Impact of Temperature and Humidity on the Perception of Indoor Air Quality

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Abstract Sensory responses to clean air and air polluted by five building materials under different combinations of temperature and humidity in the ranges 18-28°C and 30-70%RH were studied in the laboratory. A specially designed test system was built and a set of experiments was designed to observe separately the impact of temperature and humidity on the perception of air quality/odour intensity, and on the emission of pollutants from the materials. This paper reports on the impact on perception. The odour intensity of air did not change significantly with temperature and humidity; however, a strong and significant impact of temperature and humidity on the perception of air quality was found. The air was perceived as less acceptable with increasing temperature and humidity. This impact decreased with an increasing level of air pollution. Significant linear correlations were found between acceptability and enthalpy of the air at all pollution levels tested, and a linear model was established to describe the dependence of perceived air quality on temperature and humidity at different pollution levels.

Key words Indoor air quality; Perceived air quality; Temperature; Humidity; Perception; Ventilation.

Introduction

The purpose of ventilation for offices, lecture halls, schools, and similar spaces is to provide air of a quality that will be perceived as acceptable. The idea is to dilute the pollution from sources in the space by supplying the necessary flow of outdoor air. For many years, occupants were believed to be the only source of pollution. During recent years, however, the building has also been acknowledged as a major source of pollution. To improve indoor air quality, ventilation was usually believed to be the most effective way, and the more ventilation, the better the quality of the indoor air. This idea came from the philosophy that it is the chemical properties of indoor air that determine its quality, while physical properties of the air, such as temperature and humidity, influence the thermal sensations. In ventilation standards and guidelines (ASHRAE, 1989; DIN, 1994; and ECA, 1992), air temperature and humidity have not until now been regarded as factors that have any impact on perceived indoor air quality.

Yaglou et al. (1936) considered the effect of temperature when they performed their classic studies for ASHRAE on ventilation requirements. The required ventilation rate obtained from their experiment was based on neutral thermal conditions, as they remarked that: "temperature, in fact, is one of the most important factors in air quality and unless it is controlled the quality will suffer badly, no matter what the outdoor air supply, particularly when the air is overheated".

The effect of temperature and humidity on the perception of odour intensity and air quality has been investigated in several previous studies. In an early study, Kerka and Humphreys (1956) used human panels to evaluate the odour intensity of three pure vapours and of cigarette smoke. The authors found that the odour intensity decreased with increasing humidity, and for tobacco smoke, that the odour intensity decreased slightly with an increase in air temperature at constant water vapour pressure. Woods (1979) re-evaluated Kerka and Humphreys' results and found that the perceived odour intensity was linearly correlated with enthalpy of the air, which revealed an impact of the thermal environment on the sensitivity of the sense of smell.

In a major study by Cain et al. (1983), the impact of temperature and humidity on perceived air quality was studied for both smoking and non-smoking occupancy. In the study, subjective assessments of odour

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intensity and acceptability of air polluted with bioef-fluents or tobacco smoke were obtained for four environmental conditions: 20°C RH≤50%, 23°C RH≤50%, 25.5°C RH≤50%, and 25.5°C RH≤70%. The selection of environmental conditions did not allow the authors to study the effect of humidity at moderate temperatures. The authors concluded that for both smoking and non-smoking conditions, a combination of high temperature (25.5°C) and high humidity (RH≥70%) exacerbated the odour problem. However, the observed odour intensity difference was not significant when air was polluted by tobacco smoke at different temperatures and humidities.

In a later study, Berglund and Cain (1989) concluded that for a subjective evaluation of indoor air quality, the concentration of pollutants in the air may in some instances prove secondary to the influence of temperature and humidity. This rather surprising conclusion was derived from the subjective responses of 20 subjects studied at three temperatures, three humidities and three activities or metabolic rates. The air was perceived to be fresher and less stuffy with decreasing temperature and humidity. The effect of temperature was linear and stronger than the effect of humidity. The effect of humidity on freshness, stuffiness, and acceptability of the air quality was smaller in the dew-point range 2–11°C than in the range 11–20°C. The air quality was typically unacceptable when the relative humidity exceeded 50%.

Gwosdow et al. (1989) studied the physiological and subjective responses to the respiratory air at four levels of temperature (27°, 30°, 33° and 36°C) and two levels of relative humidity (47%, 73%). The air was supplied by respiratory protective devices, and the study showed that the acceptability of the inspired air decreased when the air temperature rose above 30°C.

Conversely, a study made by Berg-Munch and Fanger (1982) found no significant influence of air polluted by human bioeffluents on perceived odour intensity when the air temperature increased from 23° to 32°C. The authors concluded that the ventilation requirement is most likely independent of the temperature in spaces where bioeffluents are the dominant source of pollution, such as in auditoria, theatres, etc., provided that people are kept thermally neutral. Clausen et al. (1985), in their study, also observed no significant changes in odour intensity of air polluted by tobacco smoke, when the relative humidity varied between 30% and 80%.

On the other hand, temperature and humidity may also influence the emission of pollutants. The effect of temperature and humidity on the chemical emission of building materials has been reported in several studies

(Andersen et al., 1975; Bremer et al., 1993; Wolkoff, 1997). It is likely that temperature and humidity influence perceived air quality in two ways: a) the perception of odour intensity and air quality; b) the magnitude and composition of emissions. However, the information available at present is insufficient for practical applications in HVAC engineering. To investigate systematically the way in which temperature and humidity may influence perceived air quality, a comprehensive study was initiated under the Danish "Healthy Buildings" research programme and under the research programme "European Data Base for Indoor Air Pollution Sources in Buildings". The study investigated separately the impact of temperature and humidity on both human perception of air quality and on emission of pollutants from building materials. This paper presents the results of the investigation on the impact of temperature and humidity on the perception of air quality and odour intensity, with common building materials as pollution sources. The results reflecting the influence of temperature and humidity on the emission of building materials will be published separately.

Methods
Pollution Sources and the Test Environments
The effect of temperature and humidity on the perception of air quality and odour intensity was investigated at three levels of temperature (18°, 23°, 28°C) and three levels of relative humidity (30%, 50%, 70%RH) using the judgements of a sensory panel of untrained persons. The investigations were made with unpolluted outdoor air and with air polluted by five building materials. The building materials used as pollution sources in the experiment were PVC flooring, waterborne acrylic floor varnish, loomed polyamide carpet, waterborne acrylic wall paint and acrylic sealant. The floor varnish was painted on 12 mm thick beechwood parquet; the wall paint was painted on 10 mm thick gypsum board; the sealant was applied to u-shaped aluminium profiles

Table 1 Area of material samples placed in each CLIMPAQ

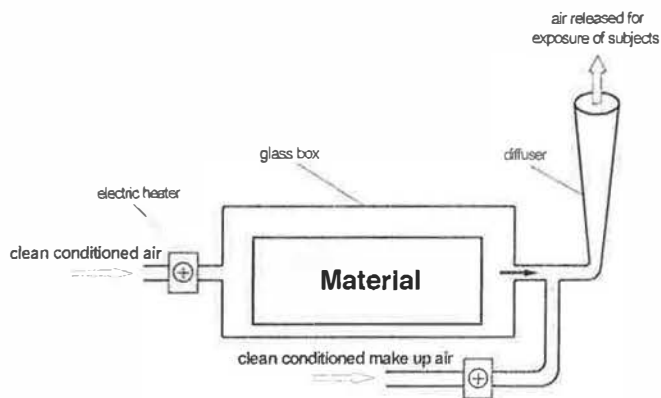| Material		Area of material (m²)
PVC flooring	(loading 1)	1.2
Carpet	(loading 1)	0.3
	(loading 2)	0.6
Floor varnish	(loading 1)	0.22
	(loading 2)	0.66
Wall paint	(loading 1)	0.62
	(loading 2)	1.55
Sealant	(loading 1)	0.015 (=1.5m)
	(loading 2)	0.0375 (=3.75m)

Fig. 1 Principle of the modified CLIMPAQ

with an inner width and depth of 10 mm and 12 mm respectively. The quantities of the material loadings are listed in Table 1. They were determined using sensory emission data of the same materials obtained from a previous study (Knudsen et al., 1996).

Experimental Facilities

The fundamental experimental principle was to study the impact of temperature and humidity separately on perceived air quality / odour intensity and on pollutant emissions from building materials.

The experiments were carried out in a climat chamber ($3.6 \times 2.5 \times 2.55$ m³) which was designed for a quality studies (Albrechtsen, 1988). Inside the chambe a specially designed test system was built. It consiste of 10 modified CLIMPAQs (Chambers for Laborator Investigations of Materials, Pollution and Air Qualit (Gunnarsen et al., 1993). The CLIMPAQ is $1.005 \times 0.25 \times 0.22$ m³ test box made of glass. Each of th modified CLIMPAQ had a diffuser to release the a for exposure of the subjects, and each of them wa equipped with two independent air-conditioning sy: tems: one supplied 0.2 L/s of clean air, conditionin the temperature and humidity inside the CLIMPAC the other supplied 0.7 L/s of make-up air, recor ditioning the temperature and humidity of the airflo released from the CLIMPAQ and controlling the ten perature and humidity of the air in the diffuser. Th test material was placed in the CLIMPAQ which wa supplied with conditioned clean air, giving an a change of 17 h⁻¹ in each CLIMPAQ. The principle c these modified CLIMPAQs is shown in Figure 1.

The principle of the air-conditioning system for th CLIMPAQs is shown in Figure 2. The air was pre-cor ditioned collectively by a multi-dew-point air-cond: tioner that can provide 20 airflows with different dew point temperatures. The multi-dew-point air-condi
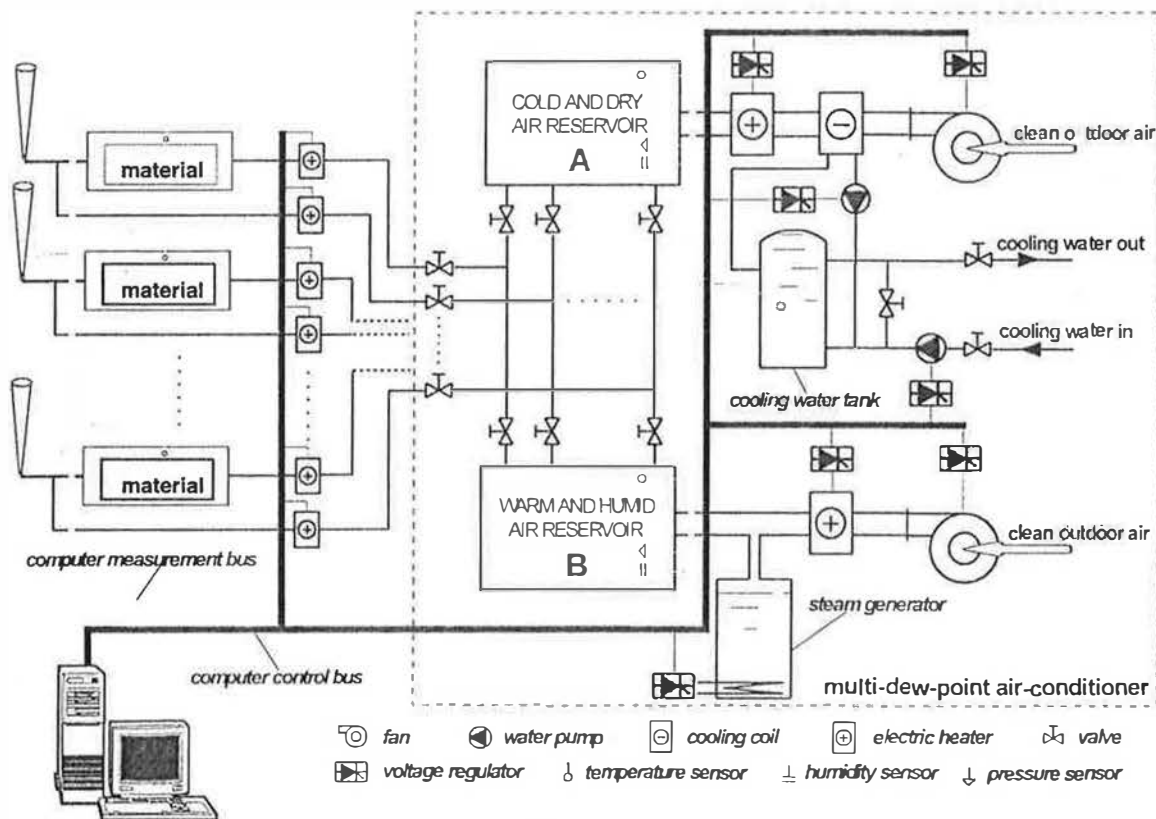

Fig. 2 Schematic diagram of the air-conditioning system for CLIMPAQs
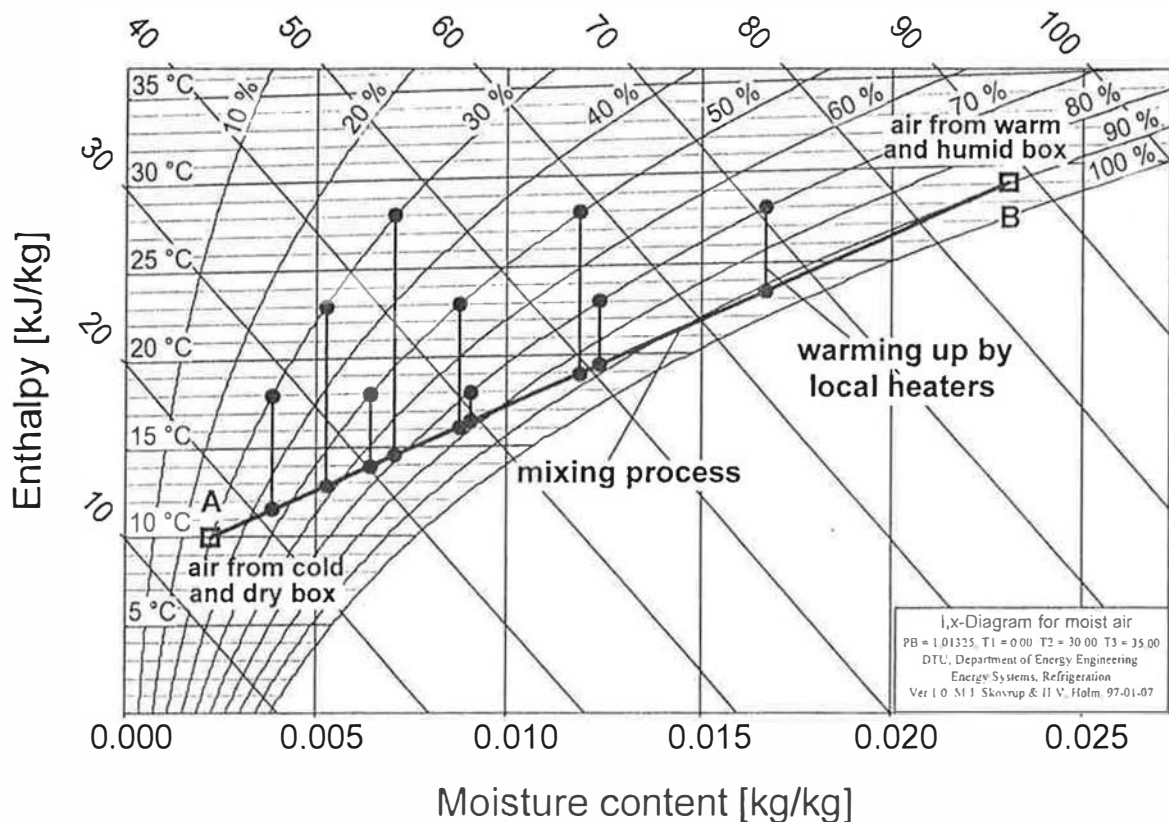
Fig. 3 Example of air-conditioning processes for the nine temperature and humidity conditions

tioner consists of two conditioned air supply systems: one supplied cold and dry air (10°C, 30%RH) to air reservoir A, the other supplied warm and humid air (29°C, 90%RH) to air reservoir B. The temperature, humidity and pressure were kept constant at the two air reservoirs. The air from the two reservoirs was then mixed through 20 sets of mixing valves and split into 20 flows. By adjusting the valves, the proper mixing rate and flow rate could be obtained, which gave each airflow a required absolute humidity and flow rate; however, the temperatures were kept lower than required. The airflows were then sent to the CLIMPAQs and heated locally by the electric heaters in each CLIMPAQ to obtain the required temperatures and relative humidities. Therefore, this air-conditioning system could simultaneously provide 20 airflows, each with any combination of temperature and humidity in the range 10°C, 30%RH to 29°C, 90%RH. An example of the air-conditioning processes that give a required matrix of the nine temperature and humidity combinations is illustrated on the psychrometric chart shown in Figure 3. The whole system was automatically controlled by a computer which maintained a stability of ±0.2°C temperature, ±3% relative humidity and ±2% airflow rate respectively for each parameter controlled in the system.

To avoid polluting the air by the equipment itself, all the surfaces that were in contact with the air in the multi-dew-point air-conditioner, the CLIMPAQs and the tubes connecting both parts were made of glass, stainless steel or Teflon. Only distilled clean water was used to humidify the air; the water boiler and all pipes supplying the steam were also made of stainless steel and were cleaned before use. While the system was in operation, the overpressure inside the water boiler guaranteed that no pollutants could be introduced into the water from the supply air. Furthermore, the water temperature was kept above 100°C, thus preventing microorganisms from accumulating in the water.

Forty untrained subjects (30 males and 10 females) were recruited to assess the air quality. The subjects were randomly selected; they were university students aged between 20 and 35 years and in good health; seven of them were cigarette smokers smoking maximum 10 cigarettes per day. Because the experiments were performed only once a week, the whole experiment lasted for two months. From time to time, subjects were unable to participate in individual experiments due to illness or other reasons. Each time the number of subjects participating in the experiment varied from 33 to 40. Before the experiment, the subjects were instructed not to eat very spicy food within

24 hours; they were also requested not to use strong perfume. Smoking and drinking coffee were not allowed one hour prior to an experiment.

Experimental Procedures

In testing the impact of temperature and humidity on perception, the ambient temperature and humidity inside the climate chamber were set at 18°C and 30%RH respectively; the air change rate in the climate chamber was set at 56 h^{-1} to achieve a good environment with very low background pollution. All the CLIMPAQs were ventilated by equal airflows with identical temperature and humidity (23°C and 50%), but the air released from the diffusers for exposure was reconditioned to the nine different levels of temperature and humidity by mixing with equal flows of conditioned clean make-up air after each CLIMPAQ. The CLIMPAQs were either empty or loaded with materials. When the CLIMPAQs were empty, the subjects were exposed to clean air conditioned at different temperatures and humidities. When the CLIMPAQs were loaded with materials, the subjects were exposed to polluted air with different temperatures and humidities. The nature of the pollutants was varied by using different types of material and the concentration of the pollutants was varied by changing the material loading. In this way, 10 air samples with different pollutant compositions giving a range of acceptability were prepared (including clean air which was not polluted by the materials); each air sample was further conditioned into 9 different temperature and humidity levels, and the impact of temperature and humidity on perception of these air samples was then tested.

The materials were used one type at a time. Before the test, each type of material was ventilated continuously (24h/day) at 23°C and 50%RH for two weeks, since the previous studies showed that both chemical and sensory emission of the materials tested tended to become stable after being ventilated for 14 days (Tirkkonen et al., 1996; Bluyssen et al., 1996; Knudsen et al., 1996; Wolkoff, 1997). In the first week, each type of material was ventilated collectively; an identical quantity of a given type of test material was then placed in each of the nine CLIMPAQs and ventilated for another week to achieve quasi steady-state emission at the CLIMPAQ. Since temperature, humidity and airflow rates inside each of the nine CLIMPAQs were controlled so that they were identical, the same air pollution could be expected in all nine airflows. During each experiment, the subjects were exposed to air with the same pollution but with different levels of temperature and humidity; therefore, any difference in perceived

odour intensity and air quality would be caused only by an impact of temperature and humidity on perception. This experiment was repeated with each of the five different test materials, each material being tested at two levels of loading (see Table 1), except for PVC flooring where only one level was tested. In addition, there was always one empty CLIMPAQ arranged to determine odour intensity and acceptability of the clean background air at 23°C and 50%RH.

On each experimental day, each subject made the sensory assessments within one hour. After a brief exposure to the air released from the CLIMPAQs, the subjects assessed their immediate perception and marked the continuous odour intensity and acceptability scales (Figure 4) to judge each assessed air sample. Each air sample was randomly assigned for assessment by the subjects, and the subjects were not allowed to compare the assessment of different air samples.

Before the subjects voted on the acceptability of the air, they were asked the following question: *Imagine that during your daily work you would be exposed to the air from the diffusers. How acceptable is the air quality?* The acceptability scale was slightly modified from that used by Gunnarsen and Fanger (1992) by splitting "just acceptable" and "just unacceptable" at the centre of the scale to avoid the vote on both "just acceptable" and "just unacceptable" and make it possible to count PD using the percentage of the votes on the unacceptable side. The mean acceptability of the subject votes can be used to describe perceived air quality and can also be converted to Percentage of Dissatisfied (PD) (Gunnarsen and Fanger, 1992) or decipol (Fanger, 1988).

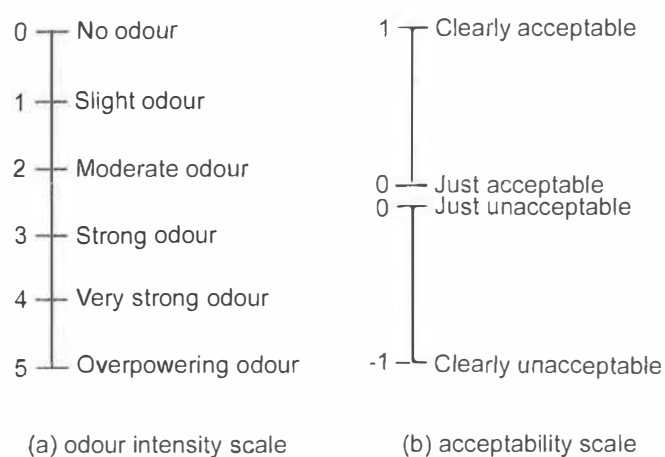(a) odour intensity scale   (b) acceptability scale

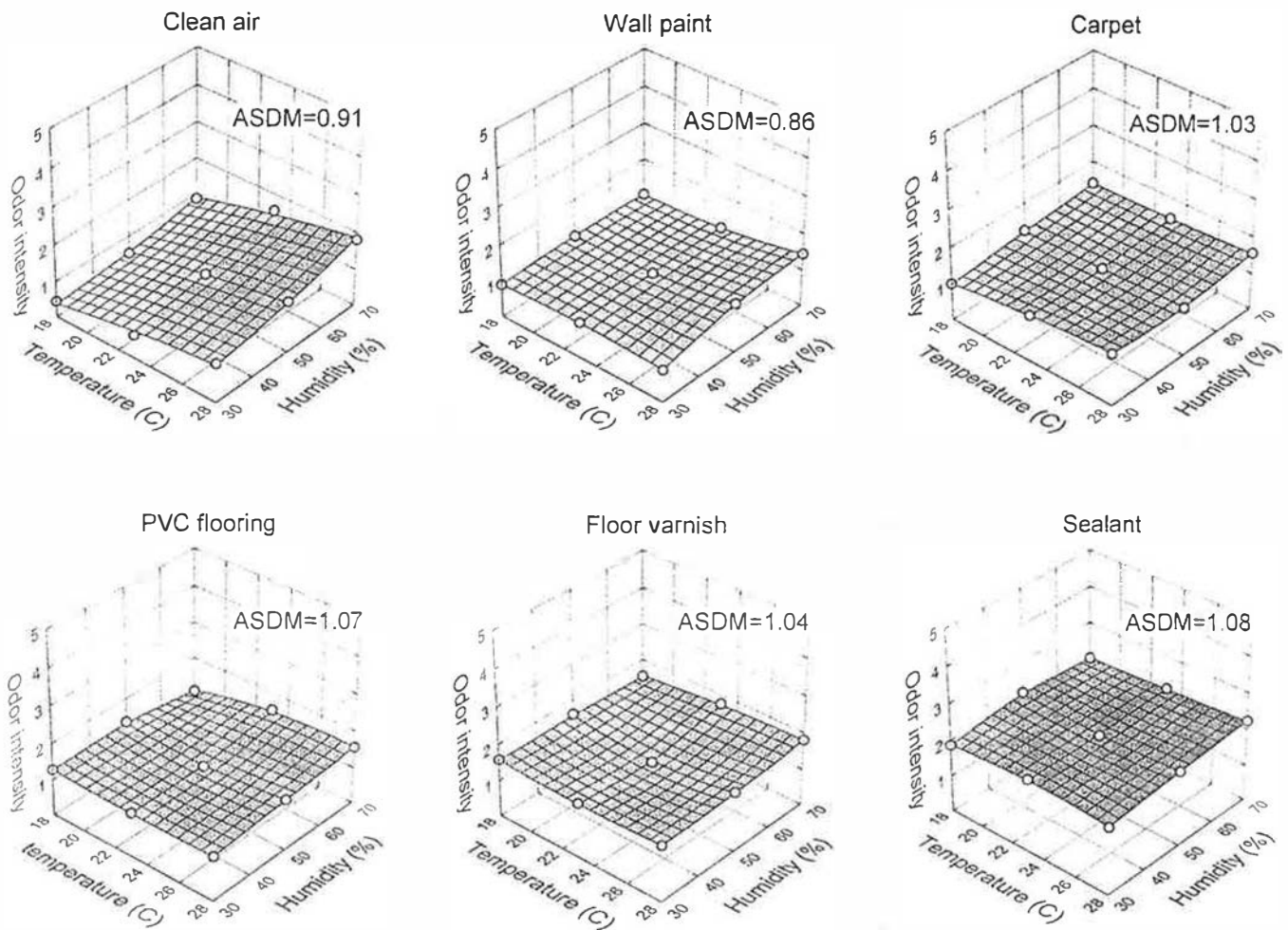Fig. 4 Odour intensity and acceptability scales used by the sensory panel during the experiment

Fig. 5 Perception of odour intensity of clean air and air polluted by the five building materials at different temperatures and humidities

Results

The Influence of Temperature and Humidity on Odour Intensity of Air

The observed impact of temperature and humidity on the perception of odour intensity was presented by fitting the response surfaces of the mean odour intensity votes obtained for the nine combinations of air temperature and humidity. Different response surfaces were fitted for the air with different compositions (e.g. clean air and air polluted by the five building materials at different loadings). Figure 5 shows sensory responses for clean air and air polluted by the five materials, each at one pollution level, arranged in order of increasing odour intensity. The nine data points shown on each surface are the mean votes of 33 to 40 subjects. The Average Standard Deviation of the Means (ASDM) is also given on each figure. The response surfaces in Figure 5 show that temperature and humidity had little influence on perception of odour intensity. Especially when air was polluted by the materials, the odour intensity of the air seems independent of the air temperature and humidity. For clean air the odour intensity slightly increased with increasing air temperature and humidity.

To analyse the statistical significance of the impact of temperature and humidity on the perception of odour intensity, analysis of variance was performed for the mean odour intensity votes of the subjects. This analysis showed that the impact of both temperature and humidity was not significant at the level of $P<0.05$ when air was polluted by building materials; however, for clean air this impact was found statistically significant at a level of $P<0.05$.

The Influence of Temperature and Humidity on the Acceptability of Air

The response surfaces of the mean perception of air quality in the temperature and humidity ranges 18–28°C and 30–70%RH are shown in Figure 6. The figure shows the mean acceptability votes of the same air samples as used for odour intensity assessment and arranged in the same order as in Figure 5. The response surfaces in Fig-
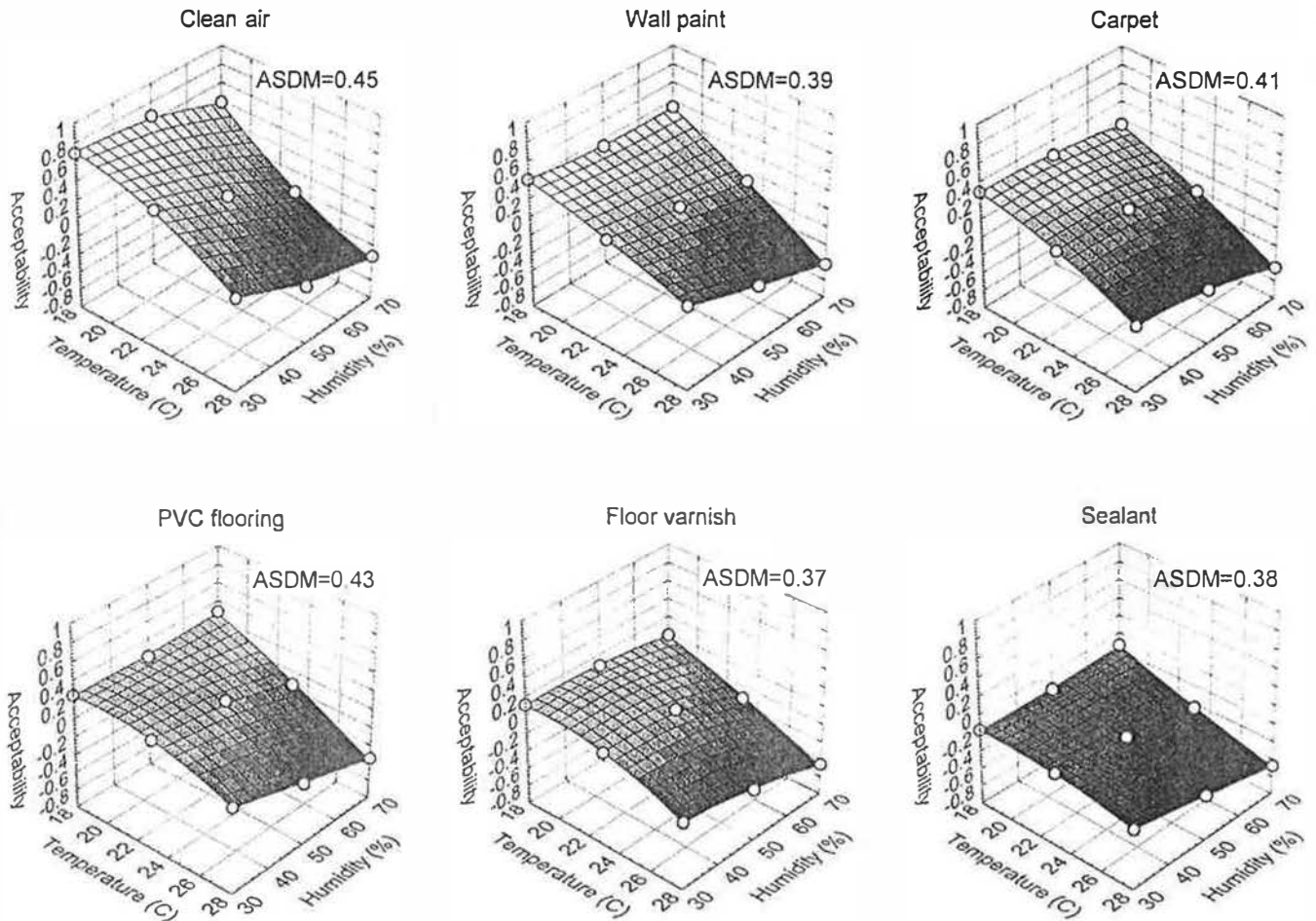
Fig. 6 Perception of acceptability of clean air and air polluted by the five building materials at different temperatures and humidities

ure 6 show that the air was always perceived as less acceptable with increasing temperature and humidity, and that this impact was less pronounced with increasing level of air pollution (indicated by decreased acceptability). Analysis of variance showed that the impact of both temperature and humidity is highly significant ($P<0.002$) at all the pollution levels tested. Furthermore, the interaction of temperature and humidity is also significant at a level of $P<0.05$.

The impact of temperature and humidity on perception was further studied by correlating acceptability with the thermodynamic property "enthalpy" which represents the energy content of the moist air. Highly significant linear relations were found at all tested levels of the different pollutants. The linear regressions of acceptability versus enthalpy of the assessed air at five selected pollution levels are shown in Figure 7. At low enthalpy (low temperature and/or humidity) the pollution level is the key factor that influences the perception of air quality, while air pollution becomes less important for the perceived air quality when enthalpy of the air increases. Beyond a certain level of enthalpy,

for instance at 28°C and 70%RH, temperature and humidity are the key factors that determine the perceived air quality; in this case, the air was perceived as unacceptable whether the air was clean or not.

Models can be created to predict perceived air quality, using the data obtained from the experiment. The
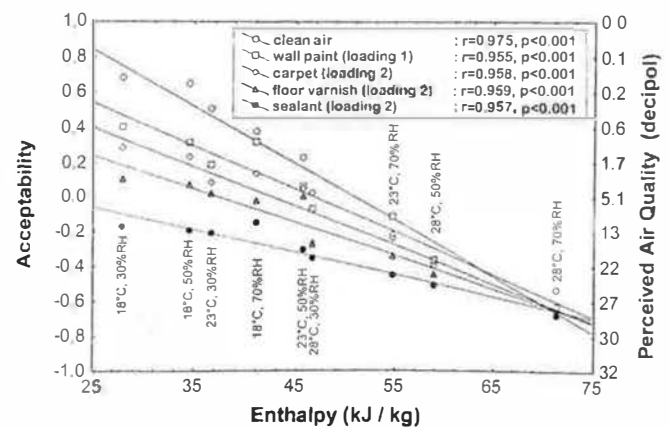

Fig. 7 Acceptability of air related to enthalpy at the selected pollution levels of different materials

Table 2 Coefficients of equation (1) for air with different compositions

Tested air (with different pollution source)		Coefficients of Eq. 1		Significant level P<
		a	b	
Background air	(clean)	−0.033	1.662	0.0000
polluted by floor varnish	(loading 1)	−0.026	1.268	0.0001
polluted by wall paint	(loading 1)	−0.025	1.162	0.0000
polluted by carpet	(loading 1)	−0.024	1.030	0.0001
polluted by carpet	(loading 2)	−0.023	0.966	0.0001
polluted by PVC flooring	(loading 1)	−0.021	0.941	0.0002
polluted by sealant	(loading 1)	−0.020	0.743	0.0009
polluted by floor varnish	(loading 2)	−0.019	0.722	0.0002
polluted by wall paint	(loading 2)	−0.018	0.713	0.0010
polluted by sealant	(loading 2)	−0.013	0.263	0.0080

models should include three factors – air pollution, temperature and humidity – to determine perceived air quality. A simple linear model was first considered by using the results from Figure 7. The linear model defined the acceptability of the air as a function of enthalpy by the following equation:

$$Acc = aE + b \qquad (1)$$

where: Acc=acceptability of the air
E=enthalpy of the air (kJ/kg)

a,b are coefficients which will be different for the air with different pollutants and pollution levels.

To determine the two coefficients, linear regressions were made between the acceptability and enthalpy for tested air with the 10 different compositions. The coefficients a and b from the 10 linear regressions are listed in Table 2.

The two coefficients are different at different levels of air pollution; however, a highly significant linear correlation was found between the two coefficients (Figure 8). A linear regression of the coefficients a and b can be expressed as:
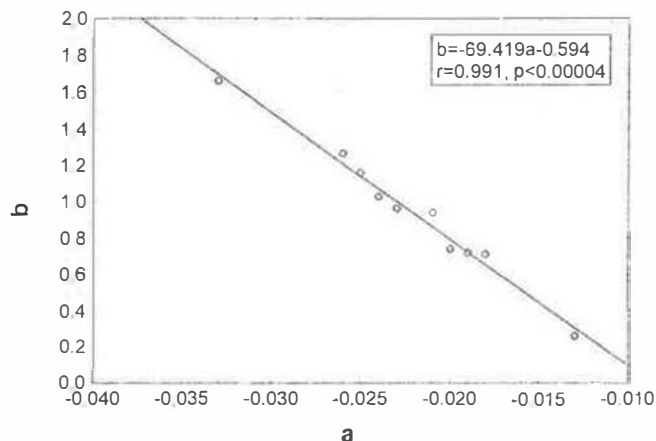

Fig. 8 Linear correlation between coefficients a and b

$$b = -69.419a - 0.594, \quad (r = 0.991, \ P < 0.00004) \qquad (2)$$

Substituting for b in eq. (1), one obtains:

$$Acc = aE - 69.419a - 0.594 \qquad (3)$$

Rewriting eq. (3) for a reference condition of 23°C, 50%RH, for which E=45.39KJ/kg, the perception model can be expressed as:

$$Acc = Acc_0 - 0.0247(E-45.39) - 0.0416Acc_0(E-45.39) \qquad (4)$$

where Acc_0 is the acceptability of the air at 23°C and 50%RH; E can be calculated from air temperature and humidity by using perfect gas laws as follows:

$$E = h_a + W \cdot h_g \qquad (5)$$
where:

$h_a = 1.006t$, the enthalpy of dry air;
$h_g = 2501 + 1.84t$, the enthalpy of water vapour;
$W = 0.622 P_w / (P_0 - P_w)$, the humidity ratio;
$P_w = 0.01\phi P_{ws}$, the partial pressure of water vapour;
P_{ws} = the saturation pressure of water vapour,
by the Antoine equation, $P_{ws} = e^{(23.58 - 4043/(t+273.15-37.58))}$.

Thus we obtain the following equation to calculate enthalpy from temperature and relative humidity of the air:

$$E = 1.006t + 0.622(2501 + 1.84t) \cdot \frac{0.01\phi e^{(23.58-4043/(t+273.15-37.58))}}{P_0 - 0.01\phi e^{(23.58-4043/(t+273.15-37.58))}} \qquad (6)$$

where: t=air temperature (°C)
ϕ=relative humidity (%)
P_0=atmospheric pressure (Pa), (typically P_0=101324Pa)

Eq. (4) indicates that the acceptability of the assessed

air is influenced by a linear combination of sensory pollution, temperature and humidity (expressed by enthalpy) and the interaction of the three factors. Also, it can be seen that when E=45.39 kJ/kg (e.g. t=23°C, ϕ= 50%), then Acc=Acc$_0$. Acc$_0$ is used here as a factor indicating the air pollution level. Acc$_0$ can also be arranged to be the acceptability of the air at any temperature and humidity by adjusting the other terms of the equation. The enthalpy correction introduced by the model makes it possible to predict the perceived air quality at any level of temperature and humidity by measuring acceptability of the air at a single level of temperature and humidity. The model can also be used together with an emission model and the comfort equation of perceived air quality (Fanger, 1989; ECA, 1992) to calculate the ventilation requirement or the sensory pollution load.

Discussion

Figure 5 and Figure 6 indicate that the decrease of perceived air quality (acceptability of the air) due to increasing air temperature and humidity was not caused by an increased odour intensity of the air. A cooling effect in the respiratory tract may help to explain the reason. It is well known that chemical pollutants influence perception of the air by acting directly on the olfactory and chemical sense, and lead to the perception of odour or irritation. Temperature and humidity, however, change the energy content of the inspired air and provide a changed cooling of the respiratory tract. In general, the effect of the thermal exchanges on inhalation is to cool the mucosa if the temperature of the inhaled air is below the mucosal temperature which is normally at a level of 30° to 32°C (Mcfadden, 1983; Proctor and Andersen, 1982). The observed linear correlation between acceptability and enthalpy of the air implies that the cooling of the mucosa is essential for the perception of acceptable air quality. Within the temperature and humidity ranges tested, the more cooling the respiratory tract was exposed to, the fresher and more acceptable was the air perceived. An insufficient cooling may be interpreted as a local warm discomfort in the respiratory tract and lead to the inhaled air being perceived as unacceptable. Recently, Toftum et al. (1997) studied jointly the respiratory thermal sensation and the perceived comfort due to respiratory cooling. The experiment led to almost the same results as those of the present study. A similar linear correlation between air freshness and enthalpy was observed by Berglund and Cain (1989). The present study further indicated that when the respiratory cooling effect decreases to a certain level, the air will be perceived as very poor whether it is clean or polluted, and increasing the ventilation rate would be a waste of energy without any improvement in perceived air quality. In this case, decreasing air temperature and humidity would succeed where decreasing the pollution level could fail to achieve acceptable air quality.

The present study shows that air quality acceptability is very sensitive to temperature and humidity, while the perception of odour intensity of materials seems to be almost independent of air temperature and humidity. The experiment used building materials as air pollution sources. However, if the impact of temperature and humidity on acceptability of air is due to the cooling effect in the respiratory tract, the results obtained from this study would probably also apply to conditions with other pollution sources. For air polluted by human bioeffluents and tobacco smoke, the studies made by Berglund and Cain (1989) and Cain et al. (1983) confirmed that the acceptability of air was also decreased significantly with increasing air temperature and humidity. Cain's study also observed the odour intensity using the butanol odour intensity scale and the continuous line-marking odour intensity scale. The odour intensity of the air polluted by tobacco smoke assessed using the butanol odour intensity scale showed little difference between two levels of air temperature and humidity. For occupancy odour, the odour intensity increased with increasing air temperature and humidity. However, in Cain et al.'s study, the impact of temperature and humidity on the emission from the occupants was confounded with the impact on perception. Therefore, the increased odour intensity was most likely due to the increased emission from the occupants when they were exposed to higher levels of air temperature and humidity. The study of Berg-Munch and Fanger (1982), and Clausen et al. (1985), using the same odour intensity scale as the present study, confirmed that odour intensity was insensitive to air temperature and humidity when air was polluted by occupants or tobacco smoke.

Kerka and Humphreys' result (1956) showed that odour intensity of tobacco smoke decreased with increasing air temperature and humidity. This result is inconsistent with that found in the present experiment and in other studies. However, the odour intensity observed by Kerka and Humphreys changed very little with temperature, and the relative humidity effect was more evident at the higher temperatures. Since only six subjects were used as a sensory panel making the judgement, the observed difference in odour intensity may not be statistically significant. However, the analysis of variance for the odour intensity data of tobacco smoke was not reported in their paper. It is

therefore difficult to judge whether the observed variation of odour intensity is an intrinsic effect of temperature and humidity or not.

Including the influence of temperature and humidity in ventilation requirements may be of practical significance in optimizing energy utilization. To provide a certain perceived air quality, the ventilation requirement may be decreased by decreasing the air temperature and/or the humidity. Obviously, this will lead to a reduction in energy consumption in the winter. Even in summer, the amount of energy saved by decreasing the ventilation rate may compensate for the increased energy required to further cool or dehumidify the reduced flow of supplied outdoor air, and compensate for the increased heat gain due to the lower room air temperature. Therefore, above a minimum ventilation requirement for health, there may be an optimum level of indoor air temperature and humidity at which a minimum consumption of energy for heating, ventilation and air-conditioning can be achieved for a given level of perceived air quality. The optimum temperature and humidity will of course depend, *inter alia*, on the outdoor air temperature and humidity, the thermal transmittance (U-factor) of the external wall, and the indoor air pollution load.

A great effort was made to avoid any pollution coming from the humidification system of the test facility. The unpolluted air supplied to the CLIMPAQs at 28°C, 70%RH and at 18°C, 30%RH was chemically analysed to further check whether any pollutants had been introduced by humidification of the air. The chemical analysis revealed very low concentrations of VOCs and no significant difference of the TVOC concentrations between the most humid and the driest condition, which further proved that the humidification system, as designed, did not pollute the air. The observed impact of humidity on the perception of air quality was a true effect of humidity as such.

The first impression on entering a space has traditionally been the basis for ventilation standards as a measure of perceived air quality. The evaluation is usually relative to clean background air of prior exposure, but the temperature and humidity of the background air has not yet been defined. The present investigation of perceived air quality was relative to clean ambient air at 18°C and 30%RH as a background in the climate chamber. This arrangement gives the best perceived quality of the background air in the temperature and humidity ranges tested in the experiment. However, the results of the experiment may vary with the temperature and humidity of the background air. Furthermore, the judgements in this study were made by exposing only the face to the air released from the diffusers. This exposure is somewhat artificial compared to practice when the whole body is exposed when people enter a room. The present results need to be validated under such conditions. A further study is therefore suggested to test the impact of temperature and humidity on the perception of air quality during immediate and longer whole-body exposure with different prior exposure temperature and humidity environments.

Conclusions
- Temperature and humidity have little influence on perception of odour intensity of air polluted by building materials.
- Temperature and humidity have a strong and significant impact on the perception of indoor air quality; at a constant pollution level, the perceived air quality decreases with increasing air temperature and humidity.
- The impact of temperature and humidity on the perception of air quality decreases with increasing level of air pollution, while the influence of pollution on perceived air quality decreases with increasing air temperature and humidity.
- At a constant pollution level, the acceptability of the air was found to be linearly correlated with the enthalpy of the air.
- A model was established predicting the effect of temperature and humidity on acceptability.
- Further studies on whole-body exposure on a full scale are recommended.

Acknowledgements

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