Objective and subjective responses to low relative humidity in an office intervention study

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ABSTRACT

The impact of dry indoor air on comfort and health in winter was investigated in a crossover intervention study in two floors of an office building in northern Sweden. The indoor air humidity (normally 10–20% RH) was raised to 23–24% RH, one floor at a time, using steam humidifiers. Questionnaires and objective (clinical) measurements were applied. The following effects of increased humidity were significant, though small: the air was evaluated as less dry (though still on the dry side of neutral), eyes smarted less (by 10% of full scale) eye irritation decreased (by 11%), symptoms of dry throat, mouth, lips and skin were reduced, and it was easier to concentrate. The results confirm similar laboratory findings in 5 h exposures (Fang *et al*., 2003, reported at this conference) to 2 week field exposures, but as the effects observed were again small, they do not provide sufficient justification for installing humidifiers.

INDEX TERMS

Dryness; Field intervention study; Humidity; Perception of environment; SBS

INTRODUCTION

ASHRAE Standard 62-2001 (ASHRAE, 2001a) recommends an optimum indoor air humidity range of 30–60% RH. In the ASHRAE Handbook of Fundamentals (ASHRAE, 2001b) a reference (in Chapter 8, p. 12) to Liviana *et al*. (1988), gives the basis for the lower limit. In the study they found that eye discomfort increases with time if the dew point temperature is less than 2ºC. However, in a large-scale field study it was found that the sensation of dryness was not significantly associated with measured air humidity in the range 10–40% RH (Sundell and Lindvall, 1993). It was also found that the perception of dryness in homes was negatively associated with indoor 'dampness' problems, including condensation on windows, similar to results from a recent large scale study (DBH) (Hägerhed *et al*., 2003). It has been hypothesized that the sensation of 'dryness' and irritation of the mucous membranes may be more due to indoor air pollutants, than physical dryness of air. Exposure to clean air with a low humidity of 9% RH for 78 h was found to have no effect on mucous membranes or on general comfort (Andersen *et al*., 1974). The objective of the study was to provide a rational basis for informed decisions on measures that might be taken to raise indoor air humidity levels.

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METHODS

The normally low air humidity in offices in a cold, dry region (Östersund, northern Sweden during the winter) was raised through humidification. Normally indoor air humidity is between 10–20% RH and the intention was to raise the RH to about 30% RH. The experiment was carried out as far as possible as a crossover intervention study with one repetition. The participants in the experiment were two comparable groups, one initially assigned to the low and one to the raised humidity condition, each group subsequently experiencing the other condition for a corresponding period of time (Table 1). The settings of temperature (supply temperature 19ºC and ventilation rates (1000 l/s to each office floor, corresponding to around 20 L/s and person) were constant. The groups were the occupants of two different floors in the same office building. The groups occupying the different floors were not significantly different with regard to age, sex, height, weight, smoking habits or allergy including asthma. Each humidity condition was maintained for two successive weeks.

Table 1 Experimental matrix

Intervention week #	Conditions	
	Floor A	Floor B
1–2	Normal	Humidified
3–4	Humidified	Normal
5–6	Normal	Humidified

The experiment started on Monday, January 21 and lasted until Friday, March 1, 2002—in total, 6 weeks of experiment. One floor was humidified up to a set-point of 30% RH at 22ºC and the other floor was kept at the normal humidity that the outdoor air gave when heated to room temperature (Table 1).

The location of the building is in Östersund, Sweden. The office in question is a phone bank (the customers make their banking transactions by phone). It is situated in Frösö Strand outside downtown Östersund. The building is part of a complex consisting of four connected buildings erected in 1967. The whole building was first used as a hospital. In 1996, the use of the building was changed into a student residence and in 1999 into the current bank-office. The bank occupies the two top floors of the total four floors in the building.

The offices are served by the same HVAC-unit situated on the roof. It is a pressure controlled mechanical supply-exhaust system with a rotating heat recovery unit. The existing HVAC-system was modified to make it possible to humidify one of the bank-office floors at a time. The ventilation system was arranged so that outdoor air passes through a damper, followed by a rotating heat exchanger, a filter, the fan, a heating coil, a damper and enters a plenum box. From the box, the air is distributed into eight ducts leading to different parts of the building, two ducts to every floor. The plenum box is situated 400 mm above the floor leaving only a small space for installation of the humidification system. Defensor® MK5 visual steam humidifiers connected to a special steam distribution system (OptiSorp) were installed.

The questionnaire was distributed and the clinical tests were applied on Wednesday each week. The objective tests that were applied throughout the 6-week period were: Eyes: Mucus Ferning (self-administrated, deposited on microscope slides and photographed within 24 h in a microscope for later classification by a medically-qualified eye specialist); Blink-rate (evaluated from digital video records of the face in close-up, taken while volunteers were engaged in a reading task). Nose: Nasal Peak Flow at inspiration (using a standard clinical flow meter). Skin: Corneometer (an instrument that measures skin dryness); Trans Epidermal

Water Loss (TEWL) (Evaporimeter, measurement of the rate of passive diffusion of water through the skin).

Visual-analogue (VA) scales were used to record the participants' sensations and subjective symptom intensity (Figure 1). Two different types of scales were used, one 100 mm long with end labels only (used for most of the SBS symptoms) and another type 50 mm long with end labels and four intermediate labels (used for irritation).

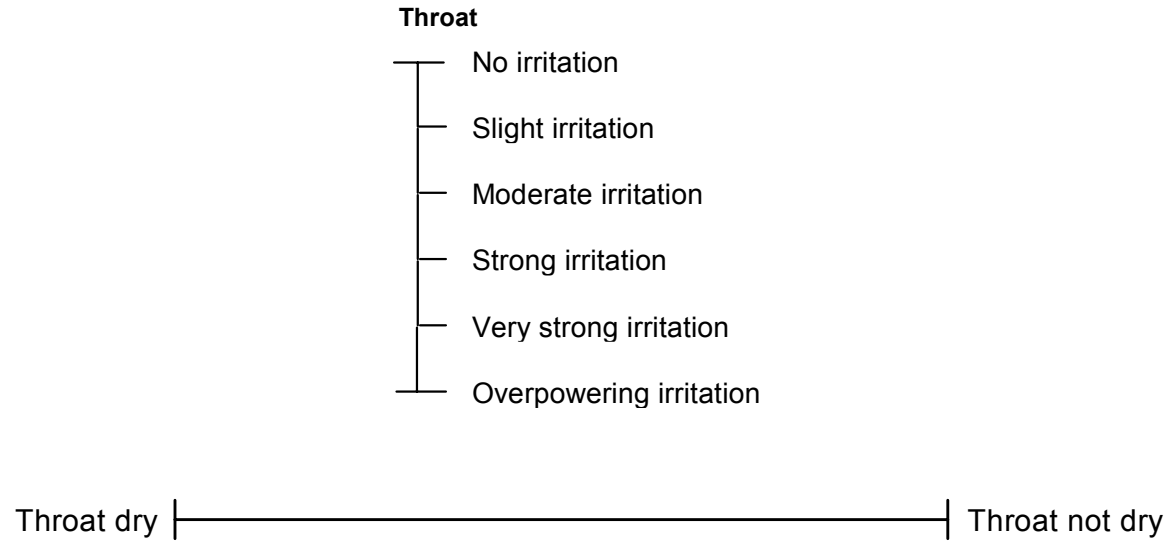

Figure 1 VA-scales used to collect data during the experiment.

All full time employees, in all 106 persons, were asked to participate in the investigation. Twenty-nine persons on Floor A participated throughout all weeks in the questionnaires and 15 persons participated in the objective tests. On Floor B 28 persons answered completed all six questionnaires and 15 persons took part in the objective tests.

Statistics

Data from the questionnaire (used every week) and clinical measurements were coded and arranged according to the actual average absolute humidity in each week. Missing data for a given subject were replaced using the other subjects' average for that missing week, a procedure that does not alter the group average results obtained in each week. The data were then analysed within subjects using the non-parametric 'Page test for ordered alternatives' (Siegel and Castellan, 1988). The Page test is a one-tailed test for an effect in the expected direction.

RESULTS

Due to an unusual warm winter, and technical problems, the intended difference (around 15%) between non-humidified and humidified weeks in RH indoors was not achieved. Table 2 shows the actual differences in indoor RH were smaller: over the 6-week period of the experiment the difference was greater than 10% RH only in the first two weeks. In the remaining 4 weeks, although the difference was always in the intended direction, the greatest difference in indoor air humidity between the two floors was less than 6% RH.

Table 2 Average humidity transformed to relative humidity at 22ºC during experimental weeks measured in the exhaust air and at a weather station at Östersund Airport

Week/location	Floor A	Floor B	Outdoors
1	10.2%	23.0%[a]	5.9%
2	11.6%	23.5%[a]	12.9%
3	23.6%[a]	20.4%	18.8%
4	22.9%[a]	17.3%	17.5%
5	18.5%	22.9%[a]	12.5%
6	20.0%	23.6%[a]	14.4%

[a]Humidified floor.

The normal and intervention conditions may have been insufficiently different to produce differences in effects. In the following sections, response measures taken on different weeks have therefore been analysed between occasions (humidity levels) but within each floor.

The weekly average indoor temperatures remained within the narrow and thermally comfortable range of 20.9ºC–22.1ºC on both floors. Weekly average CO_2 values ranged from 407–457 ppm, with a mean of 433 ppm, which is only slightly above the average outdoor value of 395 ppm that was recorded during the 6 week period, reflecting the fact that there was no re-circulation and low occupant density.

Odour intensity increased with increasing humidity on Floor B ($P < 0.0005$), with no significant effect of humidity on Floor A, and assessments of stuffiness were also inconsistent: the air was rated as less stuffy as humidity increased on Floor A ($P < 0.01$) and more stuffy as humidity increased on Floor B ($P<0.0002$). These effects should probably be disregarded as spurious. Eye irritation decreased with increasing humidity on Floor A ($P < 0.02$), and but no effect could be shown on Floor B. Subjects on Floor A rated humidity significantly higher as it increased ($P<0.008$), while subjects on Floor B did not.

On Floor A, at raised humidity levels, symptom intensity estimates of six SBS symptoms were significantly reduced, although only by about10%, and thermal acceptability was improved. An identical between-week analysis of data from Floor B yielded no corresponding effects. The SBS symptoms that were alleviated by an increase in humidity on Floor A are listed in Table 3.

Table 3 Floor A: significant effects of indoor humidity on SBS symptom intensity

VA-scale	*P*-value	Effect of raised RH	Size of effect (%)
Throat dry	0.04	Less dry	10%
Mouth dry	0.03	Less dry	10%
Lips dry	0.02	Less dry	9%
Skin dry	0.05	Less dry	11%
Eyes smart	0.004	Smart less	10%
Difficult to concentrate	0.02	Easier	10%
Thermal acceptability	0.00003	Improved	12%

No statistically significant differences were observed on the objective medical tests

DISCUSSION

The field experiment was located in a region that normally has very low outdoor temperatures and therefore low indoor humidity at the time of year in which the experiment was performed.

The significant subjective responses on floor A, but not on floor B were in the expected direction and partly confirm the results of a prior laboratory exposure study (Wyon *et al*., 2002). However, these associations are not apparent in an examination of the group average response obtained each week, which shows large and apparently random differences between weeks. The results do extend the findings in the laboratory experiment from 5-hour to 2-week exposures and validate them for building occupants in a cold region. In the present study, levels of indoor humidity down to 10% RH caused little discomfort, no more than occurred randomly in the field when humidity levels were not low. Additionally, no effects of low humidity on objective measures of the physiological function of the eye, skin or nasal passages could be shown.

When a large number of comparisons are made, some differences will appear to be 'statistically significant at the 0.05 level' by chance, so the critical alpha-value for significance should be adjusted upwards. However, while some of the results in Table 3 are of borderline significance, the effects on the eye and on thermal acceptability are unlikely to have occurred by chance. Another uncertainty is the influence of confounding factors: for example, ratings of brightness of the illumination apparently increased with indoor humidity ($P < 0.02$) on Floor A (but not on Floor B), and this is almost certainly due to the fact that while uncontrolled indoor humidity levels increase over time during this period of the year as outdoor temperatures increase, so also does the sun angle, the length of the day and the amount of available daylight.

CONCLUSIONS AND IMPLICATIONS

Increasing the humidity for 2 weeks in an office located in a cold dry region had small positive effects in only nine out of 28 investigated perceptions and sensations. This is similar to the results obtained in 5-hour laboratory exposures that preceded the field study (Wyon *et al*., 2002).

The results of this field experiment should not be taken to indicate that increasing indoor humidity in winter by artificial humidification would improve occupants' comfort or health. They do not justify the minimum level of indoor humidity currently recommended by e.g. ASHRAE comfort standards.

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