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DESIGNING AND CONSTRUCTING MILDEW-FREE HOTELS

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ABSTRACT

Many hotels in humid climates develop severe mildew problems, but others escape serious affliction. The most important factor that separates these hotels and determines which will develop mildew and which will not is a combination of design and construction decisions. In many cases, the potential for future mildew problems as a result of these decisions is unknown. However, by knowing what these critical decisions are and by making the appropriate choices at significant milestones, the designer and contractor can substantially influence the mildew prognosis for the hotel. The cost of designing and constructing a mildew-free hotel in humid climates is not necessarily greater than the cost of designing and constructing a mildew-plagued hotel. This paper focuses on the critical design and construction decisions that can be made to successfully minimize moisture and avoid mildew problems.

INTRODUCTION

Excessive moisture is the primary cause of mildew-related problems in hotels and, consequently, controlling moisture is paramount to avoiding mildew and reducing the costs associated with rehabilitating mildew damage. Mildew problems can occur exclusively within the building envelope, on surfaces within the guest rooms, or in both locations simultaneously. In addition to mildew, manifestations of the moisture problem can include stains, structural failures caused by corrosion, crumbling wallboard, and mold odors. The location and severity of these problems will largely determine the extent of future impacts on hotel operation and the magnitude of associated rehabilitation costs.

The potential moisture sources in hotel guest rooms are well known and include the following:

- Outside air infiltration induced by weather conditions and/or heating, ventilating, and air-conditioning (HVAC) systems.
- Water vapor diffusion through the building envelope due to differential vapor pressures.
- Moisture in construction materials.
- Moisture generated internally by guests and housekeeping activities.
- Water intrusion from leaks in the roof, plumbing, and building envelope.

The relative significance of each of these moisture sources as a contributor to mildew growth varies among hotels. Consequently, to avoid future mildew problems, it is important for the hotel designer and contractor to determine which moisture sources are expected to have the greatest effect on any individual hotel design project and to effectively minimize the impacts of these sources.

Although mildew problems are more severe in humid climates, there is little evidence to suggest that construction-related moisture (including leaks) and guest-generated moisture sources are any more significant in these areas than in more temperate climates. Thus, many investigators attribute the prevalence of mildew problems in humid climates to outside air infiltration and vapor drive through the building envelope. Like the other moisture sources, infiltration and vapor diffusion can be substantially reduced through the use of proper humid-climate design practices and faithful application of the design during the construction phase.

DESIGN AND CONSTRUCTION PROCESS

As shown in Figure 1, the design and construction of a new hotel typically involves the following phases: schematic design, design development, construction document preparation, construction, and post-construction start-up and commissioning.

During each phase, decisions are made that will determine the potential for future mildew problems. Industry surveys (AH&MA et al. 1990) have shown that specific design decisions in humid climates will increase the chances for future mildew problems to occur in hotel guest rooms. Evidence is growing that certain combinations of design decisions will almost guarantee future mildew problems, regardless of construction moisture conditions. Conversely, other combinations of design decisions will most likely result in mildew-free conditions and will even provide the contractor and owner

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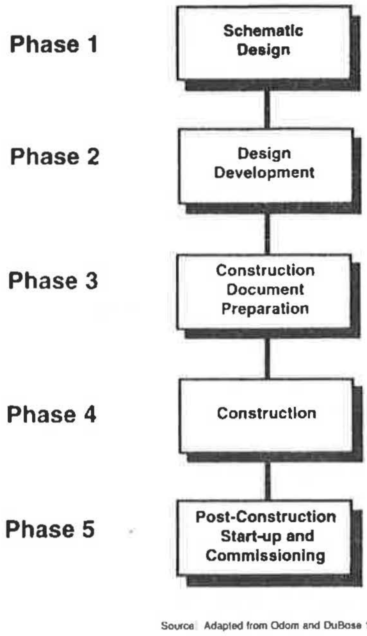


Figure 1 *Typical phases in the design and construction process.*

with some margin for error during the construction and operation process.

Some of the options that must be considered by the design team are illustrated in the decision tree in Figure 2, including the use of permeable or nonpermeable interior wall finishes, continuous or noncontinuous (intermittently operated) toilet exhaust, and a conditioned or nonconditioned source of make-up air. The greatest potential for preventing mildew-related problems exists during the design phases, when the HVAC and wall system options shown in Figure 2 must be evaluated and selected. During these design phases, building systems (architectural and mechanical) that are either conducive to or forgiving of mildew problems are selected, construction moisture control guidelines for the constructor are provided, and operational requirements to minimize mildew potential are determined. As shown in Figure 2, several decision pathways are more likely to lead to mildew in either the guest room or the wall system. For example, if nonpermeable wall finish is used in combination with a continuous toilet exhaust system and no conditioned make-up air is provided to the guest room, mildew is likely to form, regardless of the type of air-conditioning unit selected or the amount of construction-related moisture that occurs.

Typically, crucial mildew-related design decisions are divided between the architectural and mechanical design professionals. Because the architectural design for the building envelope must integrate successfully with the mechanical systems to eliminate mildew in the facility, maintaining continuous interaction between the two design professionals during design is essential. To accomplish this integration, each design professional must be aware of the critical items that need to be addressed during the design phases and how the design decisions interact to cause mildew.

The remainder of this paper provides guidelines for design professionals and others involved in hotel design

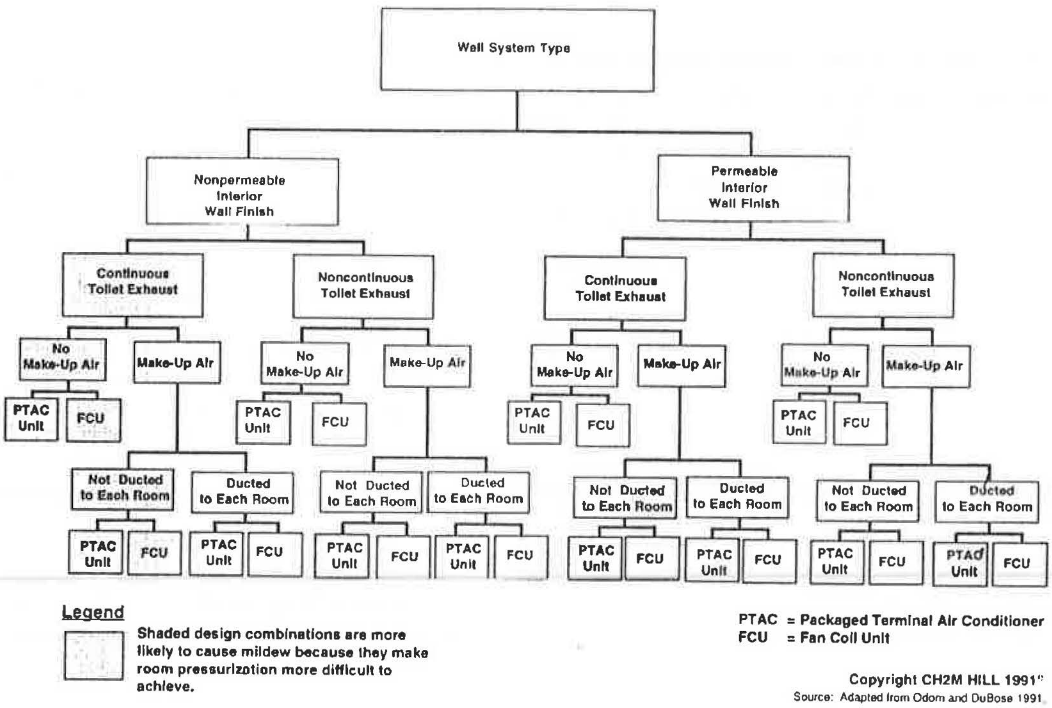
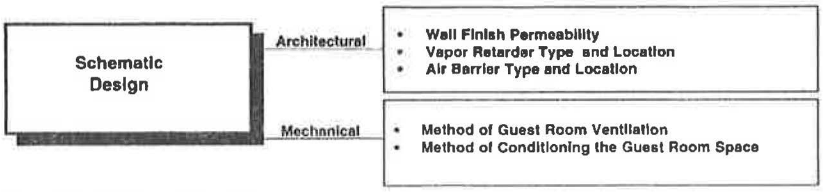


Figure 2 *Architectural and mechanical design options for hotel guest rooms.*



Source: Adapted from Odom and DuBose 1991.

Figure 3 Mildew considerations during phase 1.

and construction to help them make informed decisions for effective moisture and mildew control in each of the design and construction phases.

SCHEMATIC DESIGN

The schematic or conceptual phase is the first design phase and culminates with approximately 30% of the design completed. This phase is considered the most critical to the avoidance of future mildew problems because it is when concepts and systems are developed that will ultimately determine if the guest rooms and other areas of the hotel (public areas) will be adequately pressurized with conditioned air. Additionally, initial selections are made of wall system types and components, as well as interior and exterior wall finishes.

As described below and shown in Figure 3, the schematic design phase can be divided by function into the architectural and mechanical design tasks. Continuous interaction between these two disciplines is particularly important during this phase to prevent future mildew problems. The decision tree shown in Figure 2 graphically represents some of the critical interrelationships between the architectural and mechanical systems that can influence mildew formation.

Architectural Design Considerations

The architect makes initial decisions about the wall system design and finishes during schematic design. Systems are not actually designed during this phase, but the selections that will drive the designs in the following phase are made. Although interior finishes are selected primarily for aesthetic appeal, their ability to allow moisture to penetrate through the wall system (shown by permeance rating) can affect the potential for mildew problems within the building envelope. Therefore, it is important for the architect to coordinate with the mechanical design professional at this phase to identify the best permeance rating of the wall finish for the HVAC system being considered.

The type and location of the primary vapor retarder are typically decided during schematic design. If low-permeance construction materials are used at a point in the wall where the temperature might approach dew-point conditions, condensation of moisture from unconditioned air can occur and might become trapped within the wall. For example, vinyl wall covering, which is commonly used as an interior finish, can act as an effective (albeit unintentional) vapor retarder because of its relatively low permeability. The success of vinyl wall covering as a mildew-free interior finish, however, is largely determined by the design of the guest room mechanical system. When the HVAC design permits excessive outside air to infiltrate into a wall cavity that has vinyl wall covering on the inside wall surface, the warm, moist air inside the wall cavity may condense on cool surfaces and become trapped. This condensation, which typically occurs on the exterior side of the interior wallboard, will degrade the wallboard behind the wall covering and create an environment conducive to the growth of mildew. Thus, the selection of vinyl wall covering increases the importance of mechanical system designs in reducing the potential for outside air infiltration into the building envelope.

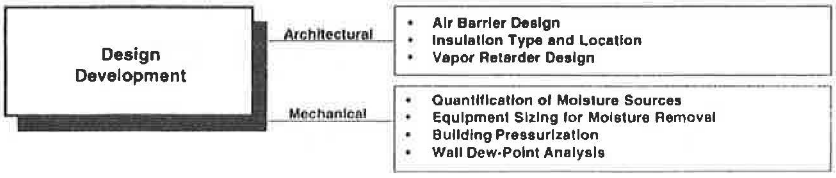
Another critical decision at this stage in the design is whether or not to include an air barrier. It is both unrealistic and expensive to use an air barrier to attempt to hermetically seal a building and prevent the infiltration of nonconditioned outside air into a negatively pressurized building envelope. Standard, good-quality building envelope construction should be adequate under most conditions to control infiltration due to normal wind and thermal forces.

Mechanical Design Considerations

During this design phase, the mechanical designer will address several processes that have a significant impact on the potential for mildew formation. As shown in Figure 2, these critical decisions involve the following options:

- Using continuous or noncontinuous exhaust for toilet ventilation.
- Whether or not to provide conditioned compensating make-up air and, if provided, ducting or not ducting it to each guest room.
- Selecting guest room air-conditioning methods.

The HVAC system options selected, and their relationship with the building envelope design, are a function of their general characteristics and the specific design parameters used. For example, the effectiveness of a



Source: Adapted from Odom and DuBose 1991

Figure 4   Mildew considerations during phase 2.

conditioned make-up air system in minimizing outside air infiltration is the result both of the type of make-up air system selected (ducted vs. nonducted) and the amount and quality of the conditioned make-up air (specific design parameters for the system). The success of the combined architectural and mechanical design will not only determine whether the hotel will develop mildew problems, but will also influence the severity and location (wall system, guest room, or both) of the problems.

DESIGN DEVELOPMENT

Design development is the second design phase and ends when the design is about 50% complete. Using the concepts developed in the schematic design phase, equipment is selected and specifications are prepared. Figure 4 illustrates some of the critical architectural and mechanical decisions made during the design development phase that can impact future mildew formation.

Architectural Design Considerations

The primary objective for the control of mold and mildew when designing the building envelope is to avoid the intrusion of moisture. As previously mentioned, it is impractical and expensive to hermetically seal a building to offset depressurization leading to outside air infiltration. Most designs include standard precautions against weather-induced moisture. In humid climates, however, additional design factors relating to air barriers, insulation, and vapor retarders must be considered to preclude excess moisture.

Air Barrier The effectiveness of an air barrier is directly proportional to the integrity of its installation and its airtightness. Thermal insulation must be installed as well to ensure that the dew point of the air barrier (which also may be the primary vapor retarder) remains above the dew point of outside air over the entire operating range of the hotel's air-conditioning system. If the dew point is reached, the air barrier will become a surface of potential condensation.

Vapor Retarder Vapor retarders are relatively impervious to moisture flow and in humid areas should be installed on the nonconditioned side of the thermal insulation system. Although the proper location of the primary vapor retarder in humid climates is toward the exterior of the building, in more temperate climates, its proper location is toward the interior of the building. Closed-cell, nonhygroscopic insulation board that includes an effective vapor retarder can provide a complete thermal and moisture insulation system. Although a vapor retarder does not have to be completely penetration-free to be effective, its effectiveness will be compromised by the presence of breaks in the retarder.

The inclusion of a vapor retarder will not guarantee the absence of mildew, but it can effectively protect the insulation from moisture intrusion and the associated reduction in thermal resistance. Because using materials with a low permeance can allow moisture to become trapped within the wall system, the permeability of the wall system components should be lowest at the exterior wall surface and become progressively higher toward the inside. Temperature and vapor pressures can be calculated for a given wall system, as shown in *ASHRAE Fundamentals*, Section 20.15 (ASHRAE 1989). These calculations will assist the designers in determining where the primary vapor barrier should be installed within a wall system to avoid approaching dew-point conditions.

Mechanical Design Considerations

During design development, the primary mechanical considerations are quantifying moisture sources through calculation of cooling and heating loads, reviewing wall system dew points, selecting and sizing equipment that will properly remove expected moisture, and maintaining adequate building pressurization.

Guest Room Air-Conditioning Load Calculations It is important in air-conditioning system design to quantify all the potential sources of moisture to ensure that the building mechanical system will adequately dehumidify the space. Potential sources of moisture include the following:

- Moisture generated by guest room occupants and internal activities such as housekeeping.
- Moisture diffusion through the building envelope due to differential vapor pressures (vapor drive).
- Introduction of nonconditioned outside air through infiltration or ventilation.

Methods of calculating cooling and heating loads are described in Chapter 23 of *ASHRAE Fundamentals* (ASHRAE 1989) and are not reiterated here. Internally generated moisture loads are usually considered by designers, so traditional equipment selection methodology will adequately remove this moisture source. However, the added moisture loads that typically occur in a guest room space from infiltration and vapor transmission are often not considered by hotel designers. The relative contribution of external moisture sources to mildew problems can be significant and normally will exceed the amount of internally generated moisture and the ability of the air conditioner to dehumidify the guest room.

Equipment Selection and Sizing for Proper Moisture Removal Mildew problems resulting from the improper design of guest room air-conditioning units cannot be reversed without modifications to the system. Consequently, proper sizing and selection of the air-conditioning equipment during design is important. In order to accomplish proper equipment sizing, all moisture sources must be identified and quantified, as described in the preceding discussion on "Guest Room Air-Conditioning Load Calculations."

As shown in the decision tree in Figure 2, two types of air-conditioning systems are most commonly used in hotel guest rooms: packaged terminal air conditioners (PTACs) and packaged unitary fan coil units (FCUs). Each type offers unique advantages and disadvantages, but mildew problems can occur in guest rooms conditioned by either type of system. Therefore, although the type of system chosen will not eliminate the problem, the method of application will be important.

Ducted guest room air-conditioning systems may affect the pressurization of the building envelope if either excessive supply- or return-side leaks exist. The PTAC system is self-contained and does not include ductwork for air distribution. Lack of ductwork minimizes the potential for duct leakage to affect pressurization of the building spaces. The FCU is designed with ductwork and is available as either a four- or two-pipe unit. FCUs typically offer greater inherent dehumidification capabilities than PTACs. If operational deficiencies arise in a PTAC system, problems are confined to a single location; in an FCU, system operational changes in a central chilled/hot water plant can cause propertywide problems that affect the dehumidification of all the guest rooms. For example, raising the discharge temperature of the chilled water can dramatically affect the dehumidification capabilities of the guest room air-handling units.

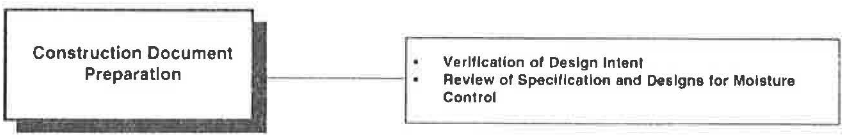
Guest room air-conditioning equipment is often sized for the peak design sensible cooling load, which is then standardized for all the guest rooms and controlled by a room thermostat. As a result, the amount of time the air-conditioning unit will run is a function only of the temperature variation rather than relative humidity. Consequently, when the rooms are below peak design load, the air-conditioning units will run for short periods of time and fail to maintain adequate humidity levels. The lack of adequate operating time requires the designer to minimize latent cooling loads to allow the air-conditioning units to properly dehumidify the guest room space. The designers must evaluate conditions that may result in lower sensible loads to verify that air-conditioning run time is sufficient to handle the anticipated latent loads.

Building Pressurization Maintaining proper building pressurization is a significant factor in reducing the infiltration of outside air into the building envelope and guest rooms and is one of the most important mechanical design considerations for the elimination of mildew problems. For example, if a continuous toilet exhaust system is used for the guest rooms, a continuous source of dehumidified make-up air must be provided and distributed directly to the guest room to keep the room under positive pressure. If a corridor make-up air pressurization system is used in combination with a continuous exhaust system, proper pressurization of the guest rooms may not be achieved. There is no guarantee that the amount of bathroom air exhausted can be replaced through the small door undercut without an excessive pressure gradient.

CONSTRUCTION DOCUMENT PREPARATION

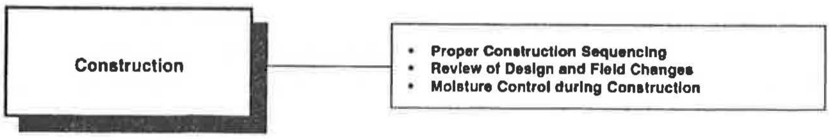
As shown in Figure 5, the final design phase involves completing the construction documents and verifying that the design drawings and specifications comply with the design intent. During this phase, the draft specifications and construction drawings should be reviewed by the entire design team, including someone who is thoroughly familiar with humid climate requirements and mechanical systems. The following specific design items should be reviewed:

- Design criteria for HVAC system sizing and equipment selection.
- Wall construction details, so that the building envelope designed by the architect complements the HVAC system designed by the mechanical engineer to aid building pressurization and minimize building infiltration.



Source: Adapted from Odom and DuBose 1991.

Figure 5 Mildew considerations during phase 3.



Source: Adapted from Odom and DuBose 1991.

Figure 6 *Mildew considerations during phase 4.*

- Building envelope dew-point location analysis under maximum heating and cooling conditions.
- Guest room load calculations, including sensible and latent dehumidification requirements.
- Start-up sequencing for all HVAC systems to preclude infiltration of nonconditioned outside air even for relatively short periods.
- Testing requirements for all HVAC systems, including documentation requirements.
- Final commissioning requirements for project acceptance and closeout.

CONSTRUCTION

Mildew considerations during construction are shown in Figure 6. The contractor selected for the hotel construction must be held accountable for any contractor-initiated changes to the design and for controlling moisture introduced during the construction process. Frequently, the selected contractor proposes alterations to the design. However, construction sequencing modifications or other contractor-proposed changes may affect the integrity of the design, requiring the owner or owner's representative to involve the design professional in reviewing any alterations to the design that could compromise its mildew-preventing characteristics.

Control of excess moisture in building materials during construction is usually a short-term problem and is most critical during material installation. Throughout the construction process, protecting building materials from exposure to inclement weather is an obvious means of controlling excess moisture. When the building envelope is being completed and interior finishes are being applied, materials begin to dry out and release naturally occurring or absorbed moisture. Although dehumidification is needed most during this time, the mechanical systems are not always performing optimally and may not provide sufficient dehumidification without also affecting building pressurization. Additional temporary sources of dehumidification may be required during this period to prevent mildew. These temporary sources of dehumidification can include portable dehumidifiers.

Proper start-up sequencing of the HVAC system is also critical to ensure proper pressurization and dehumidification of the building during the final stages of construction and thereby avoid future mildew problems. For example, mildew problems can occur if the toilet exhaust system and the guest room air-conditioning systems are operated before the make-up air system is fully functional to ensure building pressurization.

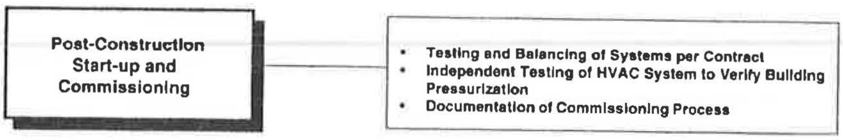
POST-CONSTRUCTION START-UP AND COMMISSIONING

Post-construction commissioning of the HVAC system is an important stage in the prevention of mildew-related problems because it is during this process that the operational adequacy of those systems is verified (Figure 7). HVAC system commissioning includes testing and balancing normally required by the design documents and should be performed by an independent testing team contracted directly to the owner. The testing procedures and instrumentation should be reviewed by the design professional to verify that the criteria agree with the intent of the design for overall system operation and are within the established design tolerances.

Post-construction testing of the HVAC system should measure the pressure differentials between building spaces to verify the building pressurization. Unlike testing and balancing using airflow quantities, which are typically required by the design documents, post-construction pressure measurements are made throughout the HVAC systems and reveal how all of the building systems interact to create either positive or negative pressure conditions.

SUMMARY

At each phase in the process of designing and constructing a hotel, decisions can be made that will control



Source: Adapted from Odom and DuBose 1991.

Figure 7 *Mildew considerations during phase 5.*

moisture and minimize mildew. Even in extremely humid climates, the potential for mildew problems is predictable and controllable if the design professionals are cognizant of the ways in which the mechanical and architectural systems interrelate to control moisture. Mildew control requires a basic understanding of equipment capabilities and limitations for HVAC systems, as well as envelope thermal and permeability characteristics under a variety of conditions. If the critical items are correctly addressed at each phase of the process, the cost of designing and constructing a mildew-free hotel should be comparable to the construction cost of a hotel that is much more susceptible to future mildew problems.

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