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Commissioning for Humidified Buildings

by
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Moisture control problems account for up to 80 percent of all associated premature wear expenditures made on built facilities. Although proper commissioning procedures have been noted to reduce the potential for approximately 70 percent of these claims, no standards exist for the control of moisture migration in building commissioning guidelines. The development of commissioning guidelines for the control of moisture migration involves quantifying, with a risk management approach, the performance thresholds that distinguish acceptable from unacceptable design. These criteria should define allowable threshold values regarding mold growth, corrosion, loss of structural strength, and indoor air quality.

This report includes an introduction and brief history of building commissioning and the code regulations intended to address moisture in buildings, a description of the commissioning process as related to the building envelope in humidified buildings, and discussions of building humidification and the criteria and guidelines for commissioning humidified buildings.

The guidelines explain the role of a building envelope commissioning agent, from early in the design phase, through construction, to assuring proper operation after occupancy. This process includes the use of performance modeling techniques to predict the envelope performance prior to completion.

Establishing guidelines for the commissioning of humidified buildings is an important step toward anticipating and preventing the conditions that may lead to moisture problems and related health effects and maintenance expenditures.

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Moisture control problems account for up to 80 percent of all associated premature wear expenditures made on built facilities. Although proper commissioning procedures have been noted to reduce the potential for approximately 70 percent of these claims, no standards exist for the control of moisture migration in building commissioning guidelines. The development of commissioning guidelines for the control of moisture migration involves quantifying, with a risk management approach, the performance thresholds that distinguish acceptable from unacceptable design. These criteria should define allowable threshold values regarding mold growth, corrosion, loss of structural strength, and indoor air quality.

This report includes an introduction and brief history of building commissioning and the code regulations intended to address moisture in buildings, a description of the commissioning process as related to the building envelope in humidified buildings, and discussions of building humidification and the criteria and guidelines for commissioning humidified buildings.

The guidelines explain the role of a building envelope commissioning agent, from early in the design phase, through construction, to assuring proper operation after occupancy. This process includes the use of performance modeling techniques to predict the envelope performance prior to completion.

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Foreword

This study was conducted for Headquarters, U.S. Army Corps of Engineers under Project 4A162784AT45, "Energy and Conservation"; Work Unit X68, "Energy Facility Strategy." The technical monitor was Joe McCarty, CEMP-ET.

The work was performed by the Engineering Division (FL-E) of the Facilities Technology Laboratory (FL), U.S. Army Construction Engineering Research Laboratories (USACERL). The USACERL Principal Investigator was Brian Deal. Larry M. Windingland is Acting Chief, FL-E, and L. Michael Golish is Operations Chief, FL. The USACERL technical editor was Linda L. Wheatley, Technical Information Team.

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1 Introduction

Background

Up to 80 percent of all premature wear expenditures made on built facilities are associated with moisture control problems. These problems can often be attributed to the improper design, installation, or operation of the building's humidification system, especially in cold climates. Although proper commissioning procedures have been noted to reduce the potential of approximately 70 percent of these claims, no up-to-date commissioning guidelines exist for the control of moisture migration in buildings. In this report, the U.S. Army Construction Engineering Research Laboratories (USACERL) establishes commissioning guidelines for anticipating and preventing the conditions that may lead to moisture problems and unnecessary maintenance expenditures in humidified buildings. The guidelines will explain the role of the commissioning agent (CA), from early in the design phase, through construction, to assuring proper operation after occupancy.

Objective

The objective of this report is to provide guidance on building commissioning for humidified buildings that are subject to cold winter temperatures. This report is intended to be used by those interested in the performance of buildings, including: building owners and managers, commissioning authorities, design professionals, mechanical engineers, construction managers, operation and maintenance personnel, and contractors.

Approach

This research began with a study of the literature on the commissioning process and on humidification in buildings. The development of these historically unrelated fields was examined and the advantages of integrating humidification concerns into the building commissioning process were asserted. Guidelines for the commissioning of humidified buildings were then established and their implementation into a historic preservation project outlined.

Scope

This report establishes guidelines for the commissioning of humidified buildings. Humidification is of benefit only in the northern United States during wintertime conditions. The recommendations contained in this report do not pertain to summertime performance of buildings or the performance of buildings in the southern United States, where winters are typically mild.

Mode of Technology Transfer

Information from this study will be published in the *Public Works Digest* and disseminated through Energy Awareness and Energy Managers Conference seminars. This technical report will be posted to USACERL's web page at: http://www.cecer.army.mil

2 Methodology

This report provides guidance on building commissioning for humidified buildings that are subject to cold winter temperatures. It is intended for use by those interested in the performance of buildings, including:

- building owners and managers
- commissioning authorities
- design professionals
- mechanical engineers
- construction managers
- operation and maintenance personnel
- contractors.

Commissioning for humidification requires that a person or entity be assigned the responsibility of controlling moisture in the building and be accountable for any moisture damage due to elevated indoor humidity. To be consistent with other documents on building commissioning, this responsible person or entity will be referred to as the commissioning agent (CA). The CA could be an engineer, architect, designer, contractor, or consultant. The focus of this report will be to enhance the reader's knowledge of both moisture control in humidified buildings and how the commissioning process can be used to avoid problems due to moisture in the building envelope. The knowledge and skills presented in this report will facilitate the user's ability to implement a commissioning program for a humidified building.

Focus on Building Performance

Building owners expect a new building to work once it has reached substantial completion. Just what it means for a building to work, to perform, or to operate correctly is an unwieldy topic. It involves providing for, at least:

- comfort
- appropriate conditions for activity
- assurance of health and safety
- durability and economy.

Building codes are intended to assure health and safety, but their scope is not intended to extend to expectations of appropriate conditions for activity, durability, and economy.

Building owners are often disappointed with the overall performance of buildings. This disappointment is due, in part, to specialization and compartmentalization of the work of design and construction. If performance is a system effect, and project delivery is separated into components, it is easy to see how performance might be lost. Performance might be viewed as more than the sum of the parts, but economical project delivery might mean that nothing more than the sum of the parts is provided. The disappointment is due also to the reluctance by designers to allow the imposition of quantifications on their design products.

In most cases, design professionals are capable of delivering a building that functions properly. But the incorporation of humidification systems has historically been problematic for designers, engineers, and owners. It is quite common for humidified buildings to show moisture damage to the building envelope during cold weather. From an engineering point of view, wintertime humidification imposes a moisture load on the building, and the envelope offers resistance to that load. Failure occurs when the load exceeds the resistance.

The engineering approach might be desirable for enhancing the moisture resistance to buildings; however, its application is very limited. This approach involves using (1) design loads as inputs into (2) an analytic tool, which provides an output in comparison to (3) allowable criteria. The design loads for moisture resistance are not as well defined as are, for example, structural loads. Nor are the allowable criteria well defined.

In the absence of established engineering, the design and construction for moisture resistance must rely on varied sources as guidance. Herein lies the principal problem for moisture-resistant design and construction; the sources of guidance vary by climate, by local tradition, by building code variations, and by individual training and experience. Contradictions in advice are widespread. Faced with this set of conditions, this report suggests the commissioning approach.

Building Commissioning Approach

Project delivery usually depends on (1) the design professional (architect, engineer, designer) and (2) the construction manager or contractor (together with subcontractors and suppliers). Traditionally, these two parties have cooperated to deliver a building that is considered to be complete if the design intent matches the program and the product matches the design.

With this as the principal chain of responsibility, the operation and functioning of the building may not be guaranteed. Naturally, the view that traditional product delivery is not sufficient will be met skeptically by design professionals and contractors. It is expected that the building should work, even if the expectation finds its only expression in the planning and programming documents. Usually, however, no single party in the project team assumes responsibility that the building will work.

Building commissioning addresses the split between the owner's intent for performance and the designer/contractor's intent to deliver a product by assigning the responsibility for building performance to the CA. The CA may be the designer (or agent of the designer), the contractor (or agent of the contractor), or some third party. For this report, the CA is taken to be a separate party, not because the designer and contractor are incapable of delivering performance, rather because the definition of their traditional roles was not first and foremost building performance. Because both designers and contractors have found moisture problems in buildings to be troublesome, it is appropriate that a nontraditional approach to the delivery of humidified buildings be undertaken here.

The method by which the commissioning approach will be discussed consists of: (1) background information on moisture performance and moisture regulation, (2) a description of building commissioning, (3) a presentation of the peculiarities of humidified buildings, (4) a discussion of the commissioning of humidified buildings, and (5) references and resources.

Sources

This report relies to a large extent on the Handbook series of the American Society of Heating Refrigeration and Air Conditioning Engineers (ASHRAE). The chapters that are most pertinent are:

- *Handbook of HVAC Applications,* Chapters 1 through 7, on Comfort Air Conditioning and Heating, which describe the temperature and humidity requirements for buildings of different uses
- *Handbook of HVAC Applications,* Chapter 39, on Building Commissioning
- *Handbook of HVAC Systems and Equipment*, Chapter 20, Humidifiers
- *Handbook of Fundamentals,* Chapter 22, Thermal and Moisture Control in Insulated Assemblies Fundamentals and Chapter 23, Thermal and Moisture Control in Insulated Assemblies Applications.

Also used is ASHRAE Guideline 1-1996, The HVAC Commissioning Process. Other sources are listed in the reference section at the back of this report.

3 Humidification

Historical Background

The design of buildings with resistance to high interior humidity has its own history. Documentation appears as early as the baths of Caracalla in Rome. In at least one of its rooms, the *calorium,* where the water temperature was kept quite high, the interior surfaces were glazed to form, in effect, a vapor barrier. The roof of the typical calorium, however, was constructed of wood and appears to have required frequent replacement, despite Rome's mild winter temperatures. One can only infer that the cause of this maintenance nightmare was the extreme humidity in the building. Through the subsequent centuries, the problem of moisture in buildings has been a common topic of architectural prose.

Industrial age humidification problems within building interiors probably began with the advent of industrial processes that generated considerable amounts of water, such as laundries, or that needed mechanical humidification as part of the production process (e.g., printing presses and textile mills where dry air would lead to brittle and broken threads). It has been speculated that the early mills of 18^{th} and 19^{th} century England were more successful than their counterparts in France because of the higher ambient humidity in England. These industrial buildings needed to be insulated, typically with cork, not for energy savings but to prevent mold growth on the cold and humid interior wall surfaces (Barrett 1923).

The first mechanical humidification process, introduced in the last decade of the 19^{th} century, was air washing (Barrett 1923). At that time, the burning of coal gas for public lighting led to extremely high amounts of soot in the air. They found that the soot could be removed effectively only with whole building ventilation systems, which did not become fully practical until the introduction of the electric motor. The key was to provide a continuous spray of water to the ventilated air. The soot particles would then attach to the water spray and the contaminated water could be drained to the outside. As a result of this process, it was discovered that the temperature of the water used affected the humidity in other parts of the building.*

The first scientific study of moisture transport in buildings was begun at the University of Minnesota in 1938 (Rowley, Algren, and Lund 1938). Their results led to the use of vapor barriers and attic ventilation in common building construction in the United States (Rowley 1939). The first regulatory document to require the use of vapor barriers and the ventilation of attics and crawl spaces was published by the Federal Housing Administration (FHA 1942). Only one copy of this document has been found to date. It cites no research, gives no references, and is so obscure that much dissension on these issues has occurred in the ensuing years.

Following World War II, Ralph Britton of the Housing and Home Finance Agency (HHFA) undertook research into the prevention of moisture problems in buildings (Britton 1948). That research revealed that the vapor barrier and attic ventilation theories being proposed were only moderately successful at controlling moisture problems (Britton 1948 and 1949a). Coincidentally, some of the findings directly opposed theoretical expectations, as when roofs without ventilation performed well, but adding ventilation led to problems (Britton 1949b). Unfortunately, the project lacked funding and was halted soon after these studies. So the wide promulgation of moisture control methods — vapor barriers, attic ventilation, and crawl space ventilation — was left to proceed with little or no research (Rose 1995 and 1997a).

In 1949, HHFA published a booklet titled "Condensation Control," which was based on the 1942 FHA regulations. It contained drawings and explanations that promoted three measures necessary for moisture control:

- vapor barriers of one perm or less
- attic ventilation with a 1/300 ratio of net free vent area to horizontal projected roof area
- crawl space ventilation of 1/150 (or 1/1500 with a ground cover).

* A very good description of the history of humidity standards for museums is given in Brown and Rose (1996).

These regulations became the basis for moisture control in buildings and are the same regulations in use today. These "Condensation Control" provisions were also cited in the 1951 edition of *Architectural Graphics Standards*. They appeared for the first time in the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) handbooks in 1950, and they also appeared in the first editions of most model building codes, where they can still be found.

Little or no research was performed that led to the formulation of the provisions for moisture control. Research that was intended to substantiate the provisions described by Britton did not indicate any great effectiveness of these measures.

Regulatory Background

The principal vehicles for the regulation of construction practices are the model building codes. Prior to World War II, most codes were municipally originated. The only nationally scoped codes were those developed by insurance companies (the original National Code) and those used for implementation of Federal programs such as the FHA. The purpose of these documents was primarily to ensure health and safety, and they addressed structural sufficiency, fire protection, and plumbing. They were not intended to prescribe techniques for the prevention of moisture-related problems.

Code organizations such as International Conference of Building Officials (ICBO) and Building Officials and Code Administrators International (BOCA) allowed comparison of code requirements beginning in the 1920s, but not until after World War II did those organizations publish, for widespread use, the first model building codes. These codes contained moisture-damage prevention provisions lifted directly from the documents of the FHA and HHFA.

Despite the territorial differences among the model building code agencies, and their differences in other areas such as structures and fire protection, and despite the differences in local adoption, there is a strong commonality to the provisions for moisture control. These provisions might be summarized as follows:

- A vapor barrier (retarder) of one perm or less should be placed on the warm side of the wall. The perm rating should be measured using an appropriate wet-cup or dry-cup method from ASTM E67.
- Enclosed attics and rafter spaces formed where ceilings are applied directly to the underside of roof framing members shall have cross ventilation for

each separate space by ventilating openings protected against the entrance of rain and snow. The net free-ventilating area shall be not less than 1/300 of the area of the space ventilated.

- Crawl spaces shall be vented by openings having a minimum net free area of not less than 1/150 of the floor area. With a ground cover of 1 perm or less, the required net free area is a minimum of 1/1500 of the floor area.

These requirements are *prescriptive*. That is, they require strict execution of the precise terms in the code requirements. Prescriptive building codes provide significant benefits:

- compliance is simple
- enforcement is simple, since the compliance criteria are visible and readily measurable
- the criteria for product development in support of the requirement are simple.

In contrast to prescriptive requirements, there are *performance*-based code requirements. Performance requirements direct only that the end result be defined; the means to achieve that end need not be explicit. Although performance-based requirements lack most of the benefits of a prescriptive requirement, they compensate with one substantial benefit — they intend and promise that the end product will perform according to the desired criteria.

A recent shift on model code development in the United States has lead to the formation of the International Code Council (ICC), composed mainly of model code agency representatives. The current direction of the ICC includes an effort to replace prescriptive building code requirements with performance-based requirements.

4 Building Commissioning

History

Commissioning is not a new process. It has been in use by the United States Navy for centuries. The process of methodically testing each component of naval ships and other seafaring vessels to ensure material and workmanship quality was originally seen as a safety issue, but the economic advantages were immediately apparent; the further the vessel is from shore, the more difficult and costly the repair. This same process was later extended into the shipyard itself to provide shipbuilders protection from buyers and their attorneys (Lawson 1996). More recently, the commissioning process has been used as an equipment startup mechanism for major defense and nuclear facilities. Chemical and petroleum processing facilities have also followed suit.

The introduction of the commissioning process into the building industry first appeared during the 1980s. The first applications were designed for heating, ventilating, and air-conditioning (HVAC) systems because of the complexity of the systems and the difficulty associated with the initial startup of the equipment. Today, the process has evolved into whole-building commissioning, in which virtually all specified components and systems of a building are tested and calibrated, from building envelope systems to mechanical, lighting, elevator, and fire-safety systems (Solomon 1995).

Proponents argue that such a rigorous process of quality assurance has become necessary because architecture has become so technically complex. Sophisticated computer systems and sensors must be precisely tuned, in conjunction with the building's envelope, for example, to achieve the energy efficiency, air quality, and other performance criteria increasingly demanded by government regulations and educated clients. In the design and construction industry, which suffers from increasingly shorter delivery times, smaller profit margins, and a generally litigious atmosphere, any project will gain from better communications between project team members. Better communication is one of the main benefits of building commissioning (Solomon 1995).

Definition

> The commissioning of an installation is the process for achieving, verifying and documenting the performance of buildings to meet the operational needs of the building within the capabilities of the design and to meet the design documentation and the owner's functional criteria, including preparation of operator personnel. (ASHRAE 1995)

The *ASHRAE Handbook of HVAC Applications 1995,* Chapter 39, Building Commissioning, begins with this definition:

> The commissioning of an *installation* is the process for achieving, verifying and documenting the performance of *buildings* to meet the operational needs of the building within the capabilities of the design and to meet the design documentation and the owner's functional criteria, including preparation of operator personnel.

The difference between substantial completion, as it is normally considered in project delivery, and the commissioning process is the measure of completeness. Substantial completeness requirements typically ask if the building meets the criteria as intended in the design documents. Similar to performance-based codes, however, a real measure of completeness might more accurately be based on meeting functionality or operational needs — does the building perform as intended? This commissioning concept parallels the manufacturing industry's move toward total quality management. Solomon cites the auto industry: "Building commissioning tries to replicate in the architecture profession what total quality management achieves in the automotive industry, where a systematic program of development and testing ensures that a car runs well the first time it rolls off the lot" (Solomon 1995).

To illustrate the importance of the commissioning process, consider an example of questionable practice: The client (in this case a museum), decides to humidify their building to 50 percent relative humidity (RH) year round (+/- 5%) in order to accommodate shows on loan from other galleries. The client engages an architect and describes the humidity requirement in the design brief. The architect finds that moisture control can be achieved by the installation of a 1 perm vapor barrier "with good workmanship." The mechanical engineer takes the humidity requirement in the design brief and designs the equipment to provide this level of indoor humidity. The vapor barrier specifications require the barrier to be free from holes or other defects, and the contractor provides as tight an assembly as possible. The building is completed during the summer months and handed over to the owner. As late fall sets in, a visible accumulation of condensation forms on the windows and skylights. A concern for interstitial condensation sets in. The building operator and the collections manager have a falling-out over whether the humidity setting should be high to protect the artifacts or low to protect the building envelope. Representatives of all the parties are called in and the finger pointing begins. The resolution is unsatisfactory to all parties.

Errors on the parts of several parties are noted below, and all are solvable within the guidelines of proper building commissioning.

- The client should have investigated more thoroughly the actual humidification requirements for museums. The seasonally constant humidity that was specified most likely does not represent the best practice.
- The architect might have investigated the humidity requirements for the client and advised the client on appropriate adjustments.
- The architect might have recognized the importance of several design parameters to achieve moisture control rather than rely on a single prescriptive approach.
- The mechanical engineer might have viewed the interior building loads as changing seasonally and advised the architect of options for humidity control.
- The building operator might have met with the collection manager to determine how to control humidity during prolonged cold spells.
- The building manager might have used diagnostic equipment to determine where potential trouble spots in the building might occur, and correct those prior to the onset of the coldest weather.
- The collection manager might have identified the fragile artifacts in the collection and taken special care to ensure their safety.
- The owner might have advised the collections and the building staff to keep their eye out for any damage to either the building or the collection during cold spells.

Elements of Building Commissioning

The makeup of the commissioning team depends on the size and complexity of the building project. The ideal team would include all the participants in the construction project: a commissioning authority, owner, designer, construction manager, general contractor and subcontractors, operations and maintenance engineers, equipment suppliers and manufacturers (ASHRAE 1995).

Elements of the building commissioning process as contained in Owens (1997) include:

- systems installation per plans and specifications
- point-by-point verification of systems
- systems testing and cleaning
- generation of punchlists
- completion of punchlists
- written commissioning procedures
- verification of balancing and testing
- review of design after all of the above is completed
- documentation
- training.

This process can be viewed in terms similar to the typical construction process:

Planning → Design → Construction → Substantial Completion → Post Occupancy

with a few alterations as noted below.

Planning Phase

During the planning phase, the design professional sets the parameters for building commissioning to include documentation and the responsibilities of each team member. These parameters also include benchmark information that will be used to evaluate the final performance of each system (ASHRAE 1995).

Design Phase

The design phase outlines the commissioning requirements for each building system. These requirements typically include (ASHRAE 1996):

- design criteria and assumptions
- descriptions of each system
- the intended operation and performance of each system
- the commissioning plan
- documentation requirements
- verification requirements
- maintenance requirements.

Construction Phase

During the construction phase of the commissioning process, the building systems are installed in conformance with the contract documents and the commissioning plan. Similar to a typical construction phase, prior to installation of each system or subsystem, shop drawings and operation and maintenance manuals are submitted, reviewed, and documented (ASHRAE 1995).

Substantial Completion

Sometimes referred to as the acceptance phase, this is the point at which pre-startup inspections are performed. Inspections include verifying that the components were installed as intended and follow intended prescriptive criteria. Acceptance procedures include functional performance tests, verification and documentation of corrective measures (if necessary), intersystems performance testing, and acceptance (ASHRAE 1995).

In addition to the above measures, the time dedicated to the training of operational personnel depends on the complexity of the building system. Complex systems may require a more rigorous training regime. Operator participation in the initial verification and testing phase is an important part of the training strategy. Instruction is provided by several different sources: the design professional, equipment manufacturers, controls contractor, testing contractor, and other specialty contractors.

Post Occupancy

Operations or post-acceptance commissioning is a critical step for effective and ongoing functioning of a building. Buildings are dynamic structures and, as the occupancy and use requirements of a building change, the building systems need to be adapted. The history of the modifications and changes to the facility must be carefully monitored and documented, and the commissioning procedures and testing of the facility must also be continually updated. Systems should also be retested periodically to measure and verify actual performance.

5 Humidified Buildings

Why Humidify?

Industry

Certain industries require or naturally achieve humidification. Printing plants require strict humidity control for dimensional stability of the paper. The threads in textile mills may fracture at low humidity. Laundries and other wet process facilities will have interior humidities elevated above the outdoors. Some industrial applications for humidification, however, have questionable roots. For example, conventional wisdom asserts that electronic data processing equipment requires a controlled RH. According to ASHRAE, the recommended design and operating range for computer systems is 35 to 55 percent RH (ASHRAE 1995). Electronic equipment, however, is designed to be robust and withstand extremes of wetness and dryness. It is common to clean and reuse electronic equipment following floods, and problems of excessive dryness rarely appear to lead to computer problems.

Medical Facilities

In operating rooms, a high concentration of flammable substances such as oxygen and anesthesia gases may be present. Sparks can ignite these gases and lead to severe and life-treating problems. The prevention of sparks in operating rooms involves grounding appliances and (sometimes) clothing, and controlling humidity. It is common for operating rooms to be controlled to 22 °C (71.6 °F) dry-bulb temperature and 55 percent RH.

Museums

Museums, libraries, and archive buildings are often humidified. After World War II, interest increased in establishing standards for humidification. As a consequence of the well-documented and well-preserved condition of British art works stored in the Manod slate quarries during the war, the stability of environmental conditions became a concern among curators and conservators. From the principal books on museum environments, Plenderleith (1956) and Thompson (1940), conservators drew the conclusion that a tight range of about

50 percent RH was desirable. Moreover, such a range could be achieved by mechanical engineers thanks to improvements in air-conditioning equipment. More recent work at the Canada Conservation Institute and the Smithsonian Conservation Analytic Laboratory has tended to move the conservation community away from severe "flatlining." But the legitimate concerns for avoiding extremes of humidity and dryness are very much intact (Brown 1996).

Objects can be damaged from both high and low humidity. The threat from high humidity is primarily from mold growth and the enhancement of chemical reactions due to the presence of water. The damage from low humidity is primarily to wooden objects that are designed so they cannot withstand changes or gradients in moisture content. Most objects (particularly paper, metals, and photographs) benefit from the lowest possible humidity. Conservators are in substantial agreement that 65 percent RH represents a high-end threshold. Conservators also agree that a lower humidity limit is a much softer number, a number that must be very specific to the artifacts in the collection (Brown 1996).

Homes

Homes in the northern United States are frequently humidified. For decades, the pot of water on the radiator was a familiar sight in winter. In Europe, where hydronic systems are much more widely used, special decorative ceramic pots are designed to hang from radiators and evaporate water into the room air. In more modern forced air applications, mechanical humidifiers are integrated into the air supply system.

Many individuals find dry air to be irritating to sinuses. Other complaints from dryness include dry skin and the discomfort of sparks from walking on dry carpet. A good discussion of the health effects of humidification is found in the work of Baughman and Arens: "In general, molds do not become an issue below 70% or even 80% relative humidity unless there are other factors influencing their growth on building surfaces. In setting a maximum limit to air humidity in the space, there is little if any evidence from field studies that provides a reason for distinguishing 60% relative humidity from 70%" (Arens and Baughman 1996). It is important to note that this limit relates to the RH at an indoor surface where mold may grow.

The claim of health benefits from humidification has little research support, and the most commonly cited work in support of the health benefits for humidification may no longer be credible (Baughman and Arens 1996). A search of the literature for health effects associated with humidity records found detrimental health effects only for excessively high humidity, not for low (Baughman and

Arens 1996). If any health benefits from humidification exist for the general population, they have not as yet been recorded in the literature.

Impacts of Humidification

The overall aim of commissioning humidified buildings is to avoid damage to the building envelope and to prevent negative health effects during periods of cold weather. The following discussion provides a framework for effective, hands-on solutions to building moisture problems.

Windows

The classic and traditional means of determining excess humidity inside a building is window condensation. It forms a reliable and easily visible sign. Window condensation may take several forms. Early indications can the presence of a slight film of dew or frost on the pane (or occasionally on the frame if it is more thermally conductive than the glass). Often such a film will evaporate with rising temperatures and will typically have no detrimental effects. If the rate of accumulation starts to collect into droplets that run onto the window frame, the conditions for water damage and mold growth are in place.

Logically, condensation should occur when the temperature of the inside surface of the glass is at or below the dew point temperature of the indoor air. Interestingly, this may not always be true. A clean, dry surface as it is cooled may fall to 5 °C (41° F) or more below the dew point temperature of the air and still remain dry. This occurrence is called "super-cooling" though "super-saturation" may be a more descriptive term. Condensation occurs not at the instant that the dew point temperature threshold is crossed by the surface, but upon nucleation. Nucleation depends on the cleanliness of the window, or on the presence of jagged spots of dirt or scratches. During nucleation, water vapor near the surface condenses as dew or frost. That formation of a liquid or solid from vapor produces heat, and the heat generated raises the temperature of the dew or frost to the dew point temperature of the air. The fern-like patterns of window frost occur quickly, in bursts, as super-saturated air nucleates on a cold surface (Rose 1997b).

Walls

The primary concern for wall assembly moisture in humidified buildings is interstitial condensation; that is, moisture damage to cold surfaces that are invisible to the indoors. The defensive strategy, for most of the United States, is to use vapor barriers against moisture diffusion. A closer look at the problem may provide a different approach.

First, most moisture damage to walls comes from rain, not from interior humidity. The best protection from the negative impacts of rain is good rain-water management. It is extremely difficult to completely "waterproof" the exterior of a building. So it is important to direct the water back out of the assembly once it has penetrated the exterior surface materials (TenWolde 1995a).

Second, interstitial condensation occurs in building cavities. Many assemblies do not have cavities (e.g., solid masonry or foam-insulated construction types). If mold growth is the controlling condition, it is important to note that mold growth is a condition of building *surfaces* and does not occur within the thickness of a material. The easiest way to avoid moisture problems in cavities is to design wall assemblies that have no cavities.

Third, interior moisture-related problems are often seen as condensation problems. Some materials (metal, glass, or ceramic surfaces) are prone to this condition. Other materials (wood, brick, stone, etc.) are porous and hygroscopic — absorb moisture from the air — and the moisture content of the material will vary over a range of conditions. In moisture-storing materials, the concern shifts from the existence of condensation conditions to the existence of damaging conditions from mold growth (or other damage criteria). In particular, the rate of moisture exchange between the air and the material is the governing parameter, which is very different from condensation.

Fourth, the moisture contents of materials will tend toward equilibrium with the conditions of the air surrounding the materials. Temperatures of the materials and conditions in the air vary and cause variances in the moisture content of the materials. What is critically important is to reduce the rate at which humid air comes into contact with cold surfaces. This reduction involves manipulating connective flow through the cavity assembly.

Fifth, the rate at which moisture migrates outward across a cold surface depends on air pressures. Wind and stack pressures may play a part, but usually pressures produced by the mechanical system provide the steadiest outward pressures within a building. It is common for mechanical systems to be designed without intentional paths for air exhaust or relief so the humidified air escapes through the building envelope along the path of least resistance, very likely passing along potentially cold surfaces, which leads to moisture accumulation.

Attic Spaces

Attic spaces, like walls, suffer from the imposition of prescriptive standards. A performance-based approach holds much more promise. The traditional concern for attic spaces is the formation of frost on the underside of the roof deck, and the classic solution is attic ventilation. Several elements of this problem statement and solution deserve clarification.

First, most of the water problems are not moisture related. These problems include roof leaks, snow entry through vent devices, condensate on cold exposed pipes and ducts, leaking mechanical equipment, etc.

Second, interstitial condensation is a problem only in assemblies with cavities. Most low-slope roof systems are constructed with dense cellular foam insulation directly beneath the roof membrane. Such systems are called compact roof systems, to distinguish them from cavity roof systems. Since there is no cavity, interstitial condensation is not possible.

Third, the materials contained within attic cavities can be porous or hygroscopic, and their moisture content will vary with changes in the ambient air. The moisture performance of cavities can be estimated and predicted using only transient rather than steady-state methods (TenWolde 1995b).

Fourth, the moisture content of the materials will strongly depend on the humidity characteristics of the air. An attic is a mixing bowl. The concentration of air in the attic will be a function of the relative contributions of indoor and outdoor air. Simple placement of a vent to the outdoors does not guarantee a high concentration of outdoor air and a low concentration of indoor air — both of which would be desirable. The relative concentrations of indoor and outdoor air will be most greatly affected by the aerodynamics of the roof, by mechanical systems, and by passive ventilation systems (including infiltration).

Fifth, to design attics for good performance when the building is humidified requires preventing humidified indoor air from being transported into the attic. The first step toward achieving this with cavity construction is to provide an airtight ceiling plane.*

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* While airtight ceiling construction is the exception rather than the rule, efforts in weatherization and stopping the spread of fire have tended to move ceiling construction practices toward an effectively airtight ideal.

Moisture Engineering

Moisture engineering is the term adopted by the National Institute of Building Sciences (NIBS) to describe how quantification and science can be applied to solving moisture problems. The approach borrows concepts from structural engineering practices that are fundamental to the solution of engineering problems: loads, analysis, and criteria.

The solution of structural problems begins with the assignment of design loads (e.g., 40 psf live load for occupancy). These loads are used as inputs to the design and analysis process. The result is tested against appropriate criteria (e.g., L/360 deflection for floor systems). The same concepts may be used in design for moisture resistance.

Loads

As noted previously, the moisture load is the beginning of the moisture engineering process. Indoor and outdoor conditions constitute the loads needed for a hygrothermal (temperature and relative humidity) analysis.

Indoor conditions play a very strong role in determining the likelihood of moisture problems in buildings. In conditioned buildings, the engineered approach attempts to control the humidification level. Such buildings are the most troublesome and the focus of this report. In many buildings, the indoor humidity level is not controlled. These unconditioned buildings are typically noted as having the same moisture concentration inside and out, within the buffering capabilities of the building. But in most buildings, there is a swing in indoor humidity that is tempered by mechanical equipment and by natural buffering.

Outdoor conditions are noticeably more difficult to manage for engineering models. The critical parameter is outdoor temperature. Other important outdoor moisture transport considerations include: radiant effects (cooling and heating), rain, horizontal wetting rain (for porous claddings such as brick), and strength of drying conditions following wetting or condensing.

Analysis

Several analytical tools are used to perform moisture analysis of building envelopes. The simplest tool, which has been in common use under various names since the end of World War II, is referred to as the dew point method, the ASHRAE method, or the profile method.* This method is one-dimensional and steady-state, using diffusion as the sole transport mechanism (ASHRAE 1993). The method does not account for moisture storage, radiant effects, convection, capillary movement, varying permeances, phase change, and changing conditions. Despite its limitations, it has been the principal tool used in predicting the moisture performance of building envelope assemblies for 50 years.

A more advanced approach to modeling the movement of moisture in building assemblies is a transient (time-dependent) based approach used in the International Energy Agency's (IEA's) Annex 24 (Hens 1996). The U.S. contribution to this approach, MOIST, was developed at the National Institute of Standards and Technology (NIST). The MOIST program uses hourly weather data from several sites in the United States and Canada, calculating one-dimensional heat and vapor transport via diffusion and capillary action. It accepts fixed as well as floating indoor humidity conditions.

Criteria

What constitutes moisture damage? The IEA Annex 14 (IEA 1991) proposes a threshold value separating moisture safety from moisture problems. The IEA has determined that the condition of excess moisture is critical when it permits mold to grow on a surface.† That threshold has been set at 0.80 surface/water activity level on a monthly mean basis. This level may be interpreted to mean that an excess of 80 percent RH (monthly average) at a material's surface will allow mold growth. Note that surface RH will be quite different from room RH, principally because of the difference in temperature from the center of a room to the exterior envelope surfaces.

Depending on the construction type, the IEA criteria may not be appropriate. In steel construction, potential for corrosion may predominate. In construction with

* Outside the United States, it is called the Glaser method.

† Mold growth is a precursor to wood-destroying fungi.

cellulose insulation, where fire-retarding salts provide natural inhibition to mold growth, the potential for mechanical degradation of building materials may predominate.

In summary, the work of commissioning humidified buildings will consist of applying engineering principles. Commissioning will begin with agreement on what constitutes failure. The assembly design and the appropriate analytic tools will be developed during the design process. It is precisely in the selection of input values to the analytic tools that commissioning can make its greatest contribution during the design phase.

6 Commissioning Humidified Buildings

Contract

Because building envelope commissioning for humidification is a fairly recent concept, it becomes critically important to develop a contractual relationship between the client and the CA. The contract should describe and explain the responsibility of the CA with respect to the responsibilities of the other parties. The responsibility of the CA, consistent with the aim of commissioning, must be: (1) to meet the operational needs of the building, (2) to meet them within the capabilities of the design, (3) to meet the design documentation and the owner's functional criteria, and (4) to include preparation of operator personnel.

1. The description of the operational needs should be explicit. It should be relatively simple to be explicit about the operational needs in response to humidification; a humidified building should be designed, constructed, and operated in a way that the humidification needs are met and moisture problems in the building envelope are avoided.
2. The CA must be involved in building design because it is the design intent that determines whether or not the criteria can be met.
3. The CA must prepare a report that documents the testing and modeling procedures that will be used to meet the functional responsibility of the task.
4. The CA must remain involved following completion of the design and construction contracts to ensure that the building is being operated safely and as designed.

Of particular importance is the question whether acceptance of the work hinges on approval by the CA. In principle, if the client is resolute regarding building performance as a condition for acceptance, then the role of the CA is clear and the building cannot be considered substantially complete until the CA certifies that the building will perform as intended. But because the weight of design and construction traditionally lie with the delivery of a product rather than performance, commissioning must be accepted to be a matter of adjusting the performance of the product rather than a rewriting of the conditions of acceptance.

Negotiate an Acceptable Range

The CA is advised to negotiate a humidity range acceptable by parties. This negotiation is preferable to having the interested parties express dissatisfaction for any deviance from their parochial (narrow) ideal.

The only strong reasons for humidification are programmatic. What activities within the building require humidification? What are the consequences to these activities if the building is occasionally, seasonally, or regularly at a lower humidity? Is humidity a physical requirement (the process cannot go forward without humidity), a contractual or regulatory requirement (e.g., lending agreements for traveling museum exhibits), or a convenience? Are cost thresholds involved? For example, could a museum collection withstand lower humidity if a certain part of the collection is housed in a microclimate?

It is important for the CA to receive frank and explicit answers to these questions. Once a lower limit is established as a target or threshold value, those concerned about damage from excessively low humidity should describe what the expected damage might be and the extent to which their programs are impacted by occasional excursions past the limit.

In climates with cold winters, interior humidity is the strongest determinant of the likelihood and severity of moisture damage to the building envelope. The choice of upper limits to the allowable humidity range will have an effect on design constraints and equipment sizing.

Programming and Predesign

Initial Meetings

A clear statement from the CA and the client regarding the role of commissioning and its importance to the project is critical to the success of building commissioning. It is at the programmatic meetings that design responsibilities are assigned and the humidification range is established. The initial meetings also set the tone for the level of cooperation to follow.

It is important for the CA to be seen as an advisor to all the parties, who is capable of assisting the designers to deliver a product — a building capable of humidification — which might otherwise be a challenge to the design team. A capable CA must inspire confidence.

Commissioning Brief

Soon after the initial meetings, the CA should develop the commissioning brief, which is incorporated into the planning documents. The purpose of the brief is to guide the design and it should contain the following:

- building humidification design intent
- the acceptable or negotiated range of humidity
- the CA's understanding of the design direction
- critical elements of design and construction
- means of testing compliance with the critical elements, both for design and construction
- anticipated future course of action in commissioning.

An opportunity for discussion should follow the distribution of the commissioning brief.

Design

Envelope

It is in the design phase that the use of hygrothermal modeling is most appropriate. As described earlier, steady-state models can be used as a "first cut" indicator of condensing conditions. Transient models (e.g., MOIST) can be used to estimate the performance in the absence of convection.

The moisture performance of insulation materials vary widely. Fiberglass insulation is typically of a low or light density and moisture in the insulation zone can diffuse easily. As noted above, the vapor barrier was developed precisely to accommodate the vapor protection needs of low-density insulation materials. Conversely, foam insulation has a high resistance to moisture transfer and is, in effect, its own vapor barrier.

Avoid unworkable specifications. The performance requirements of materials and assemblies should be clearly specified. In addition, guidelines that provide the means for achieving the desired performance should also be defined and detailed in the construction documents. If seams in the vapor barrier membrane are to be made airtight, the means for achieving this must be spelled out. A designer who requires "airtight" construction must acknowledge that, if inadequate provision is made for balanced intake and exhaust, the building skin will rupture. A common, and regrettable, design error is to simply require "good workmanship." Designers who are not capable of managing moisture transport in building envelope assemblies might be inclined to absolve themselves of performance responsibility with such a vague specification. A contractor who would read such a specification without amplification in a bid document would be well warned to include a very large contingency. A "good workmanship" specification for a vapor barrier is no assurance of good performance. However, a concise description of the sequence of application, with fastening and sealing details, together with test criteria can make for excellent performance. Or, better yet, a judicious selection of insulation material may remove the criticality from managing membrane materials.

A general, moisture-resistant wall assembly design guideline for humidified buildings in northern climates might consist of the following points:

- Design for airtightness — assure airtightness with mechanical joints, not sealant.
- Set a specification for airtightness; design for that specification; ensure construction to that specification — do not allow "workmanship" to be used as a substitute for a vapor/air barrier specification.
- Make provisions for outdoor air, both intake and exhaust — the volume of air moving through intake and exhaust should be a much higher percentage than the anticipated amount of air flowing through the incidental cracks in construction.
- Detail corners and other potential cold spots carefully, with attention to continuity of the thermal envelope.
- After assuring airtightness, design for diffusion protection.
- Walk through the sequence of assembly carefully (TenWolde and Rose 1995c).

As the design proceeds, the CA should identify which spots are likely to be the spots where construction may be difficult, and where moisture problems are most likely to appear.

Mechanical Equipment

Operation outside of the intended humidification ranges could be particularly damaging to the building, to the activities, and to the health of the building occupants. The principal role of the CA during mechanical system design should be to assure safe operation, under both normal and accidental circumstances.

More damage is done from high humidity than from low humidity, so the control system should fail to the off condition. Humidified air supplies can cause localized high humidities unless the air is well mixed after its discharge into the space. In particular, the equipment and ductwork immediately downstream from the site of injection of humidity should be easy to inspect and maintain.

Construction

The role of the CA during the construction process should be to ensure that the design intent is achieved in the execution. At preliminary meetings with the contractor, there should be an opportunity for presentation and questions to the CA. In particular, the details and specifications that are intended to achieve airtightness need to be reviewed by the contractor. Any difficulties in execution should be reviewed with the design professionals well in advance of the work.

Substantial Completion

In normal project delivery, substantial completion is the contractual event that signals acceptance of the work by the client. Normally, the architect will certify substantial completion. It would be uncommon, given the weight of traditional project delivery, for the certification of the CA to have a critical bearing on the acceptance of the building and the certification of substantial completion. The client and architect may wish to have information regarding building performance before their certification, and the CA should comply to the extent possible. The tests for critical performance, however, can typically be done only in critical seasons. It is very difficult to predict wintertime performance in any season but winter. An acknowledgment by the CA that the building "should" perform as anticipated should not be considered to have the weight that physical test results would have.

Post Occupancy

The principal activity of the commissioning of humidified buildings takes place after substantial completion. It is the CA's responsibility to make sure the building continues to work properly. If the commissioning process is approached rigorously, the chances of success are greatly enhanced.

Performance Log Maintenance

A crucial activity in the first year after construction is recordkeeping. The CA should maintain a log of the building performance, from the time that the mechanical systems are put into service, up to the completion of the commissioning report. The CA will not be onsite during the entire startup period, so arrangements should be made with occupants or appropriate staff that can collect and record observations on the performance of the building.* Simple observations during noncritical periods should include: the "feel" of the indoor environment (e.g., smells and sensations), water spots (especially window condensation and basement leaks), conditions in unoccupied or rarely occupied areas of the building such as basement and attic spaces, the performance of finishes (including cracking), and the suitability of the indoor environment for the intended purpose.

Other critical data regarding the indoor environment must also be collected at this time. This work usually involves programming the operations control system to regularly download performance data. It may also involve the collection of regular indoor temperature and humidity measurements. During this period, outdoor temperature and humidity information must also be collected. A spreadsheet-type file should be maintained and should contain at least the following information:

- Indoor temperature and RH at critical locations in the building. It may be noted that the sites of placement for mechanical system controls do not necessarily represent the environment at locations critical to the activity of the building.
- Outdoor temperature and RH
- A macro that uses temperature and humidity to calculate a measure of water concentration in the air, such as humidity ratio, mixing ratio, or dew point temperature — These terms and the means to perform these calculations are found in ASHRAE *Handbook of Fundamentals,* Chapter 6, Psychrometrics (ASHRAE 1993).
- Comments on the indoor and outdoor conditions, including at least daily summaries of rainfall.

Airtightness Testing

Once the building is complete and occupied, the airtightness should also be tested. It is best if airtightness is a performance criterion defined from the outset. A blower door is the most commonly used testing instrument. A blower

* The first year a building is constructed is the "drying out" period for most construction materials – especially wood and concrete. This strengthens the argument for careful observation of building conditions during this period.

door “pumps up” the indoor air pressure to measure the indoor/outdoor pressure differential and the building's total air leakage area.

Cold Weather Testing

Cold weather testing is important to determine the building's performance during the winter months. One important piece of equipment for this phase of testing is the infrared pyrometer, an expensive but indispensable piece of equipment for a humidification CA. A pyrometer is handheld and measures surface temperature. The cost of the equipment depends on the optical arc — an instrument with a wide angle (measuring temperature in a wide patch from a short distance) may cost $400, while an instrument with a fine arc (measuring a patch of a few inches diameter from a distance of several feet) may cost up to $2,000.

The pyrometer is used on the interior of the building to identify cold spots, which are important determinants of moisture-related problems. A pyrometer allows the CA to reduce the number of critical visual inspection sites down to a few. These critical areas can be continuously evaluated for moisture problems as humidity loads are increased over the course of the season. The pyrometer can also be used on the outside of the building to determine the location of hot spots, which correspond most typically with areas of low insulation or air leakage.

The pyrometer (or an infrared thermography camera) can be used very effectively during a blower door test to determine not only the amount of leakage area but also the site of leakage. This measurement is particularly helpful if the identification and repair of a few sites makes a difference between acceptable and unacceptable performance of the building envelope.

The performance of windows must be an important part of the cold-weather investigation. Humidity is more common on high windows and on exterior panes of storm windows. A window investigation should include pane temperatures and indicated directions for airflow. The patterns may also be recorded in photographs or drawings, which can help establish the relative contribution of pane conductivity and frame conductivity to the overall window performance. Most important is to distinguish film condensation on windows from running condensation.

Commissioning Report

The main focus of the CA is issuance of the commissioning report once the work is complete. The essential elements of the commissioning report should include, at least:

- restatement of the aim and intention of the commissioning activity, with results of the negotiated acceptable range of humidity
- discussion of the design of the building envelope and the mechanical equipment
- results of modeling, both steady-state and transient
- discussion of the suitability of the construction with respect to the design intent and the anticipated humidity performance
- results of the recordkeeping period showing the actual performance of the building during the period
- results of the calculation showing the concentration of moisture inside and out
- observations during the critical cold-weather visit
- conclusions from the study
- recommendations for operation and maintenance
- training schedules.

7 Historic Structures

Although the commissioning process is typically associated with new construction, it can also be applied to historic structures. Historic structures were designed based on the technology of the time and, therefore, were seldom humidified. When modern mechanical systems are introduced during adaptive reuse projects, a proliferation of moisture-related problems can result. In these cases, the commissioning process can be applied to ensure both interior comfort and protection of the historic building envelope.

An example of such a project is the historic Stockade Building (#216) at Fort Riley, KS. The Stockade is slated for conversion into a museum curation facility. As part of this adaptive reuse project, USACERL recently initiated the envelope commissioning process to ensure the proper balance between the needs of the facility's historic artifacts and the constraints of the historic building envelope.

The Building Envelope

A new chapter has been proposed for the ASHRAE *Handbook of Applications* (1999 edition). The proposed chapter refers to methodologies for conditioning the indoor environment of historic structures used as museums, libraries, or archive buildings. This chapter warns against controlling the indoor environment in ways that might be harmful to the historic fabric of the building.

In a historically unconditioned structure such as the Fort Riley Stockade, the indoor environment varies seasonally and with changes in the weather. Such a floating indoor environment is typically more beneficial to the building envelope than one designed for fixed setpoints of humidity and temperature. However, traditional mechanical engineering design often begins with specified indoor conditions of temperature and humidity and associated tolerances. Then, in traditional practice, a building envelope design is imposed, to accommodate the indoor environment specification. This typically imposes thermal insulation, vapor retarders, and infiltration control.

An alternate mechanical engineering design approach is being pursued for the Stockade. It may be described as identifying the temperature and moisture "signature" for an existing historic structure, then using that signature as a starting point for equipment design.

The temperature (T) and RH will be monitored outdoors and at several locations in the interior of the building. The T and RH values will then be converted to moisture concentration or other measure of absolute humidity. The conditions of absolute humidity are generally more uniform throughout the building than measured T and RH, and they can be used to disclose rates of moisture generation and dilution. The moisture concentration may disclose the amount of buffering of temperature (and with greater difficulty, moisture), and the normal fresh air dilution. In a stone building with large mass such as the Stockade, the enthalpy exchange — i.e., the temperature modulation by sorption and desorption — may be of considerable interest.

The product of this envelope performance assessment will be a report showing the ranges of T and RH for the measured locations. The report will show, to the extent possible, how heat, air, and moisture move through the building. That information will form the baseline for determining what changes are necessary to affect the interior conditions.

Range of error in these measurements is considerable, as only a few measuring sites are used, and the monitoring campaign cannot extend through all possible conditions of exterior climate. Nonetheless, this information can be very valuable. The standard literature for the mechanical engineering field — the ASHRAE Handbooks — does not address conditions in existing buildings. Thus, mechanical engineers may not be familiar with using monitored building performance data. But, the use of such data may be considered similar to the use of drawings of an existing building by restoration architects.

The objective of the work to be performed at Fort Riley is to identify the envelope performance "signature" of the historic Stockade Building and provide recommendations for the pre-design phase of the building commissioning process. These recommendations will be applied toward the design and commissioning of the mechanical and building envelope systems during the adaptive reuse project. At that time, recommendations for the continuation of the process will be outlined.

The Building Signature

To begin the development of the building performance "signature," the CA must conduct an initial site visit. A visual (nondestructive) inspection and assessment of the building's thermal and moisture conditions should be made. From these observations and discussions with building staff, locations for sensor placement can be defined. A minimum of five T and RH dataloggers and two multi-channel thermocouple dataloggers should be placed in various locations throughout the building. These locations should represent typical conditions and potential problem areas identified during the visual inspection.

A second site visit will be conducted by the CA to download data from the dataloggers and to review and verify the preliminary findings from the initial site visit. Again, a meeting with the building staff to discuss the preliminary findings and their experience with temperature and moisture problems in the building can provide valuable insight.

With the data in hand, the CA then prepares the Envelope Performance Report. This report should present the findings in a format that will facilitate discussion of acceptable and unacceptable indoor environmental conditions and should do, at a minimum, the following:

- summarize the temperature and humidity findings
- summarize the findings of temperature profile through the wall assembly
- estimate moisture concentrations and track humidity balance
- estimate thermal and moisture buffering
- describe building environment performance "signature."

Through discussion of the findings in the Envelope Performance Report, an acceptable range of indoor environmental conditions is determined. Based on this range, the CA prepares the Building Envelope Commissioning Guidelines. The guidelines should estimate the form and severity of potential building envelope failure under conditions of elevated indoor humidity and should accurately describe the design, equipment, and control measures required to avoid future moisture problems. Once the Building Envelope Commissioning Guidelines are complete, the CA will submit them for review and acceptance to the building owner, the project design team, and other contractors and consultants involved in the commissioning process.

8 Conclusions

The building commissioning process faces difficulties in adoption as a result of potential conflicts and uncomfortable interactions with other design professionals. These commissioning guidelines for humidified structures may, due to the specialized nature of the work, demonstrate the need to move the process of commissioning buildings into the typical design and construction process.

Commissioning guidelines for the control of moisture migration involves quantifying, with a risk management approach, the performance thresholds that distinguish acceptable from unacceptable design. These criteria define allowable threshold values regarding mold growth, corrosion, loss of structural strength, and indoor air quality.

This report establishes guidelines for the commissioning of humidified buildings. The guidelines explain the role of a building envelope CA, from early in the design phase, through construction, to assuring proper operation after occupancy. This involvement includes the use of performance modeling techniques to predict the envelope performance prior to completion.

An adaptive reuse project currently in progress was presented to demonstrate how the commissioning process can also be of substantial benefit in the redevelopment and protection of historic structures.

Guidelines for the commissioning of humidified buildings is an important step toward anticipating and preventing the conditions that may lead to moisture problems, related health effects, and unnecessary building maintenance expenditures.

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