

EXTERIOR MOISTURE CREATES INDOOR HUMIDITY, DEWPOINT & BIOAEROSOL INCREASES IN HEALTHY BUILDINGS

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ABSTRACT

Indoor environmental parameters and bioaerosols were studied in relation to exterior moisture events in healthy buildings. Significant differences between both relative humidity and dewpoint were observed when paired samples from wet and dry climatological conditions were compared ($p < 0.001$). Relative humidity averaged almost 20 percent (7.2 scale points) higher indoors following rainfall. Bioaerosols determined during these climatological conditions were observed to remain elevated up to three days following heavy rainfall periods in building locations exhibiting increased humidity. Results indicate that heavy rainfalls can produce sustained indoor bioaerosol increases in healthy buildings. HVAC systems cannot control such high level, short-lived exterior moisture. These findings are discussed relative to HVAC system limitations, and bioaerosol concentration implications, in hot and humid climates.

INDEX TERMS

Indoor Air Quality, Bioaerosols, Relative Humidity, Moisture, Dewpoint

INTRODUCTION

The problematic role of fungal growth generating office or other non-industrial indoor air quality (IAQ) issues has been widely reported (Croft et al. 1986; Burge 1990; Harrison et al. 1992; Flannigan and Miller 1994; Crawford and Filip 1998; Hodgson et al. 1998; Ryan et al. 1998; Samimi 1998). Sick Building Syndrome (SBS) symptoms have been causally associated with *Penicillium chrysogenum* (Meyer et al. 1998), while others have found a significant correlation between increased *Penicillium* prevalence and SBS in school buildings involved in IAQ complaints (Cooley et al. 1998). There is therefore clear justification for increased attention to total bioaerosol concentrations when investigating certain IAQ complaints.

The American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) has long recognized the role that outdoor to indoor vapor pressure differential plays in high humidity climates. Accordingly, it is currently recommended that moisture load attributable to diffusion through the building envelope be considered in the control of indoor air temperature and humidity (ASHRAE 1993). Control of relative humidity within ASHRAE acceptable ranges is dependent on thermal insulation, vapor barriers, proper sizing of the air conditioning system, and the use of reheat. In most applications climatological data averages

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based on 2160 hours of winter data or 2928 hours of summer data are utilized to design HVAC systems to adequately control indoor air for the purposes of comfort and the reduction of mold and mildew (ASHRAE 1991). The impact of considerable exterior moisture events (such as heavy rainfall) on these operational goals appears to have been unappreciated. This project specifically studied the importance these relatively short duration events have on interior environmental measures and bioaerosol concentrations.

METHODS

Thirty (30) healthy buildings served by conventional HVAC systems employing reheat air conditioning for humidity control were selected for study. Indoor sampling locations were selected to maximize potential differences among both the environmental measures and bioaerosols collected at those locations. Specifically, paired samples, from a potentially moist site ("Wet") and a typically dry location ("Dry"), were collected from all facilities twice, during meteorologically defined "Low" (rain) and "Hi" (no rain) sampling periods (n=120). Hi periods were defined as all days of 0.1 inches or less of precipitation subsequent to at least a consecutive three day (72 hour) period of 0.1 inches or less of precipitation (i.e., dry periods began three days after the most recent rainfall of 0.1 inches or less). Low periods were defined as any 60 hour period commencing 12 hours following at least 0.5 inches of precipitation, inclusive (i.e., 12-72 hours after the beginning of rainfall exceeding 0.5 inches in a 24 hour period). Actual on-site rainfall was verified with instruments atop one of the study buildings, as later confirmed from U.S. National Weather Service data.

Environmental factors of room relative humidity (RH), and room temperature, were recorded for all areas; dewpoints were calculated from this data for all sample locations using standard formulae (NWS 1997). Temperature and relative humidity were assessed both indoors and outdoors. Accuracy of the direct reading probe was compared to a calibrated recording hygrometer, with readings within 2% of scale taken as acceptable.

Culturable bioaerosol samples were collected with single stage impactor samplers. Five minute samples were collected indoors (sampled air volume 0.142 m³). Air was impacted into plastic petri plates containing 27 ml of media. Trypticase Soy Agar (TSA) was utilized for mesophilic fungi and total bacteria enumeration, and Inhibitory Mold Agar (IMA) was used for fungi enumeration. Three minute bioaerosol samples were also collected from outdoor locations each day facilities were sampled.

Plates were grown out in fluorescent light at a room temperature of 22°C (71°F) in a standard microbiological laboratory. Plate counts were determined by the positive hole method (Andersen 1958). Counts were related to volume of air sampled in order to report colony forming units per cubic meter air sampled (CFU/m³).

Environmental measures of relative humidity and dewpoint were compared across climatological condition and building sampling location dichotomies using ANOVA. Tukey confidence intervals were computed to ensure acceptable overall significance levels when making *a priori* pairwise multiple comparisons. Descriptive point estimates and measures of variability for these bioaerosols were computed by climatological condition and location.

RESULTS

Sampling was conducted over a 6 week period in the fall of 1997 (November 3 - December 16, 1997). A two-way ANOVA was performed on data for climatological conditions by sampling location within the building (Table 1). Results reveal that climatological category (Hi/Low) was the major cause for the differences in environmental parameters (p values ranged from <0.001 - 0.007), as opposed to sampling location category (Wet/Dry) results. Tukey's pairwise confidence intervals confirmed the importance that climatological category had in determining the differences seen. On average there was a 19% elevation (7.2% absolute scale difference) of mean relative humidity during climatological Low conditions compared with Hi conditions (two sample t-test, $\alpha=0.05$).

Table 1. Two-way ANOVA: Climatological Conditions (Hi/Low) by Location (Wet/Dry)

| | Relative Humidity | | | Dewpoint | | |
|----------------|-----------------------------------------|-------|-------------|----------------------------------------|-------|-------------|
| | P value | Mean | 95% CI | P value | Mean | 95% CI |
| <u>Hi/Low</u> | <0.001 | | | <0.001 | | |
| | Hi | 43.13 | 41.40-45.00 | Hi | 49.04 | 47.80-50.40 |
| | Low | 51.40 | 49.50-53.10 | Low | 53.71 | 52.40-55.00 |
| | Tukey's 95% CI: 3.43-13.11 ^Δ | | | Tukey's 95% CI: 1.31-3.36 ^Δ | | |
| <u>Wet/Dry</u> | 0.385 | | | 0.061 | | |
| | Wet | 47.84 | 45.96-49.68 | Wet | 52.24 | 51.00-54.00 |
| | Dry | 46.69 | 44.88-48.48 | Dry | 50.50 | 49.20-51.84 |
| | Tukey's 95% CI: -3.74-5.94 | | | Tukey's 95% CI: -1.62-5.51 | | |

^Δ Significant Difference ($\alpha=0.05$)

Indoor environmental data from this period showed distinct differences between relative humidity and dewpoint according to climatological condition. Differences between climatological Hi/-- and Low/-- data were highly significant ($p<0.001$) for both relative humidity and dewpoint (two-tailed two sample t-test). Visible condensation problems at floor or wall surfaces were not seen owing to the high dry bulb temperatures of the indoor air and massive masonry construction of most of the facilities.

Results of culturable bioaerosols are shown in Table 2. Significant differences ($p=0.030$) were indicated between Hi/Dry (GM=252 CFU/m³) and Low/Wet (GM=494 CFU/m³) conditions for mesophilic fungi and bacteria when means of the logs were tested (two-tailed two sample t-test). Differences for indoor fungi grown on IMA between Hi/Dry (GM=106 CFU/m³) and Low/Wet (GM=235 CFU/m³) were significant as well ($p=0.020$).

Table 2. Bioaerosol Results by Climate Condition and Sampling Location

| <i>Condition/ Location</i> | <i>mean CFU/m³</i> | <i>median CFU/m³</i> | <i>SD^A</i> | <i>GM^B CFU/ m³</i> | <i>GSD^C</i> |
|-------------------------------------|-----------------------------------|-------------------------------------|-----------------------|--------------------------------------------------|------------------------|
| Mesophilic Fungi and Bacteria (TSA) | | | | | |
| Hi/Dry (n=30) | 345 | 272 | 299.8 | 252 * | 2.3 |
| Low/Wet (n=30) | 1289 | 424 | 2147.5 | 494 * | 4.5 |
| IMA Grown Fungi | | | | | |
| Hi/Dry (n=30) | 171 | 106 | 173.8 | 106 [∞] | 3.0 |
| Low/Wet (n=30) | 494 | 205 | 659.9 | 235 [∞] | 3.6 |

* Significant difference (p=0.030) [∞] Significant difference (p=0.020)

^A Standard Deviation

^B Geometric Mean

^C Geometric Standard Deviation

Outdoor bioaerosol data were collected on all days that indoor bioaerosols were sampled. There were no significant differences between the means of logs of either outdoor IMA grown fungi (Hi and Low GM = 863 and 773 CFU/m³, respectively; p=0.910) or outdoor mesophilic fungi and bacteria (Hi and Low GM = 1,176 and 941 CFU/m³, respectively; p=0.770), by weather condition ($\alpha=0.05$; data not presented).

DISCUSSION

ANOVA results definitively indicate that exterior rainfall events can result in moisture loading indoors. This finding is challenging to any notion that HVAC engineering setpoints are capable of maintaining precise interior relative humidity within tightly defined ranges in the hot and humid Gulf Coast region of the U.S. With indoor temperatures in non-industrial or office buildings typically maintained about 70 °F (21°C), any significant elevation of the indoor dewpoint could bring temperature and dewpoint values close enough to result in localized condensation at surfaces. Those events, in turn, could potentially account for the microbial blooms found in this study.

Results demonstrate that in office building occupancies interior relative humidity and bioaerosol concentrations vary in conjunction with exterior climatological events. It is rational to believe that increased indoor bioaerosol levels of the magnitude seen in this study, especially if caused by a toxigenic or highly allergenic microbial species, could be responsible for instances of SBS or Building Related Illness (BRI) (e.g., Legionnaires' Disease) under certain circumstances.

While the indoor bioaerosol blooms seen in this study might conceivably be attributed to the introduction of outside air into the facilities, there were no significant differences between outdoor air concentrations of either mesophilic fungi and bacteria, or selective fungi, by weather condition. Furthermore, because of the low replacement air used in the facilities while in reheat configuration (typically less than 15%) and the relatively energy efficient windows and other openings present, mechanical introduction of outside contamination is not

believed to contribute to the concentration increases seen. It is most likely that the bioaerosol increases are due to interior microbial growth precipitated by increases in total interior moisture resulting from exterior moisture intrusion.

CONCLUSIONS & IMPLICATIONS

In the absence of IAQ complaints in any of the study buildings, they could be characterized as healthy. Results indicate that routinely encountered, short-lived climatological moisture events produce sustained indoor humidity and bioaerosol increases immediately following such events in healthy buildings. This study could be faulted for not characterizing the genera of bacteria and fungi detected. Given the ANOVA results the findings are significant enough to warrant further research on the ecological balance of the contaminants found.

Conventional HVAC systems relying on variable air dampers or reheat air conditioning to limit indoor humidity may be unable to completely control interior moisture under exterior moisture loading conditions normally encountered in hot and humid climates.

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