, for this reason the Heyward-Washington House had mechanical systems before the Joseph Manigault House

9. Do you know why the decision was made to install this type of system?

- See above
- Also, probably because of the time period the Museum thought that a chilled water system would be best, maybe they didn’t know enough about other types of systems and technology at the time.

10. What are the priorities of the current mechanical systems installed? (i.e. visitor comfort or protecting the collections)

- Now the priority is mostly collections; 70% of furniture pieces in the house are Charleston originals dating to pre-1800, but all been refinished
- The building and visitor comfort were not the top priorities when installing this system

11. Are there any current issues (that are public record) that have developed since the existing system has been installed?

- I am not sure about new issues
- The plaster cracks seasonally, but is worse in summer time
- We also get condensation on the outside of the windows

12. Are there any general maintenance issues with the finishes in the house (wallpaper, paint, wood trim or paneling, plaster)?

- In the 2nd floor white bedroom, the paint bubbles because the plaster behind it is bubbling. We do not think it has anything to do with HVAC system because
there are records of this issue existing when the Heywards lived here in 1770s. There are rumors that a false wall may have been installed in that bedroom because of these moisture problems; though I have never seen it, only heard about it.

13. What types of control systems, if any, are installed?

- Control Management, Inc. (CMI) controls are installed on the AHUs. Unfortunately, CMI controls the HVAC system electronically from Columbia, SC. We have to call CMI to get the system turned on or off, or to make changes to the temperature set points
- Typical set points are 72°F and 50% RH (+/-)

14. In your opinion, how effective are these systems at controlling the indoor climate to the desired parameters within the house museum?

- These systems do a good job at keeping relative humidity levels down and the temperature at a steady rate.
- Now that the house is acclimated to the HVAC system, we are not having as many issues with the plaster cracking.
- If we do have an HVAC problem, it usually involves a larger piece of equipment (i.e. the boiler or condenser)
- On the 3rd floor of the Kitchen Building, there are big patches where the plaster has fallen off the ceiling and walls. I think this is due to the installation of the chiller and condenser in this building.
- The interior walls of 2nd floor of Kitchen Building had to be removed to install the large pieces of equipment.
- The boiler was having a problem not burning off the gas and we had bad smells coming from the boiler room. We had it serviced and now it is working ok, but SCE&G had to come shut off the gas service until the problem was fixed.
- I don’t think there are any problems with the AHUs in the basement.

15. Do you have a service / maintenance agreement with a mechanical contractor?  
   a. If so, do you think the maintenance agreement is beneficial to the house? Is the equipment operating as designed?
• We have a maintenance agreement with CMI, our controls company, but they are based out of Columbia, SC. If there is a problem, we have to call them to determine what the issue is. If it’s a controls issue, then they will send someone to the site to fix it; if it is not a controls issue, then we have to call Morelli Heating & Air Conditioning to fix the problem.

16. Do you know if a blower door test has been conducted on the house to test air leakage? Has a duct blaster test been conducted to test ductwork leakage?

• No, but I know we have a lot of air leaking from the house
• For instance, you can see light coming in from around the back door and the front door key hole. The floor boards are also a major area of air leakage.

17. Are there any new mechanical system technologies that you have heard of that you are interested in using at your house museum?

• No

18. Is there anything you would change about the current mechanical system installed?

• I would love to remove condenser unit because it does not seem like it is necessary. The condenser is very noisy, causes lots of vibrations, and takes away from the historic site.
• I would also like the air conditioning system to turn on and off as needed, instead of running constantly.
• The floor vents in the 1st floor front southeast room (South Reception Room) are the noisiest, but the rest of the house is not as noisy. This is because these floor vents are the closest to the AHU below in the basement.
• Floor vents are located in all rooms except on the 3rd floor where there are ceiling vents from AHU-3 in the attic. The 3rd floor stores some reproduction furniture and some original pieces, but mostly hurricane supplies.

19. Last thoughts -- Pros & Cons of the existing mechanical systems?

• After the initial 1st year, of the building acclimating to the system, there are definite Pros. The furniture collection is sound and stable, and the constant temperature and humidity levels have been very good for the house itself.
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- Cons would be the expenses of the system itself. Morelli costs at least $200 a visit, air filters are very expensive because they are odd sizes (2” thick) and have to be special ordered, the utility bills are astronomical ($4,000 was highest we’ve had, it included all utilities but most of it is HVAC system)
- Another Con would be that the system is constantly aging and replacement is inevitable

20. Are there any other case study references you can recommend?

- Magnolia Plantation
- Middleton Plantation
- Edmonston-Alston House

21. Contact Information for follow-up:

- E-mail and phone # on file


Figure 4: Heyward-Washington House, Kitchen Building, 2nd Floor, condenser unit for chilled water system. Photo by author.
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Figure 5: Heyward-Washington House, Kitchen Building, 2nd Floor, chiller (packaged compressor and evaporator) for chilled water system. Photo by author.

Figure 6: Heyward-Washington House, hyphen between the kitchen building and the main house. Boiler equipment is located in the hyphen. Photo by author.

Heyward-Washington House
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Figure 7: Heyward-Washington House, hyphen, boiler equipment and associated water piping. Photo by author.

Figure 8: Heyward-Washington House, rear west elevation, entrance into the basement level where the air handling units are located. Photo by author.
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Figure 9: Heyward-Washington House, Basement Level, AHU-1 looking north. Photo by author.

Figure 10: Heyward-Washington House, Basement Level, AHU-2 looking south. Humidifier (H-2) in foreground attached to wood post. Photo by author.

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Figure 11: Heyward-Washington House, Basement Level, behind AHU-1, looking west. The chilled water pump (foreground) and the condenser water expansion tank and air separator (background) sit on the same mechanical pad directly to the north of AHU-1. Photo by author.

Figure 12: Heyward-Washington House, Basement Level, looking southwest. The condenser water air separator (back) and expansion tank are located behind AHU-1. Photo by author.
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Figure 13: Heyward-Washington House, 1st Floor, South Reception Room, looking east. The air supply grilles are located on the floor in front of the windows. These grilles are very noisy because they are the closest to the AHUs in the basement below. Photo by author.

Figure 14: Close-up view an air supply floor grille in the South Reception Room. Photo by author.
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Figure 15: Heyward-Washington House, 1st Floor, South Reception Room, looking northwest. Ductwork runs through the closet in the northwest corner of the room. Photo by author.

Figure 16: Heyward-Washington House, 1st Floor, rear part of the central hall behind the stairs, looking north. Return air grille located in the floor in front of the entrance into the Staff Lounge. Photo by author.

Heyward-Washington House
Site Visit Images
Figure 17: Heyward-Washington House, 1st Floor, North Reception Room, looking east. The air supply grilles are located on the floor in front of the windows on the east wall. Photo by author.

Figure 18: Heyward-Washington House, 1st Floor, Dining Room, looking southwest. Air supply floor grilles installed in the floor in front of the windows on the west wall. Photo by author.
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Figure 19: Heyward-Washington House, Attic, looking west. AHU-3 supplies heating and cooling to the 3rd Floor of the house. Photo by author.

Figure 20: Chilled water and hot water supply and return piping for AHU-3, located in the northwest corner of the attic. Photo by author.

Heyward-Washington House
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Figure 21: Heyward-Washington House, Attic, looking northeast. Supply air ductwork for the 3rd Floor below. Photo by author.
1. **House Museum:**
   a. **Name:** Nathaniel Russell House
   b. **Address:** 51 Meeting Street, Charleston, SC, 29401
   c. **Year built:** 1808
   d. **Size (square footage):** 9,600 square feet
   e. **Stories:** Three stories over a raised basement, with attic
   f. **Materials (walls & roof):** Brick, slate roof
   g. **Major restoration dates:** 1990s
   h. **Visitors per year:** 50,000

2. **Interview Information:**
   a. **Date:** 12/30/11
   b. **Time:** 2:00pm
   c. **Interviewee:**
      i. **Name:** Brandy Culp
      ii. **Title:** Curator
      iii. **Role & Responsibilities:** Curator of house museums and collections,
      iv. **Length of employment:** 5 years as of August 2011

3. **Ventilation systems within the house museum?**
   a. **Use of outside air:** no

4. **Weatherization methods installed?**
   a. **Window weather stripping / seals:** Do not know
   b. **Door weather seals:** Yes, I’m not sure when they were installed.
   c. **Insulation:** only insulation on ductwork and chilled water and hot water piping.
   d. **Radiant barrier:** No
   e. **UV film:** Film was installed about 10 years ago in some of the rooms downstairs (various locations), but not on other floors to my knowledge or investigation. The condition of the objects does not reflect the use of window film or passive control of light. Bridget O’Brien (Museums Coordinator) and I are working towards installation of modern UV film with a lifetime warranty (up to 98%).

5. **Natural or passive ventilation systems installed?**
   a. **Open/close windows (when & why):** No
   b. **Use of shutters (when & why):** We use interior shutters for light control, not for ventilation. Shutters are opened when the museum opens in the morning and
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are closed at end of day. Documentation sources I have found show that in the Russell era, the shutters were used as a passive system to control light and heat. We are really trying to protect the objects, especially newly acquired objects. In theory, there are shutters in the house that can never be opened because of certain nearby objects. On the 2nd Floor there are two shutters that remain completely closed in the Withdrawing Room and two shutters in Oval Drawing Room. One window in 1st Floor Office remains closed to protect the globes. Also, the adjacent Entry Room can have the bottom shutters closed and top open, just as long as light is not streaming on the globes in the Office. In the Dining Room, the east shutters are closed in the morning and the west shutters are closed in the afternoon. The Back Parlor on the 1st Floor should always have one shutter closed.

6. What types of mechanical system(s) are currently installed on site (chilled water, geothermal, etc.)? During walk-thru look for manufacturer, model #s, serial #s, and installation date when examining equipment.

- Chilled water cooling and hot water heating system (over 20 years old)
- Equipment is located in the attic, basement and two outbuildings adjacent to rear of the house
- Ductwork runs through the closets from 1st to 3rd Floor and into the attic; there is some ductwork in ceiling of third floor as well
- Supply and Return Grilles are wall mounted and hidden over the door frames in the museum / tour spaces; in the working spaces (gift shop, ticket office, staff lounge, kitchen, etc.) the grilles are installed in more visible locations like the floor or ceiling

7. What are the operating times for the mechanical systems? Do they run constantly or only during business hours?

- The system runs continuously 24/7/365

8. Were there problems inside the house museum that needed to be addressed with a climate control system? (i.e. condensation, mildew, mold, failure of finishes, etc.)

- Inconsistency of temperature and humidity and their associated problems affecting the decorative and fine arts collections
9. Do you know why the decision was made to install this type of system?

- The system was installed over 20 years ago, so a chilled water system was most likely selected due to the technology available.

10. What are the priorities of the current mechanical systems installed? (i.e. visitor comfort or protecting the collections)

- The priorities of the current system are visitor comfort, the historic interior finishes, and protecting collections. The system does not always satisfy all three of these needs.

11. Are there any current issues (that are public record) that have developed since the existing system has been installed?

- Consistent mechanical issues that require repair work
- There is mildew and mold on the air supply grilles on the 2nd and 3rd floors
- Condensation forms on the windows; mostly on exterior, but on rare occasions it does occur on the inside of the windows.

12. Are there any general maintenance issues with the finishes in the house (wallpaper, paint, wood trim or paneling, plaster)?

- Most of the issues are not because of the system itself, and are caused mostly by human errors (i.e. bumping up against the walls and damaging the paint).

13. What types of control systems, if any, are installed?

- Siemens Direct Digital Control (DDC) Building Automation System (BAS)
- “The system has many capabilities for controlling, monitoring and verifying building indoor temperature conditions. Most of those features are not being utilized. The building is kept at indoor heating and cooling set points of between 68 Degrees F and 70 degrees F almost year round.” – Dennis Knight’s Energy Audit of the Nathaniel Russell House dated 9/12/2011
- Morelli Heating & Air Conditioning Company (service contractor) sets the controls. The museum staff has the ability to change the set points, but we prefer to leave it to Morelli.
14. In your opinion, how effective are these systems at controlling the indoor climate to the desired parameters within the house museum?

- The systems are marginally effective because of the fluctuations in temperature and the inability to control humidity. With our current system, we can only control temperature and try to influence the humidity levels. Also, there are five different HVAC zones in the house; often times it is cold in one area of the house and hot in another.

15. Do you have a service / maintenance agreement with a mechanical contractor?

- Morelli
a. If so, do you think the maintenance agreement is beneficial to the house? Is the equipment operating as designed?
  
  (Not answered)

16. Do you know if a blower door test has been conducted on the house to test air leakage? Has a duct blaster test been conducted to test ductwork leakage?

- The Sustainability Institute and Dennis Knight conducted a blower door test during the Energy Audit. I think for reasons of concern for the collections, we asked that they did not do the duct blaster test.

17. Are there any new mechanical system technologies that you have heard of that you are interested in using at your house museum?

- Personally, I am interested in a geothermal system that includes measures for controlling humidity.
- The Energy Audit completed by Dennis Knight proposed a different system. Knight is concerned with installation of a geothermal system at the Nathaniel Russell House and proposes to install a similar chilled water/hot water heating system with modifications for controls.

18. Is there anything you would change about the current mechanical system installed?
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- The equipment makes a lot of noise and we have had visitors and colleagues make comments. Fortunately, you can only hear the equipment when you are out in the yard.
- Also, the house is constructed in a way that creates a lot of echoes throughout. Sometimes I don’t know the point of origination for noises, but the current HVAC system piping creates a lot of noise inside the house. That being said, sound travels very well through this house, you can hear trucks on the street and even people walking down the sidewalk.

19. Last thoughts -- Pros & Cons of the existing mechanical systems?

- I would like to update the current HVAC system technology to be more energy efficient and create less of an environmental footprint.

20. Are there any other case study references you can recommend?

- I am very interested in other house museums that use geothermal systems such as Montpelier and Kenmore Plantation.

21. Contact Information for follow-up:

- Information on file
Figure 1: Nathaniel Russell House, 1st Floor Plan. *Source:* Glenn Keyes Architects, Nathaniel Russell House Measured Drawings, First Floor Plan, Sheet A-1, dated 3/12/1996.

Figure 3: Nathaniel Russell House, 3rd Floor Plan. Source: Glenn Keyes Architects, Nathaniel Russell House Measured Drawings, First Floor Plan, Sheet A-1, dated 3/12/1996.

Figure 4: Nathaniel Russell House, Attic Floor Plan. Source: Glenn Keyes Architects, Nathaniel Russell House Measured Drawings, First Floor Plan, Sheet A-2, dated 3/12/1996.
Figure 5: Nathaniel Russell House, front (east) elevation of the original main house, facing Meeting Street. Photo by author.

Figure 6: Nathaniel Russell House, south elevation or the original main house. The use of interior shutters to control sunlight is demonstrated in this view. Photo by author.
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Figure 7: Nathaniel Russell House, rear (west) elevation with the hyphen (middle) attached to the original kitchen building (far left), looking northeast. Photo by author.

Figure 8: Nathaniel Russell House, original brick kitchen building attached to the hyphen at right. Photo by author.
Figure 9: Nathaniel Russell House, south elevation of the rear service building (left) that houses the chiller and the boiler equipment. Photo by author.

Figure 10: Nathaniel Russell House, rear (west) elevation of the kitchen building and service sheds. The boiler is inside the smaller brick structure and the chiller is inside the wood shed in the foreground. Photo by author.
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Figure 11: The boiler located in the brick service shed. Photo by author.

Figure 12: The chiller located in the rear wood service shed. Photo by author.
Figure 13: The insulation on the chiller and associated piping in the chiller room is in poor condition. Photo by author.

Figure 14: Nathaniel Russell House, remote condenser unit at the rear south west corner of the service yard / parking lot. This piece of equipment is located adjacent to the garden that visitors tour. There have been complaints about noise from the visitors and staff members.
Figure 15: Nathaniel Russell House, Basement Level, AHU-1 that serves the 1st Floor of the original main house. This AHU is accessed via a small flight of stairs down to the basement underneath the back service stair. Photo by author.

Figure 16: Example of the brick foundations in the basement that have been cut for ductwork penetrations. Photo by author.
Figure 17: Nathaniel Russell House, 2nd Floor, Room 207A between Staff Office and Docent Waiting Room, ceiling grille with mildew. Photo by author.

Figure 18: Nathaniel Russell House, 1st Floor, Room 109 Gift Shop, air supply grille located in the floor near the visitor entrance. Photo by author.
Figure 19: Nathaniel Russell House, 2nd Floor, Room 203 Oval Room, use of interior shutters to control sunlight. Photo by author.

Figure 20: Nathaniel Russell House, 2nd Floor, Room 201 Drawing Room, southeast corner. Photo by author.
Figure 21: 2nd Floor, Room 201 Drawing Room, a hidden supply grille over door architrave on the west wall. Photo by author.

Figure 22: 3rd Floor, Room 301 Office, supply grille over the door frame on the west wall. Photo by author.
Figure 23: Nathaniel Russell House, Attic Level, view into the mechanical room, looking east. Photo by author.

Figure 24: Attic Level, mechanical room, AHU-3 in the foreground and AHU-4 in the background. Photo by author.
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Figure 25: Attic Level, historic fabric such as plaster and lath have been sacrificed to install piping and ductwork for the HVAC system. Photo by author.

Figure 26: Attic Level, mechanical room, water damage evident on the wood flooring where the condensate drains for AHU-3 have leaked or the pan has overflowed. Photo by author.
Bibliography


