RESIDENTIAL DEHUMIDIFICATION AND VENTILATION SYSTEMS RESEARCH FOR HOT-HUMID CLIMATES

Armin F. Rudd[1], Joseph W. Lstiburek[2], Ph.D., P.Eng, and Kohta Ueno[3]

[1,2,3] *Building Science Corporation, Westford, Massachusetts 01886, U.S.A.*

ABSTRACT

Twenty homes were tested and monitored in Houston, Texas, U.S.A. to evaluate humidity control performance and operating cost of six different integrated dehumidification and ventilation systems that could be applied by production homebuilders. Fourteen houses had one of the six integrated dehumidification and ventilation systems and also met a high standard of energy efficiency criteria. Six houses were reference houses--three having the same high standard of energy efficiency measures and controlled mechanical ventilation, while three met code minimums for energy efficiency and did not have mechanical ventilation. Temperature and relative humidity was monitored at four living space locations and in the attic where the space conditioning equipment and air distribution ducts were located. Equipment operational time was monitored for heating, cooling, dehumidification, and ventilation. Results showed that energy efficiency measures, combined with controlled mechanical ventilation, change the sensible and latent cooling load fractions such that dehumidification separate from the cooling system is required to maintain indoor relative humidity below 60% throughout the year. The system providing the best overall value, including humidity control, first cost, and operating cost involved a standard dehumidifier located in a hall closet with a louvered door and central-fan-integrated supply ventilation with fan cycling.

KEYWORDS

dehumidification, ventilation, humidity, cooling, fan-cycling

BACKGROUND

Like year-around temperature control, year-around humidity control in homes is important to improve indoor air quality, building durability, and owner satisfaction, Lstiburek (2002a). In hot-humid climates, constructing thermally efficient building enclosures with controlled mechanical ventilation provides unique challenges for controlling humidity levels, Lstiburek (2002b). As sensible heat gain is reduced for a building, primarily through better windows, more insulation, and locating air distribution ducts inside conditioned space, the latent load increases in proportion to the total load to the point that conventional cooling systems have difficulty keeping humidity levels within comfortable and healthy limits, Lstiburek (1993). Conventional cooling systems are controlled by thermostats that sense temperature and not humidity, hence, during periods of low sensible load and high latent load, high indoor humidity levels can be problematic. The objective of this study was to identify the best performing, most energy-efficient and cost-effective techniques to provide controlled mechanical ventilation and humidity control for residences in hot-humid climates with thermally efficient building enclosures. It was known that these strategies vary greatly in first cost, however, the whole-house humidity control performance and operating cost was much less known.

RESEARCH APPROACH

A total of 20 homes were included in the year-long study conducted in cooperation with a production homebuilder in Houston, Texas. Six different integrated dehumidification and ventilation systems were evaluated in homes that were at least 30% better than that required by the Model Energy Code 1995. These homes were constructed with unvented-cathedralized (conditioned) attics, Rudd et al (1998a) and Rudd et al (2000). Three reference houses had the same energy efficiency measures and controlled mechanical ventilation, but no dehumidification separate from cooling. Three other reference houses met code minimums for energy efficiency, had no mechanical ventilation or dehumidification separate from cooling, and had conventional vented attics. The central-fan-integrated supply ventilation system used in many of the houses, Rudd (1998b) and Rudd et al (2001), involved an outside air duct routed from a fresh air location outdoors to the return side of the air handler. A manual damper was installed in the outside air duct to set the flow rate at 60 to 80 ft^3/min, while a motorized damper was installed to control the air flow volume as a function of time. Outside air was intermittently drawn in by normal thermostat-driven operation of the central cooling and heating system, and when necessary, by automatic activation of the central air handler blower via a fan cycling control. Automatic timer control of the motorized damper limited over-ventilation. Table 1 provides a detailed description of the six different dehumidification and ventilation systems.

Test Plan

The test plan was designed to evaluate the humidity control performance, energy consumption, and cost effectiveness of the different integrated dehumidification and ventilation strategies. All of the houses were commissioned for the study, including setting the appropriate controls and setting the ventilation air flow rate. Proper air filtration and condensate drainage were verified. The 17 houses with improved energy efficiency measures were inspected for insulation quality and spectrally selective glazing. These houses were also tested for compliance with building enclosure leakage, duct leakage, and room pressurization criteria.

Monitoring Instrumentation

All of the houses were instrumented for hourly monitoring of temperature and relative humidity at four interior locations (master bedroom, two other bedrooms, and near the thermostat) and one location in the attic. Hourly outdoor temperature and relative humidity were monitored. The mechanical equipment was instrumented for monitoring operational time of heating, cooling, central air handler fan, ventilation fan, and dehumidification. Hourly electrical energy consumption was calculated by multiplying the measured power draw for each device by the measured on-time. The monitoring period was one year.

TABLE 1

Description of the six dehumidification and ventilation systems

System 1: Stand-alone dehumidifier in hall closet with central-fan-integrated supply ventilation and 33% fan cycling (2 homes tested) This system involved installation of an off-the-shelf 50-pint-per-day dehumidifier in an interior closet with a louvered door near the central air return. The dehumidistat built into the dehumidifier energized the dehumidifier whenever the humidity level rose above the user setting. The fan cycling control was set to make sure the central fan operated at least 10 minutes each half hour to distribute ventilation air and average air conditions throughout the house.
System 2: Stand-alone dehumidifier in conditioned attic with central-fan-integrated supply ventilation and 33% fan cycling (2 homes tested) This system involved installation of an off-the-shelf 50 pint/day dehumidifier in the conditioned attic with a small return air duct located near the dehumidifier outlet. The dehumidistat built into the dehumidifier energized the dehumidifier whenever the humidity level rose above the user setting.
System 3: Ultra-Aire Dehumidification and Ventilation System with 17% central fan cycling (3 homes tested) This system involved installation of a ducted, high-efficiency, air filtering, ventilating dehumidifier located in the conditioned attic. The Ultra-Aire blower operated continuously on low speed, drawing in about 40 cfm of outside air and about 120 cfm of recirculated house air. The mixed air was filtered and supplied to the main supply air trunk of the central air distribution system. A remote dehumidistat located in the living space activated the dehumidifier compressor if the humidity level rose above the user setting. The central fan cycling control was set to assure at least 10 minutes operation each hour.
System 4: Filter-Vent Ventilation with Dehumidifier in Ducted Cabinet, with 17% central fan cycling (3 homes tested) This system involved installation of a blower/filter unit and a stand-alone dehumidifier placed inside a sheet-metal cabinet located in the conditioned attic. The Filter-Vent blower operated continuously on low speed, drawing in about 40 cfm of outside air and about 120 cfm of recirculated house air. The mixed air was filtered and ducted through the dehumidifier cabinet where the dehumidifiers' built-in dehumidistat energized the dehumidifier whenever the humidity level rose above the user setting. The air was then supplied to the main supply trunk of the central air distribution system.
System 5: Energy Recovery Ventilator (ERV) System with 17% central fan cycling (3 homes tested) This system included a desiccant wheel energy exchanger installed in the conditioned attic. The ERV blower operated continuously, drawing in about 40 cfm of outside air, and exhausting about 40 cfm of inside air. In the energy exchanger, heat and moisture were exchanged between the incoming outside air and the outgoing inside air, so that as much as 60% of the outside heat and moisture was rejected. In this way, during the cooling season, introduction of heat and moisture from ventilation air was lessened. This system could not dehumidify house air, but only lessen the need for dehumidification. The house exhaust air stream exited through the roof, and the tempered ventilation air was supplied to the main return air trunk of the central air distribution system.
System 6: Enhanced Dehumidification with 2-stage Cooling and ECM Fan with central-fan-integrated supply ventilation and 33% fan cycling (1 home tested) This system included the installation of a Carrier cooling system with a 2-stage compressor, an electronically commutated motor (ECM) indoor fan unit, and a Thermidistat controller. The system was designed to allow better matching of the cooling load to the cooling system capacity, avoiding poor humidity control inherent with short-cycling of over-sized systems. The ECM fan allows lowering the air flow rate over the cooling coil for enhanced moisture removal. The Thermidistat control is both a temperature and humidity controller that coordinates the 2-stage compressor and ECM fan features to achieve enhanced humidity control, especially at start-up and part-load conditions.

RESULTS

The cost of each system over the Standard Reference house was: $400 for stand-alone in closet; $430 for stand-alone in attic; $1,253 for Ultra-Aire; $749 for Filter-Vent; $1,470 for ERV; $1,735 for 2-stage+ECM; and $190 for the Energy-efficient Reference house.

Humidity Control Performance

There was some inconsistency in humidity control performance among houses in each group, largely explained by known occupancy effects and mechanical equipment problems. Thus, some houses were considered outliers in the humidity control and operating cost analysis. In order to allow a more compact comparison of the results between system categories, a representative home from each category was selected for this reporting. The humidity control performance of these selected homes is shown in Figure 1.

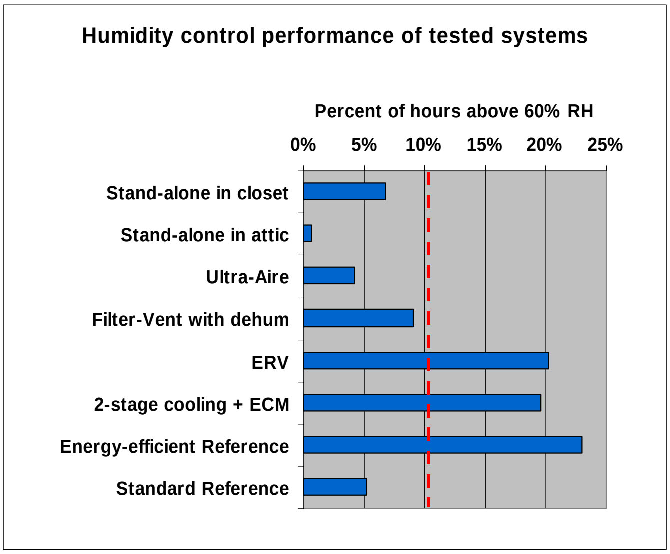

Figure 1: Humidity control performance of the representative house in each category

As shown in Figure 1, all of the homes with dehumidification separate from cooling and the energy-efficient reference house had fewer than 10% of the monitored hours with relative humidity greater than 60%. In comparison, all of the homes without dehumidification separate from cooling had relative humidity greater than 60% about 20% of the year. This two-fold difference points to the need for additional humidity control means in energy-efficient homes in hot-humid climates.

Energy Consumption Performance

The stacked bar chart in Figure 2 gives a detailed, yet big picture view of the electrical energy consumed by each piece of space conditioning and ventilation equipment. While both houses are similar in size, total energy consumed for the Energy-efficient Reference house was less than half that of the Standard Reference house. However, because of the reduced sensible heat gain and the resultant reduction in cooling system operation, humidity control performance in the energy-efficient house was inferior. Cooling energy consumption was predictably more for the Stand-alone system houses and the Energy-efficient Reference house (larger 2-story houses) compared to the Ultra-Aire, Filter-Vent, ERV, and 2-Stage with ECM system houses (smaller 1-story houses). Energy consumed for central fan cycling to affect ventilation air distribution and whole-house mixing was about 2 kW-h/day, or about one-third of the total air handler energy consumption for the non-ECM fan systems with 33% duty cycle. It was about half that for the systems with 17% duty cycle. Fan cycling energy consumption for the ECM fan system was about one-third that of the standard fan systems with permanent split capacitor motors. Constant ventilation fan operation for the Ultra-Aire, Filter-Vent, and ERV systems was about 3 kW-h/day, or about three times the fan cycling energy for those systems. Energy consumption for dehumidification was low for the Stand-alone dehumidifier in the hall closet system and the Ultra-Aire system. For the 2-stage cooling system, dehumidification energy was considered to be that of first stage cooling alone, which was active 16% of the time. In general, dehumidification energy consumption was a small fraction of the total energy except for the Stand-alone in attic system and the

Filter-Vent system where dehumidification was high because of the location of the dehumidistat (discussed in more detail further on).

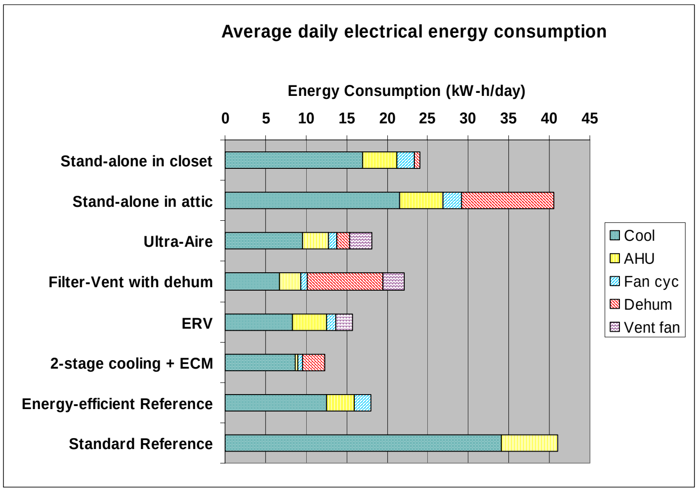

Figure 2: Average daily electrical energy consumption for all mechanical equipment monitored

DISCUSSION

Table 2 gives a discussion of the results for each system or house category.

TABLE 2
Discussion of results by house type or system

Standard Reference House: Minimum code requirements for energy-efficiency, and no whole-house mechanical ventilation system nor dehumidification separate from the central cooling system While the cooling system runtimes were predictably shorter due to cooling system over-sizing, there was little correlation between cooling system short-cycling and high relative humidity. Humidity control performance was good in these houses, but cooling energy consumption was very high.
Energy-efficient Reference House: 30% better than code requirements, and central-fan-integrated supply ventilation with 33% central fan cycling These houses had much lower sensible heat gain compared to the Standard Reference houses. Therefore the cooling system operated less, removing less moisture, and resulted in poorer humidity control performance. Indoor humidity was generally higher with low cooling system on-time fraction.
System 1: Stand-alone dehumidifier in hall closet with central-fan-integrated supply ventilation and 33% central fan cycling This is the recommended system—it had the lowest initial cost and operating cost while providing good humidity control. It does require loss of a lower closet shelf, and some occupants may be sensitive to the new noise.
System 2: Stand-alone dehumidifier in conditioned attic with central-fan-integrated supply ventilation and 33% central fan cycling This system had low initial cost and very good humidity control. However, the dehumidifier operating cost was high since the attic was kept very dry (30 to 40 percent relative humidity), even though the dehumidistat setting was the same for all systems with that type of dehumidifier. It is suspected that that type of dehumidistat is very sensitive to the warmer daytime temperatures experienced in the conditioned attics (5 to 10 F warmer than the living space). The dehumidistat should be located remotely in the living space.
System 3: Ultra-Aire Dehumidification and Ventilation System with 17% central fan cycling This system showed excellent humidity control but had the highest first cost and higher operating cost, the latter due to the continuously operating ventilation fan. This is an excellent system for less price-sensitive markets.
System 4: Filter-Vent Ventilation with Dehumidifier in Ducted Cabinet and 17% central fan cycling This system showed generally good humidity control but had higher first cost and much higher operating cost. The high operating cost was due to the high runtime fraction of the dehumidifier and the continuously operating ventilation fan. The high dehumidifier runtime was probably due to the dehumidistat location inside the metal cabinet in the conditioned attic instead of in the living space.

System 5: Energy Recovery Ventilator (ERV) System with 17% central fan cycling This system did not show good humidity control performance. Its first cost was high but operating cost was low. While this system had the capability to lessen the latent load of ventilation air, it could not dehumidify the conditioned space. This can be thought of as dehumidification in "ventilation mode" as opposed to dehumidification in "recirculation mode." This system exhibited less control over indoor relative humidity than the systems with recirculation mode dehumidification capability.
System 6: Enhanced Dehumidification with 2-stage Cooling and ECM fan with central-fan-integrated supply ventilation and 33% central fan cycling The 2-stage compressor with ECM air handler and Thermidistat control did not show good humidity control performance. Its first cost was the highest but operating cost was low. We believe that the humidity control performance could be improved if the fan speed could be lower during first-stage cooling (keeping the evaporator coil temperature colder), and if the fan was stopped at the end of cooling calls.

CONCLUSIONS

All of the systems with dehumidification of recirculated air exhibited much better humidity control than the Energy Recovery Ventilation (ERV) systems with dehumidification of ventilation air only. If the problem of elevated humidity was due to the introduction of ventilation air, then the Energy Recovery Ventilation system should have mitigated the problem. Therefore, the problem of high humidity does not seem to lie with mechanical ventilation. All of the systems with dehumidification separate from the cooling system showed better humidity control than those with dehumidification only as part of the central cooling system. Therefore, the solution does not lie with the cooling system, which cannot respond to a need for moisture removal once the temperature setpoint is met. The problem of elevated humidity in energy-efficient homes in hot-humid climates seems to be a result of normal interior moisture generation combined with lowered sensible heat gain resulting in less cooling system operation, and an inadequate match of the equipment latent capacity to the latent load. High-performance windows, insulation, and locating air distribution ducts inside conditioned space all serve to reduce sensible heat gain to the extent that the latent cooling fraction is often outside the capacity range of even the best currently available mass-market residential cooling equipment. The solution, for now, appears to be employing dehumidification separate from cooling in hot-humid locations.

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