The dichotomy of relative humidity on indoor air quality

Peder Wolkoff [a,*], Søren K. Kjærgaard [b]

[a] Indoor Environment Group, National Research Centre for the Working Environment, Lersø Parkallé 105, DK-2100 Copenhagen Ø, Denmark
[b] Department of Environmental and Occupational Medicine, Aarhus University, Vennelyst Boulevard 6, DK-8000 Aarhus C, Denmark

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Abstract

Dry and irritated mucous membranes of the eyes and airways are common symptoms reported in office-like environments. Earlier studies suggested that indoor pollutants were responsible. We have re-evaluated, by review of the literature, how low relative humidity (RH) may influence the immediately perceived indoor air quality (IAQ), including odour, and cause irritation symptoms (i.e. longer-term perceived IAQ). "Relative humidity" were searched in major databases, and combined with: air quality, cabin air, dry eyes, formaldehyde, inflammation, mucous membranes, offices, ozone, pungency, sensory irritation, particles, precorneal tear film, sick building syndrome, stuffy air, and VOCs.

The impact of RH on the immediately and longer-term perceived IAQ by VOCs, ozone, and particles is complex, because both the thermodynamic condition and the emission characteristics of building materials are influenced. Epidemiological, clinical, and human exposure studies indicate that low RH plays a role in the increase of reporting eye irritation symptoms and alteration of the precorneal tear film. These effects may be exacerbated during visual display unit work.

The recommendation that IAQ should be "dry and cool" may be useful for evaluation of the immediately perceived IAQ in material emission testing, but should be considered cautiously about the development of irritation symptoms in eyes and upper airways during a workday. Studies indicate that RH about 40% is better for the eyes and upper airways than levels below 30%. The optimal RH may differ for the eyes and the airways regarding desiccation of the mucous membranes.

Keywords: Indoor air quality; Ozone; Particles; Relative humidity; Volatile organic compounds

Contents

* Corresponding author. Tel.: +45 39165272.
E-mail address: pwo@nrcwe.dk (P. Wolkoff).

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1. An introduction to indoor air quality and relative humidity

Humans have difficulties perceiving changes of the relative humidity (RH), due to lack of sensory receptors for humidity, cf. (Nagda and Rector, 2003). In contrast, specific sensors exist for the perception of the temperature. However, reporting of "dry air" has been associated with poor indoor air quality (IAQ) or a sub-standard indoor environment since the 1980's (Brightman and Moss, 2000). The perception of "dry air" was correlated to mucous membrane irritation of the eyes (e.g. dry eyes) and upper airways (sensory irritation, cf. (Doty et al., 2004)), which is an important component included in the classic "sick building syndrome" in non-industrialized buildings (Burge, 2004; Hodgson, 2002; Redlich et al., 1997).

On the basis of human exposure studies with clean and humidified air, it was concluded that low RH (i.e. 10%) had little or no influence on the development of dry mucous membranes in the eyes and airways in a consistent manner (Andersen et al., 1974). The presence of a large number of different volatile organic compounds (VOCs), some in relatively high concentrations compared with outdoors, and other indoor pollutants were instead assigned as causative agents of indoor complaints, like sensory irritation (including perceived dry air). It is well known that exposure to some chemicals experimentally induce this kind of symptom, e.g. formaldehyde (Arts et al., 2006). This pollutant hypothesis was later reintroduced by Sundell and Lindvall (1993) and Fang et al. (2004). It was further concluded that indoor air pollutants, like VOCs, were the most likely cause of sensory irritation. In addition, it was concluded that high RH as well as high temperature were detrimental to the immediately perceived IAQ (a snapshot of perception) in exposure to the emission of building materials (Cain et al., 2002; Fang et al., 1998). This leads to the paradigm that IAQ should be perceived as "dry and cool" in office environments (Fanger, 2000), i.e. low RH and not too warm. Thus "dry air" has become a standard question in epidemiological studies of indoor environments as a proxy for indoor air pollution and of bodily perceptions like sensory irritation.

It has been argued, on the basis of a review on cabin air quality, that the outcome of human exposure studies about RH in many cases depend on the experimental design (e.g. age of subjects, exposure duration, and lack of proper references) (Nagda and Hodgson, 2001). Some of the studies showed decreased sensory irritation at elevated RH, while others showed no effect. The authors were sceptical about the innocence of low RH and they concluded that slightly elevated RH would have a beneficial effect (Nagda and Hodgson, 2001; cf. also Arundel et al., 1986). For example, recent chamber studies have demonstrated that the precorneal tear film (PTF) in humans (Bron et al., 2004) is altered under conditions of extreme low RH (5–10%) for some hours concurrent with a slight discomfort of the eye perceived in young subjects (Sunwoo et al., 2006a; Wyon et al., 2006).

The role of the RH in the perception of IAQ and health continues to be an important question in the indoor air science community. Our understanding of its impact is relevant for developing IAQ guidelines and ventilation standards (cf. Baughman and Arens, 1996). Although a number of recent studies have been carried out, the optimal condition for RH in the office environment or cabin air is still not clarified. Also, the dependence on the target organ, e.g. eyes versus airways is unknown. There may be differences between the two organs as the nasal cavity is very effective with respect to humidification and temperature equilibration of the inspired air. The nose is capable in increasing the RH to 100% in the nasopharynx even when exposed to cold and dry air (0 °C and RH < 10%), and at the same time in increasing temperature to a reasonable level. And, as temperatures in cool indoor environments may be down to 18 °C, there seems to be no problem in reaching 100% humidification without depletion of the nasal capacity, even at low RH (Rouadi et al., 1999). Contrarily, the eyes (PTF) appear to be more susceptible to low RH, in particularly during visual display unit (VDU) work (cf. Wolkoff et al., 2005).

The purpose of this review is to re-evaluate whether and how low RH may influence the immediately perceived IAQ, including odour. Further, how low RH may cause longer-term developed symptoms, like sensory irritation in the eyes (e.g. dry eyes) and upper airways by itself or is additional exposure to sensory irritants a prerequisite? These symptoms are often among the most abundantly reported in epidemiological studies of office environments (Kjærgaard, 2000; Wolkoff et al., 2003; Woods, 2005), open-planar offices (Pejtersen et al., 2006), in air cabins (Nagda and Koontz, 2003; Lindgren and Norbäck, 2005; Whelan et al., 2003), including clean room environments, (e.g. Su et al., 2006), but in particular during extensive VDU work (cf. Wolkoff et al., 2003; Eriksson and Stenberg, 2006; Piccoli, 2003). The health implication of high RH (>60%), as encountered in moisture-damaged buildings (e.g. Bornehag et al., 2001) is not the focus of this paper. Most of the studies reviewed have been carried out in either Northern Europe or Northern America.

2. Method

Humidity and "relative humidity" were searched in major databases: Google Scholar, PubMed and Web of Knowledge (Thompson) for the period 1990 – December 2006, and combined with the following: air quality, cabin air, dry eyes, formaldehyde, inflammation, mucous membranes, offices, ozone, particles, particle deposition, precorneal tear film, pungency, sensory irritation, sick building syndrome, stuffy air, and VOCs. Exclusion criteria were: airway infection by airway virus, moisture-damaged buildings and materials, and dermal effects.

3. Epidemiological studies

A number of questionnaire studies in offices have shown associations between low RH (5–30%) and increased prevalence of perceived dry air and sensory irritation of the eyes and upper airways, or that an increase of RH by intervention resulted in fewer complaints (Backman and Haghighat, 1999; Reinikainen et al., 1992, 1997; Reinikainen and Jaakkola, 2001, 2003; Nordström et al., 1994; Norbäck et al., 2000; Sato et al., 2003). The observed associations are more dominant at room temperatures above 22 °C and generally more common during the heating season (Mizoue et al., 2004). Several of the studies also indicate that a temperature increase (i.e. which in average could result in some decrease of RH) also increases the prevalence of eye irritation symptoms (cf. Mendell et al., 2002; Jaakkola et al., 1989). It should be added, though, that a few studies have been unable to correlate the thermal climate with symptoms (e.g. Brauer et al., 2006; Marmot et al., 2006). Reasons for this discrepancy is not entirely clear, but it may be caused by inter alia size of the study (and thus power), minimal contrasts of exposure, and different or inadequate use of methods/metrics for measurements with different sensitivity, including different kinds of measurement strategy (cf. Mendell and Fisk, 2007).

Although the studies above support the hypothesis that low RH may have a detrimental effect on IAQ by an increase of reported dry air and sensory irritation, the results should be evaluated cautiously. RH and the room temperature both influence the overall thermal climate and the perceived IAQ, as well as it plays a role for other types of exposure, e.g. formaldehyde emission from building materials. In addition, the physiological properties of mucous membranes (cf. (Hinninghofen and Enck, 2006)), in particular the PTF are also affected at low RH conditions (e.g. Wolkoff et al., 2005, 2006a). It has also been shown that an increase of RH correlates with a more stable PTF (e.g. high break-up time), and thus most likely an increased protection against desiccation of the eye, i.e. loss of water by evaporation (Wolkoff et al., 2006a), both in office environments (Brasche et al., 2005) and in air cabins during long distance flights (Norbäck et al., 2006). Similarly, it has been found that the stability of the PTF among nurses was inversely correlated with high temperature (Smedbold et al., 2001), which partially agrees with the observation that low ambient temperature and high RH is associated with a more stable PTF than at low RH and high temperature (Paschides et al., 1998; cf. Kjærgaard et al., 2004). Thus, there is fair agreement between the epidemiological findings about eye irritation symptoms and those that also involve measurements of the PTF stability (e.g. break-up time and thickness). However, the inherent risk of confounding factors, which is important, especially in the case of subtle effects with a complicated causative network, should always be considered.

4. Clinical and climate chamber studies

Clinical investigations under controlled laboratory conditions have demonstrated that high RH increases the thickness of the PTF, i.e. it becomes more stable, in particularly among "dry eye" patients; the eye blink frequency also stabilizes (Farris, 1997; Korb 2002; Korb et al., 1996; Ousler et al., 2002; Tsubota et al., 1996a). This is also true for certain types of "soft" contact lens wearers (Thai et al., 2004; Maruyama et al., 2004; and references in Wolkoff et al., 2006a). These results agree with the epidemiological findings that an increase of RH is beneficial for the PTF. This is further supported by climate chamber studies carried out at low RH for 1.5–5 h, which changed the chemical composition of the PTF and resulted in a time dependent increase of the eye blink frequency at both 10% and 30% RH (Sunwoo et al., 2006a,b), while the subjects perceived some discomfort (i.e. irritation) (Wyon et al., 2006). However, it is reasonable to assume that the effect among elderly subjects could be more pronounced, in particularly among women after the age of 40 (cf. McCarty et al., 1998; Uchino et al., 2006). The effect also increases by use of certain medication, e.g. with diuretic effects, by exacerbation of the desiccation process (cf. Craig, 2000). In addition, exposure of the eye to a mixture of sensory irritants showed the highest effect at 20% RH compared with 50% RH (Nøjgaard et al., 2005), which agrees with sensory irritation observed in an animal model with a similar mixture of sensory irritants (Wilkins et al., 2003).

Saccharin mucociliary clearance time has been found to increase significantly among elderly, but not among young, male subjects exposed to 10% RH for 90 min when compared with 30% RH condition (Sunwoo et al., 2006b). It is suggested that the increase is a result of decreased nasal mucociliary activity, thus mucous membranes of elderly men are more affected by 10% RH than young men.

In summary, field measurements of the PTF stability in offices and air cabins are generally compatible with those obtained from clinical and climate chamber studies, that prolonged exposure to low RH alters the PTF, e.g. reduced break-up time and thinner film thickness. There are similar indications that the mucous membranes, at least among elderly men, are affected at 10% RH.

5. Factors influenced by dry air (low RH)

5.1. Perceived IAQ

Immediately perceived IAQ, as assessed usually by a naive panel of 20–30 subjects, may not reflect symptoms like sensory irritation in eyes and upper airways. These symptoms, due to their latency, develop during a working day, as indicated in human exposure studies (cf. Wolkoff et al., 2006b). The immediately perceived IAQ at the entrance of a building or room strongly depends on the RH, the temperature, in addition to VOCs (including volatile inorganics) present, which have substantially lower odour thresholds than previously reported (cf. Cain et al., in press; Wolkoff et al., 2006b). The IAQ appears to be most acceptable at low RH and temperature concerning the assessment of emission of VOCs from building materials (Fang et al., 1998). The issue is complex, however, because the thermodynamic condition (i.e. the influence of temperature and RH) and altered VOC emission profiles both influence the perception of IAQ (Cain et al., 2002; Fang et al., 1998). For example, the emission profile of, in particular, polar VOCs from building materials may alter by increase of the RH (e.g. Wolkoff 1998; Fang et al., 1999). For example, it has been reported that the immediate perception of odour and "stuffy air" in offices increased slightly upon increase of RH (Reinikainen et al., 1997; Reinikainen and Jaakkola 2003). Thus, the perceived stuffiness may be caused by a slight change of the VOC profile combined with the thermodynamic effect, however, at the same time, the perception of dry air and symptoms of dry eyes and upper airways may be alleviated upon humidification (21–31% versus 30–35% RH), i.e. the longer-term IAQ improves regarding the symptoms.

5.2. VOCs and formaldehyde

VOCs are emitted from building materials and consumer products, human activities, and the outdoor air (Wolkoff, 1995), and it is well documented that they may induce sensory irritation at industrial levels above what is measured in indoor environments (i.e. low ppb) (cf. Alarie et al., 1996; Wolkoff et al., 2006b). Odour cues probably add to the overall symptom reporting, because the concentration of many VOCs is above their odour threshold (cf. Paustenbach and Gaffney, 2006; Wolkoff et al., 2006b; Cain et al., in press).

VOCs are not considered to affect the PTF in office environments (cf. Wolkoff et al., 2005). It cannot be excluded, however, that an altered PTF may result in lower thresholds for sensory irritants. It is expected that conditions of an altered, e.g. thin PFT, developed during exposure to low RH, would exacerbate the effect, if transport through the PTF of the sensory irritant is the limiting step for trigeminal stimulation of the nerve endings in the cornea.

Contrarily, the emission of formaldehyde from wooden-based materials is proportional to the RH at a given temperature (Van Netten et al., 1989). Similarly, the formaldehyde concentration has been found to increase with RH in a field study, but it was also concluded that the air exchange rate contributed strongest to the indoor concentration (Salthammer et al., 1995); for further details about temperature and RH dependences, see Baughman and Arens (1996) and Myers (1985). However, increase of the formaldehyde concentration may be counteracted by a more stable (more thick) PTF at an elevated RH (cf. Wolkoff et al., 2006a).

5.3. Ozone and nitrogen dioxide

Ozone is a strong oxidant which rapidly reacts with certain unsaturated VOCs (e.g. terpenes) in the gas phase to produce oxygenated VOCs (Weschler, 2000), further, ozone may also degrade material surfaces (e.g. paint) to aldehydes, ketones, and carboxylic acids (cf. Wolkoff, 1999). In a field study, formic acid was correlated with RH, possibly as a result of oxidation reactions (Zhang et al., 1994). It was inferred that reactions between terpenes and ozone, which produce a number of different sensory irritants, e.g. formaldehyde, formic and acetic acids, could account for reported sensory irritation in office environments (Wolkoff et al., 2006b). To what extent these oxidation reactions are responsible for sensory irritation and whether low RH is a prerequisite or may exacerbate the effect are still uncertain. A human eye study indicates that the sensory effect is less at 50% RH than at 20% RH (Nøjgaard et al., 2005). This could be explained by the formation of less irritating species in oxidation reactions with ozone and limonene (a terpene) or a more stable PFT. The molecular mass of secondary organic aerosols, that also are formed in such oxidation reactions, generally increase by increasing the RH (e.g. Jonsson et al., 2006; Seinfeld et al., 2001), i.e. their volatility decreases.

Ozone deposition rates on hard surfaces generally decrease with increasing RH up to about 50% (Grøntoft et al., 2004). Heterogeneous reactions on building material surfaces that form secondary emissions of odour active aldehydes (e.g. Tamás et al., 2006; Wang and Morrison, 2006), appear to be more important at low RH, except for wooden surfaces (Grøntoft et al., 2004). For some building materials that are exposed to ozone, e.g. textile carpets, the immediate odour preference may alter (Knudsen et al., 2003). The combined impact of RH and ozone on the immediately perceived IAQ is difficult to predict for building materials, because several factors influence: i) the thermodynamic condition alters the perception and at the same time the VOC profile may change by an increase of RH, ii) secondary emissions due to ozone degradation reaction on surfaces as well as gas phase oxidation reactions of emitted chemically reactive VOCs may remove as well as produce new odour active VOCs, which will alter the IAQ (odour) perception.

The deposition rate of nitrogen dioxide unto surfaces is expected to be greatest at high RH and the same is expected for the emission of nitrous acid, which is formed by the reaction between water and nitrogen dioxide, and greatest for fleecy surfaces (Wainman et al., 2001).

5.4. Particles

RH has an effect on the formation and size of secondary aerosols and therefore on the deposition. Low RH appears to enhance particle deposition of fine particles (Litvak et al., 2000) and high RH likewise (Miguel et al., 2004; Fromme et al., 2007). On the other hand, re-suspension of particles (>1 μm) increases with size (Blondeau et al., 2005), which possibly also is the case from textile carpets by increase of RH up to about 75% RH (Kivistö and Hakulinen, 1981).

It is probable that particle concentrations influence the immediately perceived IAQ, because they may carry odour active compounds, like VOCs (e.g. Bottcher, 2001). Whether typical indoor particles, like in indoor dust, may be responsible for sensory irritation has not been shown in a consistent manner, neither in climate chamber studies nor in field studies (cf. Schneider et al., 2003; Wolkoff et al., 2003). The deposition of particles unto the ocular surface depends on a number of external physical factors, in addition to the work situation itself (e.g. blink frequency and ocular area), which should be considered in the future studies (Schneider and Bohgard, 2005). Factors that influence deposition and re-suspension of particles are far from well understood.

5.5. VDU work

Low RH may influence the performance of certain VDU tasks (Wyon et al., 2006). The authors speculated that this may be due to: i) the increase of the blink frequency, i.e. reduction of the interblink duration, thus a reduction of the overall visual acquisition time, ii) a reduction of the PTF transparency, i.e. loss of the visual acuity (e.g. Albarrán et al., 1997; Tutt et al., 2000). Also, an increasing need for breaks is relevant, due to tiredness and irritation of the eyes (cf. Hedge et al., 1996). Finally, the increase of the blink frequency may enhance musculoskeletal tiredness and overloading of the eye (i.e. asthenopia) (Piccoli, 2003; cf. Sunwoo et al., 2006a), although the PFT stability may be retained. The overall deterioration of the performance, however, may be further advanced among women subjects over 40 years of age with a less stable PTF (cf. McCarty et al., 1998; and references in Wolkoff et al., 2003).

It is still uncertain whether the desiccation process of the PTF is a direct cause or only an exacerbating factor of the symptom development. However, there are a number of indications that low RH alters the PTF and exacerbates the desiccation process, i.e. increase of water evaporation from the PTF; for example, a 10% increase of RH resulted in on an average 36% decrease of the evaporation rate (McCulley et al., 2006; cf. Tsubota, 1998). This is compatible with reporting of dry eyes, irritation of eyes, and possibly also the upper airways. The development of desiccation and sensory irritation will further be exacerbated during intense VDU work, which is associated with a number of risk factors, like reduced blink frequency (cf. Wolkoff et al., 2003, 2005). For example, high RH reduces the blink frequency (Kay et al., 1990; Tsubota et al., 1997), and an inverse proportionality regarding the ambient temperature has been observed (Tsubota et al., 1997). Further exacerbation may also occur among wearers of certain types of contact lenses due to increased evaporation rate of water, e.g. (Thai et al., 2004; Maruyama et al., 2004). Thus, development of eye fatigue and need for breaks will increase partly as a function of duration, as well as visual and cognitive demands of the VDU work.

6. Consequences of elevated relative humidity

Sensory irritation of the eyes has been associated with moisture-damaged buildings (Åhman et al., 2000; Wan and Li 1999; Ruotsalainen et al., 1995), where the RH would be expected to be slightly elevated. However, on the other hand, high RH (≈60%) should be avoided, because of an increased risk of dust mite proliferation. Although they would not be associated with a modern office environment, some investigations have indicated their presence in office chair seats made of textiles (Janko et al., 1995; Perfetti et al., 2004; Raw et al., 1993). It has also been postulated that elevated RH (i.e. dampness) enhances spreading of certain types of airway vira, which may increase the probability of viral infection, and thus be causative of dampness-related symptoms (Hersoug, 2005; cf. Bornehag et al., 2001). However, the interrelation between RH, temperature and the mechanisms of spreading of airway vira is rather complex (cf. Morawska, 2006).

All in all, low RH (ca. 10%) desiccates the mucous membranes in a time dependent manner, first the eye, then followed by the nasal cavity (cf. Sunwoo et al., 2006b). Epidemiological, clinical and climate chamber studies indicate that RH about 40%, is better for the eye than RH less than 30% (cf. Sunwoo et al., 2006a,b). This is in slight disagreement with the study carried out with young subjects (Wyon et al., 2006), which showed little or negligible effects at low RH, although significant alteration of the PTF was observed. The apparent discrepancy between that particular study and the general finding as stated above could be inter alia age and gender dependent differences (e.g. Doty et al., 2004; Kjærgaard et al., 1992; van Thriel et al., 2006). Nagda and Hodgson (2001), in their review, discuss that elderly people somehow may be more sensitive than young people to perceive different humidity levels, as also indicated by lower mucociliary activity in the airways among elderly men (Sunwoo et al., 2006b). In addition, it is known that desiccation of the PTF may be exacerbated by diuretic effects of drugs (Craig, 2000), however, whether this also is the case for the airways is unknown. It should be borne in mind that at extended exposure to low RH, the PTF is probably more susceptible to sensory irritants and possibly also other PTF related diseases (e.g. Blehm et al., 2005). For example, it has also been reported that an increase of seborrhoeic eczema among VDU users was associated with low RH (Bergqvist and Wahlberg, 1994).

7. How to maintain a “healthy” eye

Sensory irritation in eyes and upper airways are common symptoms reported in office environments, which partly may reflect poor IAQ, although certain eye diseases and/or unrecognized accommodation (e.g. presbyopia) contribute to the background prevalence (cf. Wolkoff et al., 2003). The causes of sensory irritation can be chemical, physical and ergonomic exposure loads, in addition to lighting conditions (e.g. Piccoli, 2003). This is particularly relevant during VDU work with high visual and cognitive demands, where the altered PTF becomes more susceptible to external exposure loads (Wolkoff et al., 2003, 2006a). Maintenance of the humidity is essential to avoid desiccation of the PTF and subsequent alteration of the tear chemistry, which further may result in the typical eye symptoms, like tiredness and irritation (cf. Wolkoff et al., 2006a), and especially for post-menopausal women (cf. Wolkoff et al., 2003). For example, an increase of RH has shown to be beneficial, e.g. in air cabins and cockpits (Norbäck et al., 2006; Lindgren et al., 2006). Reduced pressure (corresponding to 1.2–2 km altitude), however, will enhance the water evaporation from the PTF (cf. Rocher and Fatt, 1995). In addition, poor illumination conditions and poor reading visibility may further reduce the eye blink frequency leading to enhanced overall water loss from the PTF (cf. Tsubota et al., 1996b, 2002).

In summary, 40–50% RH appears to stabilize the PTF towards desiccation, sensory irritants, and other indoor pollutants. For example, severe dry eye symptoms may be alleviated by glasses with side panels or moist inserts (Farris, 1997; Tsubota et al., 1996a; Korb et al., 1996; Tsubota, 1989). Similarly, humidification of the nasal cavity has shown some beneficial effect (Keck et al., 2006; Norbäck et al., 2006; see also Hinninghofen and Enck, 2006). In addition, micro-breaks (ca. ½–1 min) during VDU work and combined with exercises of complete blinks may restore the PTF, in addition to longer breaks. During the micro-breaks the eye should relax by looking far way from the VDU. Such breaks, in particular the shorter ones, have been shown to be beneficial both for the eye, and the overall performance of typical office work (Balci and Aghazader, 2003; Galinsky et al., 2000; Hedge and Evans, 2001; Henning et al., 1997; McLean et al., 2001). A downward gaze may further minimize loss of water from the PTF (Tsubota, 1998), however the angle should not impose unnecessary musculoskeletal discomfort of neck and shoulder (cf. Fostervold et al., 2006).

A number of other factors, including eye diseases like the Sjøgren's syndrome and allergic conjunctivitis, have been discussed recently (Blehm et al., 2005; Wolkoff et al., 2006a).

8. Conclusions

The immediately perceived IAQ should not be used for evaluation of office-like environments, because of the latency of symptom development. Our knowledge about the time and task dependent development of eye and upper airway symptomatology as function of the room temperature and RH is inadequate for proposing guidelines.

Previous statements about the possible association between perceived dry air and poor IAQ ("sick building") caused by indoor pollutants rather than low RH should be re-considered. The influence of RH on the combined impact of VOCs, ozone, and particles on the IAQ (both immediate and longer-term) is complex and far from being well understood. In addition to odour cues, the perception may as well be the result of dry and irritated eyes, because the trigeminal nerve mediates perceptions from both the upper airways and the eyes. This hypothesis, however, has not been explored.

Epidemiological, clinical and climate chamber studies indicate that low RH enhances the development of dry eyes, possibly more among elderly than young people, although the immediately perceived IAQ may be favourable. Similarly, it is inferred that elderly may suffer from more susceptible upper airways at low RH. It is possible that the optimal RH may differ for the eyes and the airways concerning desiccation of the mucous membranes, including their susceptibility towards indoor pollutants, in a time dependent manner. For example, the optimal RH for the eyes depends on the type of task, e.g. VDU, but the more cognitive and visual demanding and the longer duration, the more critical the RH becomes. A number of risk factors have been identified for VDU work, but knowledge about their interaction is still scarce, in particular for a full working day and week. In addition, the age should also be considered, because some elderly people may have less stable PTFs.

Thus, the obvious research question is whether low RH can be a direct cause or does it exacerbate the symptom development. For example, i) Are the eyes more susceptible at low RH and demanding VDU work? or ii) Are the eyes more susceptible to sensory irritants at low RH? iii) Are the airways more susceptible than the eyes at low RH? Finally, iv) What is the overall benefit of performance, comfort, and cabin safety compared with the cost of maintaining adequate relative humidity e.g. by steam humidification.

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