VENTILATION REQUIREMENTS IN HOT, HUMID CLIMATES

I.S. Walker M. H. Sherman
Staff Scientist Senior Scientist
Lawrence Berkeley National Laboratory
Berkeley CA

ABSTRACT

In 2003 ASHRAE approved the nation's first residential ventilation standard, ASHRAE Standard 62.2. Meeting this standard in new construction requires the use of mechanical ventilation, which in turn can often significantly increase the latent load faced in new homes. As the thermal performance of houses improves, sensible loads have decreased and existing equipment may not be able to deal with the remaining latent load. Failure to take this load into account can result in poor indoor air quality and moisture-related problems. As part of work through the Building America program, LBNL has simulated the effects of mechanical ventilation systems that meet ASHRAE Standard 62.2 on ventilation, energy use and indoor humidity levels. In order to capture moisture related HVAC system operation, such as the lack of dehumidification from typical air conditioning systems at the beginning of each cycle, we developed a simulation tool that operates on a minute-by-minute basis and utilizes a dynamic model of air conditioner performance. This paper looks in depth at the implications of these simulations in humid climates.

INTRODUCTION

A key step in designing a home's HVAC system is determining the correct amount of ventilation and the optimal system with which to provide it. There is no shortage of guidance on how much ventilation to use. The standard of care for ventilation system design is probably the 62 series of ASHRAE standards (62.1-2004 for non-residential buildings and 62.2-2004 for residential buildings). The reader can find a variety of books and other publications with recommendations including from ASHRAE (http://www.ashrae.org)

Ventilation is not an end in itself, but is part of the system intended to provide a desired level of indoor environmental quality. One of the key aspects of indoor environmental quality is controlling contaminants that can have adverse health impacts on the occupants. As a practical matter, however, an HVAC designer rarely knows the sources, their emission rates or appropriate dose-response relationships and therefore is usually provided guidance in terms of the things he can control, like the ventilation and its efficiency. This is why standards like 62 focus on ventilation.

Another key step in design can be to consider the internal moisture balance of the space. In many climates the resulting indoor humidity is typically so far from any problem area that such consideration is not usually done, but in hot, humid climates failure to properly consider moisture balances and the attendant latent loads can lead to discomfort or moisture-related problems such as mold.

In cold or dry climates, ventilation acts to remove internally generated moisture from plants, bathing, cooking and other normal human activities. Ventilation standards are not set with this as a criterion, but it is a benefit of ventilation. In hot, humid climates, this benefit is reduced and for many hours of the year, ventilation can be a source of moisture rather than a removal mechanism. Other removal mechanism must then be considered—most of which will require energy to operate.

Dehumidification occurs in the course of conventional air conditioning, but as new construction improves, the sensible load on air conditioning systems decreases and so, therefore, does that incidental dehumidification. Since the latent load is not decreasing, there is the potential of having more times where supplemental dehumidification may be necessary.

This paper uses detailed simulation tools to explore the range of humidities that conventional systems would generate in high-performance new homes and the impact that different ventilation strategies may have. The implications of acceptance criteria on the need for supplemental dehumidification will also be explored.

BACKGROUND

Ventilation[1] is principally used to maintain acceptable indoor air quality by controlling indoor contaminant concentrations—and hence doses—and minimizing occupant exposures to the contaminants. Whole-building ventilation dilutes contaminants in the indoor air with air that (ostensibly) does not contain those contaminants, and is normally used for controlling unavoidable, generic or non-specific contaminants[2]. When specific contaminant sources can be identified, they are best dealt with directly through source control methods such as local exhaust. For example, bathroom and cooking contaminants including water vapor are best addressed by exhaust fans in those spaces. Volatile Organic Compounds (VOC) are often best addressed by changes in composition or use of specific materials. Sherman (2006a) provides a broad overview of the need for ventilation and the general kinds of systems that could be considered.

Control of interior humidity levels is important for occupant comfort, building serviceability and indoor air quality. Excessively high humidities can be avoided in cold or dry climates by using outdoor air to dilute indoor moisture. In hot, humid climates, however, humidity control often has to be provided by the HVAC system.

A traditional air conditioning system provides some humidity control (i.e. latent load removal) at the same time as it provides cooling (i.e. sensible load removal). Conventional systems have well known limits to their sensible heat ratio and cannot provide arbitrary amounts of dehumidification independent of cooling. This situation used to be acceptable in many cases because the sensible load was large enough that the incidental amount of dehumidification that came along with it was sufficient to control the indoor humidity.

In an ever increasing number of homes the sensible load is not sufficient to provide the necessary dehumidification, which results in occupant complaints, building failures, and health and safety problems. Condominiums and other multifamily buildings are one class of buildings that suffer this problem due to their low sensible load. Increasingly, however, high performance buildings such as those promulgated by Building America are becoming vulnerable to these problems as their loads are reduced.

In a hot, humid climate one could mitigate moisture problems by reducing the amount of ventilation. As Sherman (2006) points out, such a ventilation reduction would likely reduce the latent load, but would also reduce the acceptability of indoor air quality by increasing the occupants exposure to indoor contaminants.

MOISTURE BALANCE

Keeping indoor humidity in an acceptable range is a balance between moisture sources and moisture removal mechanisms. In this sense moisture plays the role of any other contaminant one might consider in the indoor air, but unlike the contaminants that drive need for ventilation, there are potentially significant sources of moisture in both the indoor and outdoor environment.

Internal Moisture Sources

Moisture production is an unavoidable result of human activities. Respiration and perspiration are part of life and reasonably well understood. Cooking, bathing, washing etc. also produce substantial amounts of unavoidable moisture. Plants, pets, unvented combustion and other things common in homes produce moisture as well. Some data exist for typical amounts of these activities, but what little there is focused more on colder climates where some of these values would be expected to differ compared to hot, humid climates. In new homes, moisture problems often occur in the first couple of years due to construction moisture from sources such as drying concrete, materials that were wetted during construction (e.g., due to rain), or high moisture content lumber.

External Moisture Sources

There is undoubtedly more external moisture than internal moisture, principally in the form of precipitation. Building envelopes are intended to keep such moisture out of the indoor environment. Failure of the weather-resistive barrier to do so can lead to major problems, but that issue is not our focus here. The principle external moisture source to consider here is that contained in the air that infiltrates or is brought in through a ventilation system. The moisture content of this air depends strongly on geographical location and time of year and local weather. There is a large range of outdoor

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[1] In this paper "Ventilation" will refer to any form of outdoor air exchange that can provide dilution including mechanical ventilation, natural ventilation and infiltration.

[2] When outdoor air contains significant amounts of contaminants it cannot successfully be used for dilution and the indoor concentrations cannot be reduced below background levels without air cleaning. For the purposes of this paper, however, the outdoor air will be assumed to contain no significant contaminants of concern.

humidities from essentially zero in cold climates in the winter to a maximum of about 0.02 $kgH_2O/kgair$ in humid climates. Different placs will have different frequencies of occurance for outdoor humidities and it is important to look at this complete distribution rather than individual peak or design conditions when assessing the impact of external moisture.

Internal removal mechanisms

Moisture can be removed from the indoor by cooling the air below the dew point and draining away the resulting condensation. This happens naturally on an evaporator coil. The resulting air is much colder than is comfortable (e.g. 55F) and must be heated to be comfortable. This heat normally comes from the load in the space—which is the intended purpose of air conditioning. But if that load is insufficient another source of heat is required. Other moisture removal mechanisms (e.g. desiccants) could also be used but are currently not readily available in a suitable from for residential applications.

External removal mechanisms

Air exchange is an external removal concept whenever the outdoor humidity is lower than humidity of the air being exhausted. This is almost always true for bath and kitchen exhaust flows. In cold or dry climates this is almost always true for any indoor air. Even in many hot, humid climates indoor air has a higher humidity than outdoor for a considerable part of the year.

SIMULATIONS

As part of work through the Building America program, LBNL has simulated the effects of mechanical ventilation systems that meet ASHRAE Standard 62.2 on ventilation, energy use and indoor humidity levels for houses that meet current (2005) International Energy Conservation Code requirements. The simulation tool used, REGCAP (Walker et al. 1999, 2001, 2004), is capable of simulating minute-by-minute system operation as well as heat and mass balance. Fourteen different systems were simulated in three humid climates (Charlotte, Houston and Kansas City) for a full year of operation. The data presented here are for a two-story, 2000 ft^2 house with three bedrooms and four occupants in Houston – the most humid of these three climates.

For this study, a mass-balance moisture model was used that determined the moisture content of air in four locations: indoor, attic, supply ducts and return ducts. A storage term was also included that interacts with the indoor air that accounts for the dampening effect of interior furnishings. The interior loads were based on Table 1, taken from draft ASHRAE Standard 160P[3] (ASHRAE (2006)) combined with data from on moisture generated by bathing, cooking and dishwashing (Emmerich (2005)). This separation of moisture for these specific sources is important because the simulations used exhaust fans operating in bathrooms and kitchens to directly exhaust this moisture (as required by ASHRAE 62.2). Some simulations used the net generation rate with kitchen and bath sources removed. Others used the total generation rate with no kitchen or bath exhaust fan operation.

Table 1. Internal occupancy based moisture generation rates from ASHRAE Draft Standard 160P

Number of Occupants	Moisture generation rate	Bathing, Cooking and Dishwashing	Net generation rate
	kg/day	kg/day	kg/day
2	7.8	3.2	4.6
3	12.1	3.6	8.5
4	13.8	4.0	9.8
5	14.7	4.4	10.3

Moisture removal by the air conditioner operation used estimates of latent capacity that include both steady-state and dynamic operation combined with a model of the coil that tracks the quantity of moisture on the coil, sets an upper limit to the amount of moisture on the coil and sets condensation and evaporation rates that determine the mass fluxes to and from the coil. At the beginning of each air conditioner cycle, the system takes three minutes to ramp-up to full latent capacity. The following calculation method is based on work by Henderson (1998) and Henderson and Rengarahan (1996).

The mass flux of moisture onto the coil depends on the latent capacity. REGCAP calculates total capacity and EER as functions of outdoor temperature, air handler flow and refrigerant charge. The latent capacity is calculated using the estimate of total capacity and sensible heat ratio (SHR). The SHR is based on the humidity ratio (hr) of air entering the coil. The following empirical correlation between steady-state SHR_{ss} and hr was developed based on laboratory data (Farzad and O'Neal (1988a and b), Rodriguez (1995), and O'Neal et al. (1999)).

$$SHR_{ss} = 1 - 50(hr - 0.005) \tag{1}$$

[3] The draft ASHRAE standard used data from several sources. A more detailed discussion is given by Tenwolde and Walker (2001).

The latent model separates condensing and evaporating components with the total mass of moisture on the coil being tracked through the simulations. Condensation occurs when the cooling system operates and evaporation occurs when the coil is wet. Because the steady-state SHR is the net of condensation and evaporation, the moisture removal from the air to the coil during air conditioner operation (m_{cond}(kg/s)) is calculated as:

$$m_{cond} = \frac{(1 - SHR)Q_{total}}{2501000} \quad (2)$$

Where Q_{total} is the total system capacity (W) and 250100 is the latent heat of condensation/evaporation (J/kg). This is the mass flux of moisture onto the coil and it accumulates until the coil is saturated. This accumulation has a limit of 300g/rated ton of moisture. For a three ton system, 900g of moisture can be stored on the coil. Once this quantity of moisture is on the coil, any further mass transport of moisture to the coil leaves the system and is the latent removal used in the moisture mass balance.

When the blower fan is running without air conditioning, the condensed mass on the coil is evaporated. The evaporation rate is estimated based on a coil taking 30 minutes (1800 s) to dry. The evaporation rate (m_{evap}) is then given by:

$$m_{evap} = \frac{-0.3kg / ratedton \times ratedtons}{1800s} \quad (3)$$

This evaporation rate is maintained until there is no moisture remaining on the coil.

DISCUSSION

Ventilation is often cited as the moisture culprit in hot, humid climates, but if one is trying to allocate moisture load between internal and external sources it is important to look at the humidity of the outdoor air compared to the desired indoor humidity target. The higher the indoor target the more hours where outdoor air can help control moisture; the lower the indoor target the more hours where active dehumidification may be necessary.

Figure 1 shows a cumulative probability distribution of outdoor humidity ratio for several cities in hot, humid climates. For reference, the upper humidity ratio allowed by ASHRAE Standard 55 is shown by a vertical dashed line (i.e., Humidity ratio of about 0.012)[4]. The top line is for Kansas City and it shows that 80% of the time, the outdoor air is drier than the putative target and ventilation helps to reduce humidity. Looking at Miami, the situation is quite different and for roughly 70% of the time outdoor air brings in moisture that must be removed. For Jacksonville and Houston the fraction is around 50%.

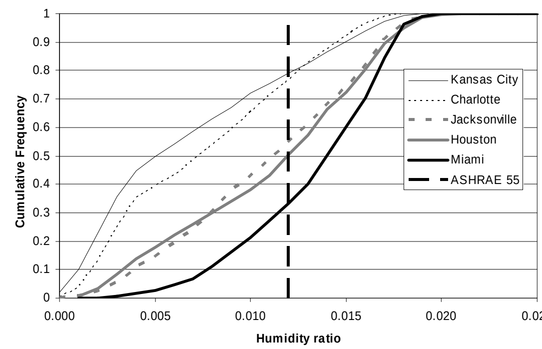

Figure 1: Cumulative frequency for humidity ratios in various climates

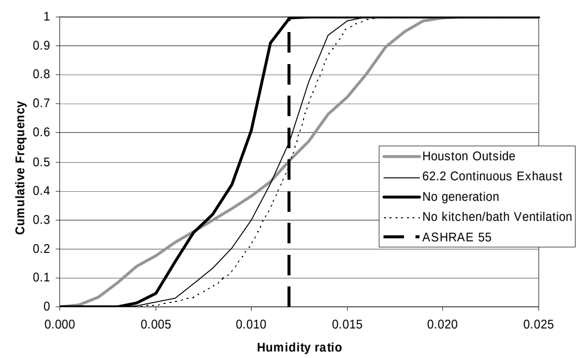

Figure 2: Cumulative frequency for indoor humidity ratios for a house in Houston

Houston, we have a problem.

Let us examine this issue a bit further by looking at one climate in a bit more detail. Figure 2 shows cumulative distributions for Houston. In addition to the outdoor data we have plotted the results of our indoor simulations for three cases. The

[4] Field studies have shown (e.g., Rudd and Henderson (2006)) that upper indoor humidty levels in residences encompass a large range, with some houses operating significantly above or below this reference value. This variability obvioiusly has a major influence on wether or ventilation with outside air increases or decreases indoor humidity, however, for the purposes of this discussion we will use the ASHRAE Standard 55 reference while bearing in mind that individual houses may differ significantly.

first two cases have a 62.2 compliant continuously operating exhaust with either constant generation (discussed above) or no internal generation with an average of 0.277 ACH. The third case has the same continuous exhaust, but is not 62.2 compliant because it has no kitchen or bath fans (with a resultant decrease in ventilation rate to 0.251 ACH and increase in moisture generation).

If you compare the indoor curves with the outdoor curve at low end of the plot, you see that there appears to be an offset with the indoor curves being to the right of the outdoor curve. This corresponds to the fact that internal moisture generation increases the indoor humidity relative to the outdoor level—just as indoor pollutant sources increase the indoor concentration relative to the outdoor concentration. Throughout this entire region ventilation is a moisture control technology and is decreasing the indoor humidity. As we go to higher humidity ratios we see the internal curves rising at a faster rate than the outdoor curve. It is this regime in which the air conditioner is having some success at controlling the indoor humidity. Without kitchen and bath fans the increase in internal generation leads to increased indoor moisture.

Because the data in Figure 2 are not correlated in time, a clearer picture of the potential for ventilation moisture control is given by the differences between indoor and outdoor humidity ratios shown in Figure 3. Figure 3 illustrates the cumulative frequency of humidity differences where a positive difference means that it is more humid indoors. For 50% of the year ventilation acts to dehumidify the house for the 62.2 continuous exhaust case. The higher humidity due to not venting kitchen and bathroom humidity means that ventilation dehumidifies the house for about 55% of the year.

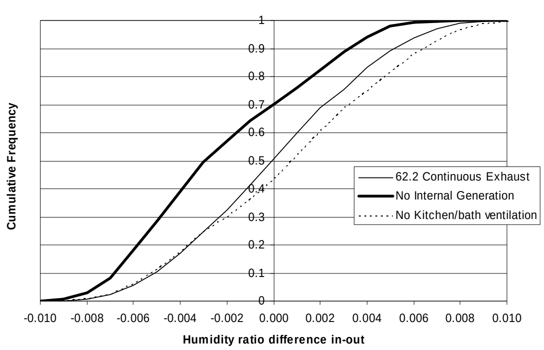

Figure 3: Cumulative frequency for differences between indoor and outdoor humidity ratios for a house in Houston

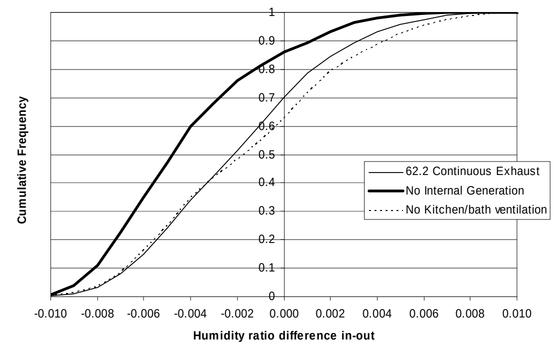

Figure 4: Cumulative frequency for differences between indoor and outdoor humidity ratios for the cooling season only in Houston

In order to focus on times when the air conditioner would be operating to dehumidify indoor air, Figure 4 shows the cumulative frequency of indoor-outdoor humidity ratio differences for the cooling season only. This reduces the fraction of time that ventilation provides moisture control – but it is still around 30% for the 62.2 continuous exhaust case.

The effect of climate on indoor-outdoor humidity differences is shown in Figure 5 for the 62.2 continuous exhaust case. As expected, the less humid outdoor conditions in Charlotte and Kansas City lead to more times when ventilation air does not contribute to the humidity load and can be used for moisture control: almost half the time for Kansas city. Similarly, a climate more humid than Houston, such as Miami, would show more hours when ventilation contributes to humidity load.

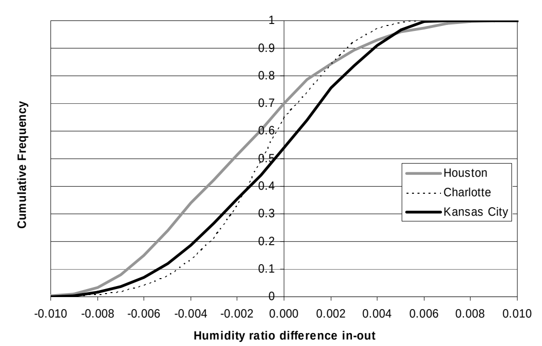

Figure 5: Cumulative frequency for differences between indoor and outdoor humidity ratios (cooling season only) for a 62.2 compliant ventilation system in three climates

Management of internal moisture

Internal moisture sources are usually more important in the moisture balance than outdoor ones. The air over cooking food or in the bathroom when baths or showers have taken place may have very high moisture contents. Most of the time these humidity ratios will be substantially higher than those outdoors and, as our results show, the most efficient thing to do is to exhaust that air directly outdoors—even if it means humid outdoor air will be brought in. It is, therefore, important for all houses even in hot, humid climates to have kitchen and bath exhaust ventilation in order to minimize latent loads.

SUMMARY AND CONCLUSIONS

Ventilation is often seen a culprit in hot, humid climates because it brings in moisture which can cause mold problems and/or increase loads on the cooling system. At times this is certainly true, but ventilation is required to dilute contaminants generated indoors and must be present at minimum amounts to provide acceptable indoor air quality.

Moisture in some ways acts as an indoor contaminant. For much of the year in a conventionally cooled house the indoor humidity is higher than the outdoor humidity indicating that ventilation is still a moisture control mechanism. The requirement to provide kitchen and bath venting in 62.2 has advantages for moisture control.

The need for supplemental dehumidification is as much determined by any ventilation loads as it is by the desired indoor conditions and the uncontrolled interior moisture sources. Further research is necessary in these areas to come to definitive conclusions.

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