LIMITING CRITERIA FOR HUMAN EXPOSURE TO LOW HUMIDITY INDOORS

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ABSTRACT
Thirty subjects (17 female) were exposed for 5 hours to clean air at 5%, 15%, 25% and 35% RH at 22 °C. Another 30 subjects (15 female) were similarly exposed to air polluted by carpet and linoleum at 18, 22 and 26 °C with humidity 2.4 g/kg dry air (=15% RH at 22 °C), and at 22 °C, 35% RH. The subjects performed simulated office work throughout each exposure. Building Related Symptom (BRS) intensity was reported on visual-analogue scales. Tests of eye, nose and skin function were applied. In these short exposures subjective discomfort, though significantly increased by low humidity, was very moderate even at 5% RH. However, tear film quality as indicated by the Mucous Ferning Test deteriorated significantly at RH<25% and at T>22 °C, significantly more rapid blink rates were observed at 5% than at 35% RH, and skin became significantly more dry at 15% than at 35% RH.

INDEX TERMS
Dry air, temperature, BRS, SBS, blink rate

INTRODUCTION
During severe winter weather, the inhabitants of cold climates may experience low levels of indoor humidity (<20% RH) for periods of up to several weeks, and they associate this with numerous symptoms of dryness, primarily of the eyes, nasal cavity and skin. There is not usually very much that can be done about it, as only large commercial buildings with full air conditioning have humidification equipment and energy conservation often ensures that it is not in use. For such buildings, ASHRAE Standard 55 (ASHRAE, 1992) for thermal comfort does include a recommendation that dew point temperatures should not be less than 3 °C, corresponding to 26% RH at 24 °C. This limit is not based on considerations of thermal comfort or on actual research results. In fact, intervention experiments in large office buildings in Sweden demonstrated more than a quarter of a century ago that subjectively reported symptoms of dryness in winter could be alleviated more effectively as well as more economically by reducing air temperatures from 23 °C to 21 °C than by raising the indoor humidity to 40% RH, thermal discomfort being also reduced (Andersson et al., 1975), and this has long been the basis for the design and operation of office buildings in Scandinavia. Although more recent studies have shown that increasing winter humidity indoors to above 30% RH would alleviate some Building-Related Symptoms (BRS, previously termed SBS-symptoms) and slightly reduce sensations of dryness (Reinikainen et al., 1992; Wyon, 1992; Nordström et al., 1994), other research has shown that perceived air quality would be reduced
(Fang et al., 1998), and complaints of stuffiness and high humidity would increase (e.g. Berglund and Cain, 1989). These conclusions were drawn in a recent review (Nagda and Hodgson, 2001), whose authors consider that there is experimental evidence that exposures of more than 4 hours to 10% RH and below has negative effects on the eyes, nasal passages and skin, as is often reported by flight crew. However, they consider that there is as yet no evidence that would justify taking steps to raise aircraft cabin humidity levels from the current average level of about 15% RH to the highest level that would still avoid condensation and corrosion of the airframe (24% RH), a change which could easily be achieved by slightly reducing the outside air supply rate.

**METHOD**

**Experimental design:** 60 subjects were exposed to two levels of air pollution, four levels of absolute air humidity and three air temperatures for 5 hours, in groups of 6. Thirty subjects (17 female) were exposed for 5 hours to clean air at 5%, 15%, 25% and 35% RH at 22 °C, with 60 L/s/p outside air. A further 30 subjects (15 female) were similarly exposed to 18, 22 and 26 °C with humidity 2.4 g/kg dry air (=15% RH at 22 °C), and to 35% RH, 22 °C, the 10 L/s/p of outside air for this set of 4 exposures being first passed over a realistic quantity of carpet and linoleum (Table 1). These conditions were established simultaneously in two adjacent climate chambers (exposure chambers). A third chamber was used for the medical examinations (examination chamber). The temperature and humidity in the examination chamber were kept constant at 22.5 °C (±0.3 °C) and 40% (±3%) RH throughout the experiment. The subjects performed simulated office work to ensure realistic levels of effort and fatigue and that their eyes were normally open. Subjects were exposed at the same time of day and on the same day of the week, the 4 conditions occurring in balanced order over an experimental period of 4 successive weeks. This design permits within-subject comparison of 4 levels of humidity (5-35% RH) at 22 °C in clean air and of 3 levels of temperature (18-26 °C) in polluted air at the second lowest level of humidity.

**Table 1. Environmental conditions for the climate chamber exposures**

<table>
<thead>
<tr>
<th>Humidity ratio</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>18 °C</td>
</tr>
<tr>
<td>0.8 g/kg (5 % RH at 22 °C)</td>
<td>L</td>
</tr>
<tr>
<td>2.4 g/kg (15 % RH at 22 °C)</td>
<td>H L, H H</td>
</tr>
<tr>
<td>4.1 g/kg (25 % RH at 22 °C)</td>
<td>L</td>
</tr>
<tr>
<td>5.7 g/kg (35 % RH at 22 °C)</td>
<td>L, H H</td>
</tr>
</tbody>
</table>

*NB: H: high level of air pollution (low ventilation rate of 10 L/s per person, with pollution source)
L: low level of air pollution (high ventilation rate of 60 L/s per person, no pollution source)*

**Exposure chambers:** The two chambers used for the experiments are identical in size (LxWxH= 5.4x4.2x2.5m). They can be controlled independently in the following ranges: air temperature 15 °C to 40°C (±0.25 °C); air humidity normally 30% to 70% (±3%) RH; outside air ventilation rate 12 to 180 L/s. Samples of building or furnishing materials can be placed in a miniature “room” in the air supply system of each chamber. Rotating desiccant wheel dehumidifiers were installed for the experiment, each able to convert air at 8 °C and 5.5g/kg to 30 °C and 0.15g/kg at the flow rate of 180L/s. The hot dry air obtained was then cooled by a cooling coil. If the outdoor air temperature and humidity were above 8 °C and 5.5g/kg, the air was cooled and dehumidified by an initial cooling coil before reaching the dehumidifier.

**Physical measurements:** Temperature, humidity, and air velocity at three heights above the floor (0.1, 0.6 and 1.0 m), were measured at each workstation on each experimental day.
before the experiment started. Ozone concentration inside the chamber and in the outdoor air was measured every day (Seres, OZ 2000) to investigate whether low relative humidity enhances the formation of ozone indoors, as ozone has both direct and indirectly irritant effects on the mucous membranes of the eyes, nose, throat and respiratory tract. The concentration of airborne dust and the distribution of particle size was measured under each condition (Grimm, 1.106) to determine whether decreasing relative humidity reduced the size of airborne particles, which would increase their penetration into the airways.

Subjective ratings: Subjective assessments of perceived air quality, thermal sensation and the reported intensity of BRS were obtained using standard visual-analogue scales (Wargocki, 1999), which in this experiment were marked by the subjects on a computer screen, using a mouse. The results were quantified and stored automatically by the computer.

Objective medical tests: Objective measurements were made before and after each exposure on the eyes, nose and skin. Eye (Wyon and Wyon, 1987): 1) Tear film stability test (Break-Up Time, observed using eye drops, a cobalt-blue slit-lamp and a stopwatch); 2) Mucous ferning test (examining the crystallization pattern of a mucous sample on a microscope slide); 3) Rose Bengal test (staining to quantify micro-damage to the cornea, equivalent to the Lissamine Green test); 4) Blinkrate (a 10-minute digital video record of the face in close-up was taken while each subject working in the climate chamber, using a small digital video camera, i.e. a “Webcam”, installed on each desk. They were not informed when recording would take place. The distribution of the inter-blink intervals was later determined by identifying each frame in which a blink had occurred.). Nose: 5) Nasal peak-flow measurement at inspiration (using a standard clinical flow meter); 6) Nasal transit time measurement (using a moistened swab to deposit saccharine particles in the nasal cavity, the time that elapsed before the subject reported tasting them was recorded). Skin: 7) Corneometer measurement of skin dryness; 8) Transepidermal water loss, TEWL (measurement of the rate of passive diffusion of water through the skin); 9) A skin irritation challenge test was also performed but the results are not yet available.

Subjects: Healthy volunteers were screened for environmental sensitivity using a self-report questionnaire. Subjects potentially sensitive to low humidity were identified (symptoms of hay fever in the pollen season, contact-lens wearers) and a total of 60 subjects were selected at random (aged 19-31, mean 23), 20 from each sensitive category (accepting overlap between categories), and the remainder from neither, with a gender ratio of about 50%. Half of the subjects in each of the three sub-groups were assigned at random to the clean air conditions. The research plan was approved by the local Medical Ethics Committee (KF 01-285/00) and subjects were free to discontinue any exposure.

Experimental procedure: The five-hour exposure periods were divided into two sections of 2.3 – 2.5 hours by a 15-minutes break. Subjects performed simulated office work, i.e. text typing, proof reading, simple addition, etc. (Wargocki, 1999). Subjective ratings were obtained upon entering the chamber and at intervals of about 20 minutes throughout each exposure. The first round of objective medical tests were applied in the examination chamber before subjects entered the exposure chambers. After 5 hours of exposure, the eyes and nose tests were applied inside the exposure chambers and the subjects then entered the examination chamber for the skin tests. Subjects maintained thermal neutrality by self-adjustment of their clothing and were allowed to drink water whenever they required it.
RESULTS
Physical measurements: The stability of air temperature and humidity measured inside the exposure chamber was ±0.25 °C and ±2% RH respectively. The size distribution of airborne dust and the concentration of ozone did not differ significantly between conditions. Monthly average maximum outdoor temperatures (April-June 2001) were 9.1, 15.8 and 16.4 °C, while the monthly average outdoor RH was 73, 63 and 71% during the experiments.

Subjective ratings: There were significant differences in the expected direction between subjective ratings obtained in the 35, 25, 15 and 5% RH conditions at 22 °C in clean air for 1) Sensation of air humidity (P<0.008); 2) Dryness of the eyes (P<0.007), but not for any other subjective rating. It may be seen in Figure 1 that the degree of discomfort reported was mild even at 5% RH. The acceptability ratings of air quality corresponded to 5-8% dissatisfied under all clean air conditions, with no effect of humidity, but in the polluted air conditions acceptability decreased significantly between 22 °C and 26 °C (7 and 13% dissatisfied).

![Graph (a)](image1.png)
(a) Sensation of air humidity

![Graph (b)](image2.png)
(b) Sensation of eye dryness

Figure 1. Sensation of air humidity and dryness of the eyes after an exposure of 4.7 hours to 5, 15, 25 and 35% RH in clean air at 22 °C.

![Graph (c)](image3.png)
![Graph (d)](image4.png)

Figure 2. Mucous ferning score after an exposure of 5 hours at the different levels of air temperature and humidity.

Mucous Ferning test: Samples were immediately removed from the exposure chamber. The crystallization pattern of the mucous was then observed in a microscope and classified into categories 1-4, where 1 is perfect and 4 would be clinically significant. The Friedman non-parametric two-way analysis of variance shows that there was a significant difference (P<0.007) between results obtained in the 5, 15, 25, and 35% RH conditions at 22 °C in clean air. Pair-wise comparison between conditions by means of the non-parametric Wilcoxon
Matched-Pairs Signed-Ranks test reveals that mucous ferning did not differ significantly between 5% and 15% RH or between 25% and 35% RH, while it was significantly worse (P<0.05) at 5% than at either 25% or 35% RH and significantly worse (P<0.05) at 15% than at either 25% or 35% RH. Similarly, Friedman analysis shows a significant difference in mucous ferning between the 18, 22 and 26 °C conditions (P<0.03) in polluted air at constant absolute humidity, while subsequent pair-wise comparison using the Wilcoxon test reveals that while there was no significant difference between 18 and 22 °C, mucous ferning was significantly worse (P<0.05) at 26 °C than it was at either 22 °C or 18 °C.

**Blink-rate:** Average inter-blink interval tended to be shorter at 5% RH than at 35% RH (Figure 3) on a Wald-Wolfowitz comparison (P<0.05). The difference is most marked for average inter-blink intervals below 10 seconds.

![Figure 3. Distribution of average inter-blink interval after an exposure of 4.5 hours to 5% RH and 35% RH in clean air at 22 °C.](image)

**Skin tests:** Corneometer values indicate that skin dryness increased during the exposure period in all conditions. Pooling data from clean and polluted air (N=60), the Wilcoxon Matched-Pairs Signed-Ranks test indicates that the increase was significantly higher at 15% RH than at 35% RH (P<0.003). The Friedman test shows that in polluted air there was a significant effect of temperature (P<0.0004) on TEWL at constant low absolute humidity: the measured values declined less during the exposure at 26 °C than at 18 °C and 22 °C, as would be expected if some thermal sweating had been initiated at the highest temperature. Note that any effect of temperature on skin dryness would have been in the opposite direction.

**DISCUSSION**

Subjective reports of dry discomfort increased as humidity levels were reduced below 35% RH, but the level of discomfort was never more than mild even at 5% RH. Even though over half of the subjects were deemed potentially hypersensitive the 5-hour exposures were too short for more severe discomfort to develop or for any measurable effects on the nose to be detected. However, clear evidence was obtained that 5 hours of exposure to 15% RH or below is sufficient for the mucous layer of the tear film to become measurably more dry than at 25% RH or above even in clean air, and that skin exposed to 15% RH becomes significantly more dry than skin exposed to 35% RH. It was not possible to determine whether increasing humidity to 25% RH would be sufficient to alleviate complaints of skin dryness, as skin dryness measurements at 25% RH did not differ significantly from measurements obtained at humidity levels below or above 25% RH. There was an observed increase in blink-rate at low humidity, and this is presumably one of the behavioural strategies that are adopted in an attempt to reduce perceptibly negative effects of low humidity on the tear film. In polluted air the eye problem was worse at 26 °C than at 22 °C. Raising humidity slightly, from 15% to...
25% RH, and keeping air temperatures down to 22 °C would reduce these effects. These changes would have a significant but small effect on subjective sensation. Whether they would provide any long-term benefit for the eye or skin remains to be determined.

CONCLUSIONS
Little discomfort was reported, but objective medical tests showed that even at 22 °C, 5-hour exposures to low humidity conditions (15% and 5% RH) had measurably negative effects on the eye and skin that did not occur at or above 25% RH. In normally polluted air, the effects on the eye were significantly worse at 26 °C than at 22 °C.

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REFERENCES