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Measurements of the Effects of Air Quality on Sensory Perception

Pawel Wargocki

Department of Energy Engineering, Technical Unversity of Denmark, Building 402, DK-2800 Lyngby, Denmark

Correspondence to be sent to: Pawel Wargocki, Department of Energy Engineering, Technical Unversity of Denmark, Building 402, DK-2800 Lyngby, Denmark. e-mail: pw@et.dtu.dk

Abstract

Occupants in indoor non-industrial environments decide whether the indoor air quality is acceptable or not. This paper describes the method by which the assessments of acceptability of air quality can be used to measure short-term sensory effects on humans caused by indoor exposures. Advantages and disadvantages of the method are discussed in the light of a need for future research in order to fully understand how many variables (environmental, organismic, physiological and psychological) influence the ratings of acceptability of air quality and to learn how the results obtained in laboratory experiments can be used to predict responses in natural environments.

Introduction

Humans are constantly exposed to varying levels of air quality, both indoors and outdoors. Since current estimates are that ~90% of people's lifetime is spent in indoor environments, a comprehensive understanding of the effects of diminished indoor air quality (IAQ) is essential. Lowered IAQ can be operationally defined in terms of adverse short-term effects on humans, rather than in physical or chemical terms. This puts the focus where it properly belongs, but the much greater challenge posed by this emphasis makes it critically important that optimally informative methods for quantifying these effects be developed, validated and consistently applied. Such methods may then be applied to support the goal that indoor air be considered pleasant and have no adverse effect on health or human performance.

Lowered IAQ can manifest itself as discomfort due to a combination of stimulation by odorants or irritants (Mølhave *et al.*, 1991) and unsatisfactory temperature or relative humidity levels (Fang *et al.*, 1998a,b). In part the effect of a given environment depends on organismic variables, such as personality traits, beliefs about the stimulus and degree of sensitivity to the contaminants being tested. In addition to, and in some cases because of, purely perceptual effects, lowered IAQ can also result in diminished human cognitive or neuromotor performance (Wargocki *et al.*, 1999, 2000). Effects on individuals involve multiple sensory pathways, a number of non-sensory systems and a variety of physiological and psychological variables. Thus research to understand IAQ issues fully must deal with considerable challenges in terms of optimizing experimental design of highly multi-disciplinary studies.

One objective of this paper is to present some methods that can be used to measure the effects of air quality on sensory perception. A second objective is to point out key areas where important issues involving the chemosensory aspects of IAQ need to be addressed in future research.

Measuring perceptual aspects of air quality

The method described in the present paper for measuring sensory discomfort caused by lowered IAQ is based on human observers rating the acceptability of air quality. The advantage of using acceptability is that, at least in principle, this approach allows individual occupants of indoor spaces to be the final arbiters of whether the IAQ is acceptable or not. The method has been used extensively in a number of investigations (Fanger *et al.*, 1988; Bluyssen *et al.*, 1996; Knudsen *et al.*, 1998; Wargocki *et al.*, 1999, 2000). Other methods that can be used for sensory evaluation of IAQ are summarized in the report by European Collaborative Action (ECA, 1999).

Acceptability of air quality is evaluated by human observers using a visual analog scale (Figure 1). Observers are instructed to indicate whether the quality of air to which they are exposed is acceptable or not. If the quality is assessed to be acceptable they mark the degree of acceptability on the upper part of the scale. If it is not acceptable they mark the lower part of the scale. No additional instructions or training are given to the observers as regards use of the scale. Assessments of acceptability of air quality are usually recorded immediately upon exposure to pollutants. During assessments temperature and relative humidity of the air are held constant, since they significantly affect

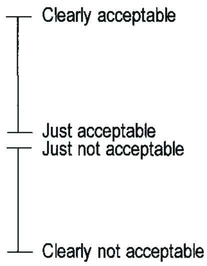

Figure 1 Continuous acceptability scale which is usually coded as follows: –1, clearly not acceptable; 0, just not acceptable/just acceptable; 1, clearly acceptable.

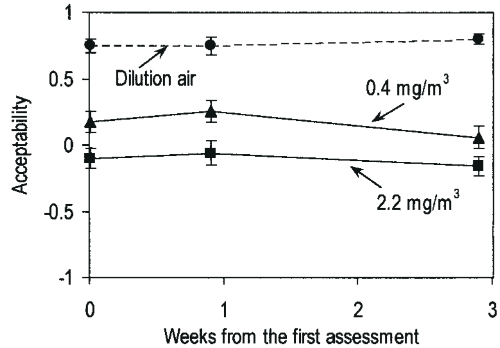

Figure 2 Repeatability of the mean vote ratings of acceptability of air quality on the continuous scale (see caption to Figure 1 for coding). Each point represents a mean vote rating of 41 observers. Each observer made one evaluation of each exposure a day. Assessments were taken immediately upon exposure to air polluted by a mixture of 22 common indoor chemical organic pollutants at two different concentrations: 0.4 and 2.2 mg/m^3. The assessments of the air used for dilution are presented for comparison. Bars show standard errors of the mean vote ratings of acceptability.

ratings of acceptability of air quality (Fang *et al.*, 1998a,b). Typically, an assessment is made after just one inhalation of the air being evaluated. Then, prior to the next evaluation, subjects take several inhalations of unpolluted air.

This laboratory-based methodology is easily followed in studies using environmental chambers and it could be applied easily to olfactometer-based research (Kendal-Reed *et al.*, 1998). However, it is rather difficult to follow such a protocol in field investigations of actual indoor environments. In field work observers render acceptability judgements after entering a space and taking, usually, more than one inhalation. Although between evaluations observers stay in a well-ventilated space, studies thus far have not provided a source of unpolluted air that observers could breathe immediately before evaluations. This could be accomplished in future field studies using, for example, pure air generators. Discrepancies between laboratory and field methodologies used to assess acceptability may help account for some difficulties reported to date in using acceptability panels to understand or predict IAQ problems in actual environments (Parine, 1996; Knudsen *et al.*, 1998; Wargocki, 1998).

Using sensory assessments of the same exposure made by the group of observers, mean votes of acceptability of air quality are calculated after the scale is coded as follows: –1, clearly not acceptable; 0, just not acceptable/just acceptable; 1, clearly acceptable. Usually, single ratings made by each observer in a group are used to calculate the group mean vote of acceptability characterizing IAQ in a given environment. Differences in the temperature and the relative humidity of air presented for sensory evaluations, if present, are accounted for in the acceptability ratings using the models of Fang *et al*. (Fang *et al.*, 1998a,b).

For a given exposure the standard deviation is typically of the order of 0.4–0.5 (Knudsen *et al.*, 1998). For this reason a relatively large number of observers (typically 30–40) is required to achieve statistically valid results. The dispersion of subjects' data is largely attributable to variations in chemosensory sensitivity, in combination with individual differences in the overall evaluation associated with the quality and quantity of a given perceptual event. In addition, it is likely that much of the apparent considerable variation among individuals may actually reflect uncertainty surrounding the single response made by each individual to a given environment. Recent work indicates that for odor perception the combined use of careful stimulus control and ample testing of responses to each concentration yields estimates of true intra- and inter-individual variation that are far lower than has generally been thought the case (Walker *et al.*, 1999). Since odor perception is one of the major determinants of acceptability, these observations suggest that IAQ research might benefit from a shift of focus toward much more comprehensive study of the responses of each individual to a well-defined set of environments.

Bearing in mind the uncertainties of measurement resulting from the fact that each individual makes only a single assessment of a given environment, there does seem to be good temporal stability, at the group level, in mean acceptability ratings. Wargocki exposed individuals to air polluted by a mixture of 22 common organic chemical indoor pollutants, with each pollutant present at concentrations reflecting levels normally found indoors (Wargocki, 1998). Mean acceptability ratings of air quality at the same exposure levels assessed by the same group of observers were reasonably repeatable, even though the assessments were separated by 1–3 weeks (Figure 2).

An example of the relationships between the concentration of pollutants in air and the ratings of acceptability of quality of air containing these pollutants is presented in Figure 3. For the range of concentrations studied the relationships exhibit a log–linear nature. Relationships similar to those presented in Figure 3 have been found in studies of the effects of exposure to air containing pollutants emitted by building materials at concentrations reflecting typical indoor levels (Knudsen *et al.*, 1998).

Information on laboratory assessments of acceptability of air quality by groups of subjects may be used to estimate

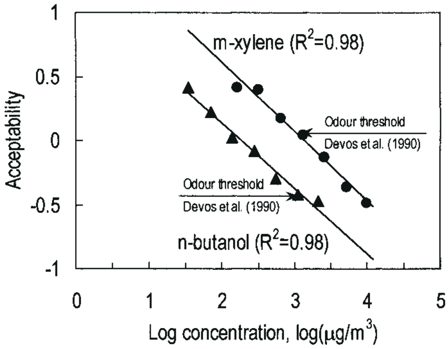

Figure 3 Acceptability of air quality as a function of concentration of *n*-butanol and *m*-xylene (Wargocki, 1998). Each point represents a mean vote rating of 41 observers on a continuous acceptability scale (see caption to Figure 1 for coding). Each observer made one evaluation of each exposure a day. Assessments were taken immediately upon exposure to air containing *n*-butanol and *m*-xylene at different concentrations. Odor threshold concentrations for these compounds (OT) according to the compilation by Devos *et al*. (Devos *et al*., 1990) are indicated in the figure.

either the proportion of occupants of actual indoor environments that will report dissatisfaction or the ventilation rate required to achieve a given level of acceptability. These two important applications are beyond the scope of the present paper and are described in detail by, respectively, Gunnarsen and Fanger (Gunnarsen and Fanger, 1992) and Fanger (Fanger, 1988).

A number of issues require elucidation when acceptability of air quality is used as an end-point for measuring sensory discomfort. For instance, it is assumed that the assessments of acceptability of air quality integrate different sensory stimulations into one measure of discomfort. However, this assumption has never been explicitly investigated by, for example, measuring acceptability simultaneously with psychophysical measurements of odor intensity, irritation and hedonic character. In addition, it would be extremely useful to learn the extent to which organismic variables, such as personality, preference, mood and prior experience, affect assessments of acceptability. The considerable variation in judgements of acceptability, discussed above, strongly implies that these variables may be important determinants of acceptability. Finally, the accuracy and repeatability of the measurements of acceptability of air quality, an issue already highlighted indirectly by Kendal-Reed *et al.* (Kendal-Reed *et al.*, 1998), should be intensively pursued.

Future work

Based on the description above of the most common approach used to assess the acceptability of indoor air environments and the sample data presented, a number of related research needs are apparent. For example, an improved understanding of the interaction between organismic and stimulus variables in the determination of acceptability would be extremely valuable. It seems safe to conclude that with the present paradigm described in this paper the variation due to those characteristics that subjects bring into the experiment can sometimes be comparable with that due to changes in environmental parameters. Research designs that minimize the contribution of subject states or traits would address this question and would also be useful in addressing a second important question, the degree to which odor and irritatant stimulation of the eyes or nose determine acceptability. This could be addressed readily by simply including psychophysical measurements of odor and irritation in IAQ laboratory studies. It is, however, a good practice in many experiments to measure odor intensity and irritation (Fanger *et al.*, 1988; Fang *et al.*, 1998a,b; Wargocki *et al.*, 1999, 2000). Depending on conclusions from such studies, efforts to model acceptability based on purely perceptual information would be either supported or discouraged. Finally, it is important to develop a much more complete understanding of the transformation rules that will allow improved prediction of responses in actual environments from laboratory results. Efforts in this area will need to elucidate how social interactions, distractions due to job duties and other factors modulate responses to indoor air composition in the 'real world'.

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