where ventilation cycles off too soon may prevent the building from purging human air contaminants (CO_2 and various chemical compounds from skin bacteria) overnight. Monitoring CO_2 concentrations would reveal if the overnight purge is optimal, which is when indoor values decrease to the outdoor value just before people reoccupy the building each morning.

Beard concludes, "Multipoint monitoring of key IAQ parameters in buildings can be a very effective way of achieving feedback on ventilation performance and can thereby reduce uncertainty and risk that otherwise could be present in the operation of the HVAC systems. Monitoring can therefore improve the management and control of ventilation system performance, leading to improved indoor environments."

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CASE STUDY

[In each issue, **IEQS** *presents a case study on an indoor air investigation in a particular building. The information in the cases comes from various sources, including published material, reports in the public record, and, in some cases, reports supplied by the consultants involved in the case.* **IEQS** *presents a variety of approaches to investigation and mitigation implemented by consultants with a broad range of experience, philosophies, and expertise. Inclusion of a particular case study in the newsletter does not imply* **IEQS***'s endorsement of the investigative procedures, analysis, or mitigation techniques employed in the case.* **IEQS** *invites readers to submit comments, suggestions, and questions concerning the case. At the discretion of the editors, correspondence may be presented in a future issue.]*

After Remediation, Unique Fan-Coils Are Key to Keeping Mold, Mildew Away at Hawaiian Hotel

Shortly after the US Army Community and Family Support Center opened its new 12-story Maile Tower addition at the Hale Koa Hotel on Honolulu's Waikiki Beach in Hawaii, hotel staff began to notice a decline in indoor air quality (IAQ). The US Army Community and Family Support Center is the proponent agency for the operation of US Armed Forces Recreational Center facilities around the world. All active military and retired military members of the US Armed Forces and their families may use these facilities. The construction of the Maile Tower was funded at a cost of $50 million with nonappropriated funds (nontaxpayer dollars). Part of the hotel tower's cost included an extensive program to ensure quality construction. Despite that conscientious effort at quality assurance, the building developed high humidity that triggered mold growth and mildew, making the room air feel damp and degrading the room wall covering.

Background and Investigation

The US Army Community and Family Support Center's contractor completed the Maile Tower in 1995. When the excess moisture and mildew became apparent, hotel staff members tried to control it by putting room fan-coil units at their coolest setting. As room temperatures dropped to about 60°F, however, relative humidity increased to nearly 90%, which foiled their action. When other attempts to combat the problems failed, the Community and Family Support Center enlisted CH2M Hill's aid early in 1997. With more than 7,200 employees at 84 US offices and nearly 20 overseas offices, CH2M Hill — headquartered in Orlando, Florida — packs plenty of firepower and bills itself as the largest environmental engineering firm based in the US.

CH2M Hill joined forces with Bruce Parzych, the Community and Family Support Center's project manager for the Hale Koa Hotel expansion, and the Army Corps of Engineers, Pacific Ocean District to identify the causes of the excess moisture, correct them, and defeat the mold. CH2M Hill engineers studied the building for about a year and pinpointed three key factors that promoted the indoor moisture, mold, and mildew problems. First, the HVAC fan-coil units didn't adequately dehumidify tower guestrooms. Second, the bathroom-exhaust system caused unconditioned outdoor air to infiltrate the building, boosting humidity. Finally, the vapor retardant — a vinyl wall covering — was deployed

in the wrong place and ended up promoting mold growth in guestrooms.

The fan-coil units in the tower guestrooms were designed to add outside air and to cool and dehumidify the rooms. Guests could set the fan to low, medium, high, or off, and could also set the thermostat from 60°F to 90°F. When a room's air temperature reached or dipped below the thermostat setting, however, the thermostat shut off the flow of chilled water to the cooling coil, and the system stopped removing humidity from the air. Meanwhile, the system continued to supply the room with mixed indoor and outdoor air. Furthermore, outdoor air frequently is less than 70°F, which is cool enough to maintain room temperature without using the cooling coil. The moisture content of the outdoor air, however, can raise room humidity to 70%, the level that supports mold growth.

CH2M Hill targeted another factor that compounded the problem. When planners design a hotel, they typically specify fan-coil units that are large enough to cool rooms even when outdoor temperature, relative humidity, solar load, and the number of occupants per room are highest. Therefore, the units typically operate at less than peak loads more than 95% of the time. At the Maile Tower, the original fan-coil units were oversized, and as a result, they cooled and dehumidified less than expected. As a result, CH2M Hill calculated that over the course of a typical day, the ventilation system added five gallons of moisture to a room. The fan-coil unit removed some of that moisture, but room furnishings also absorbed much of it. Investigators noticed, for example, that early in the day, bedspreads in rooms felt damp from the humidity.

CH2M Hill also discovered that hotel rooms in the tower were negatively pressured, which prompted unconditioned outdoor air to infiltrate. Why? Each hotel room's bathroom exhaust system operated continuously, but guests could switch off their fan-coil unit, which inadvertently eliminated positive pressure. In addition, the bathroom fans were also oversized and ductwork leaked, and this let air flow into gaps in wall cavities. In fact, the overall amount of air drawn through gaps and unsealed ducts was sufficient to negatively pressurize guestrooms even when the fan-coil units operated.

Separately, the investigators discovered that the indoor dew point of the fan-coil unit cavity equaled the outdoor dew point, and the surface temperature of the chilled-water pipe insulation was less than the dew point temperature. As a result, moisture condensing on the insulation fostered mold growth.

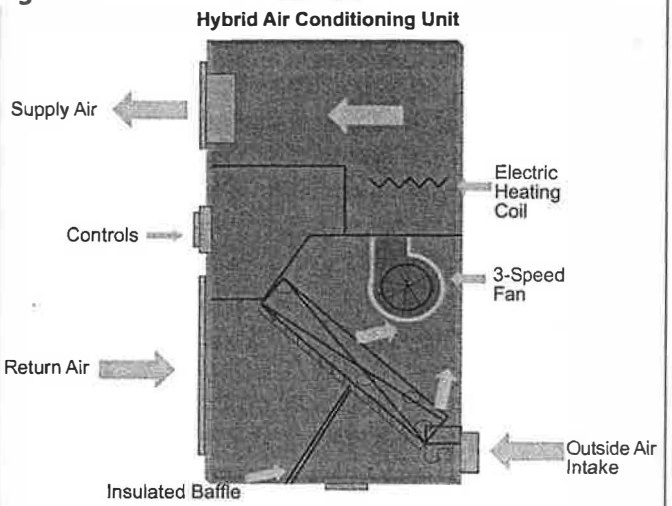
Finally, since vapor barriers belong on the warm side of thermal insulation in a wall, vapor barriers in hot, humid climates should be on the building exterior. At the Hale Koa Hotel, the vinyl wall-covering vapor barrier inside guestrooms let humidity condense on the gypsum wallboard the vinyl covered; naturally, mold began to grow there. In some rooms, in fact, you could even see the black and purple mold growing on the wallboard through the wall cover, according to David MacPhaul, CH2M Hill's project manager and senior HVAC engineer for the Hale Koa project. Typically, those rooms were on the higher floors, which sustained greater infiltration of humid air, he said.

Determining Solutions

After planning its strategy, the CH2M Hill staff recommended the following three changes, which the Community and Family Support Center and the hotel agreed to:

1. The hotel should replace the standard fan-coil air-conditioning units in each room with new hybrid fan-coil units (see Figure 5). The hybrid fan-coil unit design was similar to the fan-coil units originally installed in the Maile Tower but with an important exception: the hybrid units would continuously dehumidify outdoor air before supplying it to the guestrooms even when the room temperature was less than the thermostat setting, whereas the original units dehumidified only when the room temperature exceeded the thermostat setting. Since guests controlled their room's thermostat, CH2M Hill engineers designed the hybrid fan-coil units to maintain the indoor dew point at less than 60°F, which would prevent mold from growing in rooms. The hybrid design modifies the unit's coil so that part of it dehumidifies the outside air immediately and part dehumidifies the combined outdoor and return air before supplying it to a

Figure 5



Components of a hybrid fan-coil unit.

room. The 396 hybrid units cost more than new standard units, but ultimately saved the Community and Family Support Center $1 million by eliminating the need to construct a separate return-air system. That made the extra $40,000 cost for the hybrid units seem minor.

2. The environmental engineers recommended that the hotel replace the bathroom exhaust fans that ran continuously with fans that operated only when the bathroom lights were turned on. CH2M Hill replaced the continuously operating original roof fans with smaller roof fans and installed bathroom-ceiling fans connected to the original ducts. It also had the gaps between the exhaust registers and ductwork properly sealed. Building codes required that some air be constantly drawn through the original exhaust system, so the new system continuously draws a small amount of air (10 cubic feet per minute, [cfm]) through the room. When someone switches on the bathroom light, the system exhausts 50 cfm of air.
3. CH2M Hill's engineers recommended that the hotel replace the guestroom vinyl wall coverings with a permeable wall finish.

CH2M Hill staff began to design these changes in February 1998. The Community and Family Support Center also authorized CH2M Hill to use building-commissioning principles to test the proposed renovations before they were made. Building commissioning ensures that systems are designed, installed, tested, and operated to meet the owner's needs. For the Hale Koa, this process included:

- Making pilot installations of the proposed changes.
- Performing quality control of products before they were installed.
- Overseeing installation and related construction.
- Testing surface and air samples for microbes in remediated areas and adjacent corridors and guestrooms. This process also included standard testing, adjusting, and balancing of HVAC components when installed, and testing them after guests reoccupied the rooms to verify that the new hybrid fan-coil units maintained indoor environmental conditions that were comfortable for the guests while also preventing mold from returning under "real-life" conditions.

Pilot Testing the Solutions

The team tested the proposed solutions in four tower guestrooms. They installed hybrid fan-coil units purchased from two different manufacturers. They also used different permeable wall finishes in each of the four rooms to determine which one best combined ease of use, durability, and attractiveness. They tested varying construction techniques to learn which best controlled dust and microbial spores in the rooms. The design of the original bathroom exhaust system prevented them from testing their new bathroom exhaust fans. After making the modifications needed to allow testing, they monitored the test rooms to record their temperatures and dew points, and for comparison, they also monitored Room 544, which they hadn't modified.

The hybrid fan-coil units maintained the room dew point temperatures below 60°F for the entire test period, which lasted from June through July 1998. It also maintained a stable dew point at a level that people would find comfortable. By contrast, the room with the original fan-coil unit allowed rapid 5°F-6°F dew point changes as the cooling coil cycled on and off. The unit also couldn't keep the dew point below 60°F for extended periods. Even when its dew point was below 60°F, Room 544 with a standard cooling unit had relative humidity that cycled rapidly between 65% and 80%, whereas the hybrid unit test room's relative humidity hovered near 60%.

To control dust and spores during construction in the four test rooms, CH2M Hill used containment barriers and negative-air machines. Samples of room, corridor, and outdoor air during demolition indicated that this approach confined the dust and spores to the construction zone.

Each hybrid fan-coil unit prototype had some unique features, such as slide-out motors and fans, which the other lacked. After the tests, the hotel staff asked that certain maintenance features from each make of hybrid unit be included in the model the hotel would ultimately purchase and install. CH2M Hill engineers dutifully made those changes in their final drawings and specifications.

Pilot Testing Leads to Modified Construction Plan

The pilot test pinpointed the need for other changes, including a modified approach to the actual construction itself. The team originally planned to remediate and renovate one floor at a time while keeping vacant, as a noise buffer, a floor above and below the floor under construction. During the pilot test, however, engineers realized this would force them to drain all chilled water return and supply risers at the start and finish of construction on each of the 11 floors of rooms. (The hotel lobby took up the first floor.) To avoid this, CH2M Hill chose to renovate vertically in blocks of four rooms per floor on all 11 floors. They used two other rooms per floor to store room furniture. This minimized furniture moving and damage and reduced the number of times they drained chilled water.

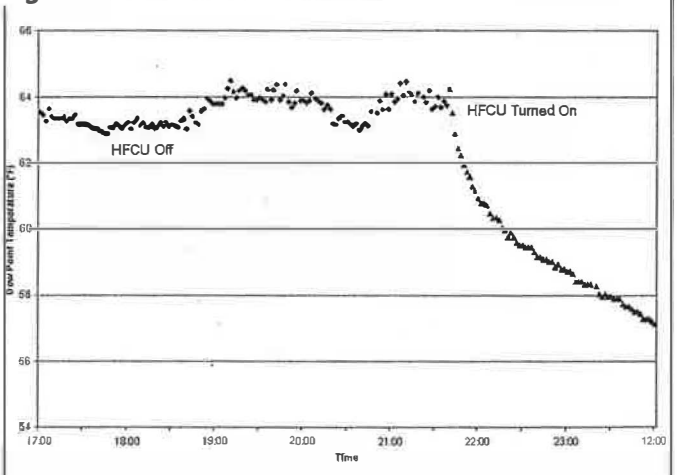
The vertical construction method provided the hotel with another bonus, according to Parzych. "When we originally planned the more typical horizontal construction approach, we figured we'd have to take three floors, or 25% of the 396 guestrooms, in the tower out of service," Parzych explained. "The vertical construction approach only took 66 rooms out of service. The hotel has an average occupancy rate of 99.2%, so from a room-revenue standpoint, keeping an extra 33 rooms in service over the course of construction saved the hotel a substantial amount of money." On top of that, the revised construction method didn't take any longer than the original would have, he said. "It took about nine months to remediate and renovate the tower, and we started and ended on the same dates as in our original plan." Parzych told ***IEQS*** that he hopes to use the vertical construction technique on the older part of the Hale Koa Hotel, which is scheduled for major renovations due to age.

CH2M Hill closely monitored the remediation and renovations, especially during the first phase to ensure that the remediation and construction firms thoroughly understood all specifications and expectations. It tested and balanced the hybrid fan-coil units before guests entered the renovated rooms and installed sensors in about 10% of the renovated rooms to verify that the units performed as expected to adequately control temperature and relative humidity as well as to monitor electrical use.

The dew points in rooms can still rise to the same level as outdoors when guests shut off the hybrid units. Sensors in one room tracked this and recorded a dew point that basically remained at 64°F for three hours. When the guest turned the hybrid unit on again, the dew point dropped below 60°F within an hour (see Figure 6).

The team knew that if room temperatures remained at or below the thermostat setting for an extended period, the hybrid unit secondary fan would remain off, preventing it from providing any additional humidity control, and moisture entering the room wouldn't be removed through a cooling coil. To determine what impact this scenario would have, CH2M Hill personnel modified a thermostat in a

Figure 6



When guests switched on a hybrid fan-coil unit after it had been off for several hours, the dew point decreased from 64°F to below 60°F in less than an hour.

room to prevent secondary cooling or heating. Only the outdoor-air portion of the unit's coil was dehumidifying. They kept fan speed constant at each setting (low, medium, or high) for one to two days and, even at the low setting, the dew point remained between 54°F and 59°F (see Figure 7).

Finally, they used sensors to record electrical use. With the fan on high speed, the hybrid unit used about 100 watts (W) of power. With the fan on high and the reheat on, the unit used 600 W. Some averages, in fact, were much higher than the team expected. They observed, however, that when guests maintained the thermostat at a constant setting, they used little or no heat, and electrical use would tend to mirror the expected power consumption by the fan alone.

Conclusions and Results

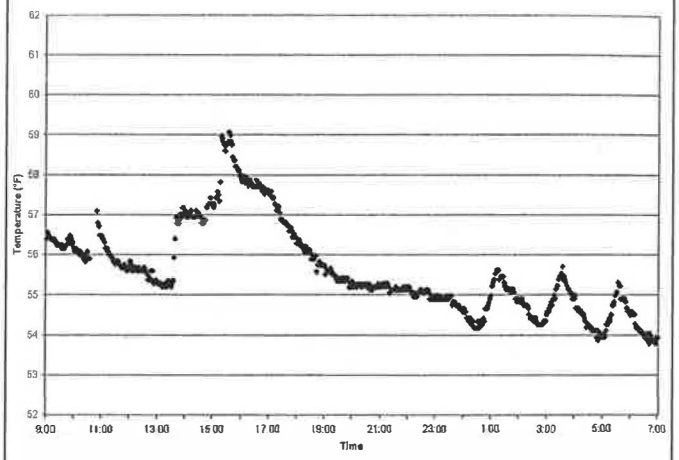
CH2M Hill concluded that the renovations would produce a building envelope and HVAC system that would properly dehumidify the air in the tower hotel rooms, as well as prevent condensation within wall cavities. Furthermore, the building commissioning techniques demonstrated that the renovations would minimize moisture, prevent the return of mold, and maintain a comfortable temperature and relative humidity for guests. The renovations were completed in August 1999, and the hybrid units and modified bathroom exhaust systems are, in fact, keeping dew points below 60°F and maintaining positive pressure in the hotel rooms.

CH2M Hill made two recommendations to increase energy efficiency. First, hotel staff members should set thermostats to 74°F rather than 70°F as they were previously instructed. Second, they should put a message in each guestroom that explains that leaving the thermostat on a single setting produces the most comfortable temperatures and relative humidity.

In all, the project cost $5.2 million. What are the overall results of the building commissioning process and renovations?

"The solutions CH2M Hill provided have been fantastic," Parzych told ***IEQS***. "The rooms were

Figure 7



Using only the outdoor portion of the hybrid unit's coil, even at its lowest fan setting, the dew point remained 59°F or less.

damp before, and now they're dry and comfortable. The hybrid fan-coil units are doing what they were supposed to and more. Guests keep their room temperatures higher and still feel comfortable. Cooling their rooms less has provided us with some modest energy-cost savings, though it is less than a year since the renovations were done, so we can't yet compare energy costs for a full year. Regardless, we haven't had any more mold or mildew problems, the rooms are very comfortable, many guests are coming back repeatedly, and we plan to install hybrid fan-coil units in our other tower when we renovate it."

CH2M Hill's MacPhaul added, "This project also underscores the advantage of the building commissioning process over the quality control process, and the hybrid fan-coil unit has again proven itself in a hot, humid environment." Overall, hybrid units remain a small percentage of the fan-coil units installed each year in buildings, MacPhaul said, but their use is growing as more people learn about them.

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