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Perception and Sensitivity to Horizontal Turbulent Air Flows at the Head Region

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Abstract This work deals with experimental investigations on human reaction to local air movements of people in global thermal comfort, performing light activity. An analysis on draught risk was developed comparing the results with previous research findings on human response to draught. The intensity of air velocity, in terms of mean value and relative turbulence, was referred to the level at which normally clothed people could perceive and feel air movements behind the neck, in global neutral thermal condition. This work provides evidence of how the exposure duration to air movements plays a fundamental role on air flow sensitivity. The human reaction to an air flow was observed to vary with exposure duration: the feeling changes in intensity while the air flow persists blowing constantly. Moreover, different reactions have been observed between female and male test persons. Although these results were observed in the typical situation of horizontal air jet flows blowing from behind, they could apply in climatically controlled environments, where air flow is supplied horizontally at low speed, and the occupants are sitting far from the inlet section.

Key words Draught; Perception and sensitivity to air movements; Thermal discomfort; Low Reynolds number; Isothermal air jet flows.

Practical Implications
This work generates a number of hypotheses that could be important for the design community. For example, how important is the female/male perception difference that is described here? In a crude ventilation system design the result has little significance. However, as we move to higher quality ventilation systems and design goals these results will become more important.

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Introduction

According to the Concise Oxford Dictionary and to the third edition of the *Dictionary of Scientific and Technical Terms*, the term "draught" indicates a "current of air in confined spaces".

Air movements in climatically controlled spaces often generate unwanted cooling effects despite the respect of the conditions of global thermal comfort for the majority of the occupants. Local air movement could increase the sensation of discomfort due to the combined effects of air velocity properties with air temperature and thermal condition of subjects. The impact of air velocity on draught discomfort depends on the direction (Toftum et al., 1997; Mayer et al., 1988), the mean value (Houghten, 1938; Fanger et al., 1986), and the relative turbulence intensity of the air flow velocity (Fanger et al., 1988; Todde, 1997). For normally clothed subjects, the head region has been found to be the most sensitive to draught in many experimental observations. The head is thermally protected from the cooler environmental air by the thermal plume rising from the trunk. The structure of this plume, which also depends on the posture of the subject (Hyldgaard, 1998), is extremely vulnerable to external air flows. Low velocity air flows are able to destabilise the thermal plume enhancing transition to turbulent structures even in layers in contact with the skin. The higher the action of an air flow to destabilise the thermal plume, the higher the cooling effect on the skin surface. In this contest, the scale of turbulent structures in the free external flow plays a significant role (Zukauskas, 1985).

Research Objectives

The aim of this investigation was to determine how people, in global thermal comfort, perceive and feel horizontal turbulent air movements flowing from behind their neck, the corresponding level of discomfort and the amount of effort they were prepared to exert to change their thermal discomfort conditions. The im-

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pact of exposure duration on human reaction was also analysed with reference to the gender.

Air flow Conditions and Measurements

The experiments took place in a climate room where a circular isothermal air jet flow was supplied from a wall orifice of 5 cm diameter (see Figure 1). The wall temperature was kept constant at around 22°C. A first experiment was carried out with twelve volunteer test persons, six males and six females, and the second one with four test persons (among the previous 12 test persons), two females and two males. As shown in Figure 1, every subject performed the test sitting with the centre of the neck placed in the centre-line of the jet flow, which was blowing horizontally from behind. The air flow velocity was recorded within time histories of 3 min at a rate of 2000 Hz, with fibre-film probe temperature compensating sensor. The velocity sensor was mounted on a thin vertical support, which could be moved transversally to the jet flow centre-line, 20 cm behind the neck. To minimise the interaction with the flow field, the probe was kept behind the neck only for the indispensable time to record the air flow properties, then it was moved away. At the inlet section of the jet there is the formation of waves which, after developing for a length that depends on the jet flow Reynolds number, roll up into large-scale vortices (Becker et al., 1968; Crow et al., 1971; Rajaratnam, 1976). These vortical structures can be considered as precursors to the full development of the turbulence. These vortices keep a strong identity for a length corresponding to some orifice diameters (around 8–10 diameters). Afterwards they destabilise and quickly decay to the chaotic structure typical of turbulence, (Tennekes et al., 1990; Rodi, 1982; Abramovich, 1963). The relative turbulence intensity of air velocity is one of the fundamental properties of air movements affecting the

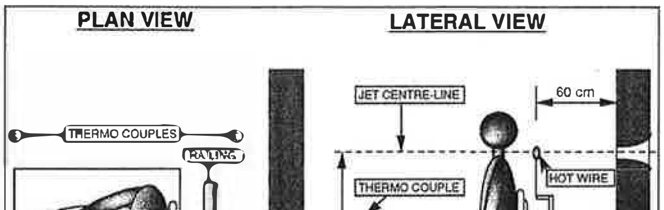

Fig. 1 Experimental design: plan and lateral view

sensitivity to draught. Hence, the experiments were designed with a particular attention to analyse this effect by exposing the neck of the test persons to a developed turbulent air flow, i.e. to a flow where large scale vortices have decayed. Moreover, from the data obtained in the jet flow investigation (Todde et al., 1998), it has been observed that the standard deviation and the mean value of the longitudinal component of air velocity in the centre-line of the jet, start to decrease their longitudinal gradient at a coordinate $\xi \cong 12–15$, ($\xi = X/D$, where X is the downstream distance from the jet orifice, and D the diameter of the nozzle at the inlet section, 5 cm). Thus it has been decided to locate the test person with the back surface of his neck at a distance of 80 cm, ($\xi \cong 16$), from the inlet section of the jet. The distance between the velocity sensor and the neck surface, 20 cm, was the minimum possible to obtain air velocity measurements free from interactions with the human body thermal plume.

Experimental Methodology

In the first experiment, twelve volunteers (six females and six males), participated in tests of around 1 h each, where they were exposed to one constant draught condition. All tests followed the same procedure. The test person was seated on a chair in the climate room, with slightly reclined posture. The position of the chair was adjusted in a way that the centre of the back surface of the neck was at 80 cm from the inlet of the nozzle. With a light laser pointer it was then checked that the neck was placed symmetrically to the centre-line of the jet flow. Long hair was tied up, and shirts without collars were worn, so that the back of the neck was always fully exposed. A thermo-couple was fixed with a small tape on the skin at the back of the neck. The room was then closed and the test person was invited to adjust clothing, to achieve thermal comfort. The subject then relaxed until the skin temperature of the neck stabilised. Generally this phase required a period not less than half an hour. When stability of the neck skin temperature was observed, the jet started to blow air in the room isothermally at constant velocity for 20 min. The presence of the subject caused the room air temperature to slightly increase between values of around 22.2°C and 22.7°C.

Communication with the test person took place over loud-speakers and microphones. It was asked to the test person impressions dealing with his sensitivity to draught behind his neck, from outside the room after 2, 5, 10, 15 and 20 min exposure to the air jet flow. The questions included impressions about overall thermal comfort and sensitivity to air movement behind the

Table 1 Draught sensitivity and relative vote

Air velocity intensity	Air temperature	Pleasanteness	Vote
A lot			4
Definitely			3
Slightly		Pleasant	2
Very slightly		Slightly pleasant	1
Not at all	Neutral	Neutral	0
	Slightly cool	Slightly unpleasant	−1
	Cool	Unpleasant	−2
	Cold	Very unpleasant	−3
	Very cold		−4

neck: the air velocity intensity, the air temperature and the pleasantness of the air movement. In the case, at a certain moment the test person was not feeling in neutral thermal comfort with the whole body, the test was stopped and results disregarded. To the question dealing with the intensity of air velocity, the test person could reply:

No air movements at all. The test person doesn't feel the presence of any air movement behind his neck.

Very slightly. The test person feels a weak air movement, but not constantly.

Slightly. The test person continuously feels a weak air movement.

Definitely. The test person continuously feels an air movement with moderate intensity.

A lot. The test person continuously feels an intense air movement.

To the question about air temperature behind the neck, the test person was invited to reply with one of the following impressions:

Neutral. The test person prefers neither cooler nor warmer air temperature behind the neck.

Slightly cool. The test person starts to have a weak feeling of the coolness of air. The air behind the neck seems to be at lower temperature than the one in the room.

Cool. The test person feels the air behind his neck definitely cooler than the one in the room, but its not cold.

Cold. The test person feels the air temperature behind the neck cold.

Very cold. The test person feels the coolness of the air behind the neck with high intensity.

The third question dealing with the feeling for the air movement was the most detailed. The test person could reply with one of the following impressions: *pleasant, slightly pleasant, neutral, slightly unpleasant, unpleasant, very unpleasant.*

To help the test persons to reply to this question, especially for the negative feelings from slightly unpleasant to very unpleasant, the scale was related to the amount of effort the test persons were prepared to exert to change their thermal conditions. They were asked to imagine themselves on a train. The vote of slightly unpleasant was attributed to the condition when the test person would like to turn off the supply of air movement by simply pressing a button, but if he could not, he would not look for another seat. The situation was considered unpleasant in the case it was impossible to turn off the air supply, and the test person, still imagining himself on a train, would look for another seat in the same carriage. If instead, the test person wished to change carriage, disregarding the available seats beside him, the feeling was dropped to very unpleasant. In Table 1, are listed the vote corresponding to the draught impressions. In some situations, when the test person had some difficulties in expressing judgements, he was allowed to use middle votes, in between the above ones. He was, for instance, allowed to judge the intensity of air movement with a " between *slightly* and *definitely*". These situations happened very seldom.

During the test, the velocity probe was moved towards the jet centre-line to perform velocity measurement for three minutes at a sampling rate of 2000 Hz. Then, it was moved away from the jet flow, with a remote control from the outside of the chamber. At the end of the test, the subject was invited to relax in an

Table 2 Mean initial skin temperature at the subject's neck, and air flow properties of each test

Test	Number of Test Person	Mean Initial Skin Temperature [°C]	Mean Air Velocity [cm/sec]	Relative Turbulence Intensity
1	5 F–5 M	34.3	14–19	27%–29%
2	6 F–6 M	34.8	20–25	25%–29%
3	5 F–6 M	34.3	30–35	24%–28%
4	6 F–7 M	34.4	36–45	24%–27%
5	6 F–5 M	34.6	46–60	24%–26%
6	6 F–4 M	34.7	61–70	24%–26%
7	6 F–6 M	34.7	80–100	23%–26%

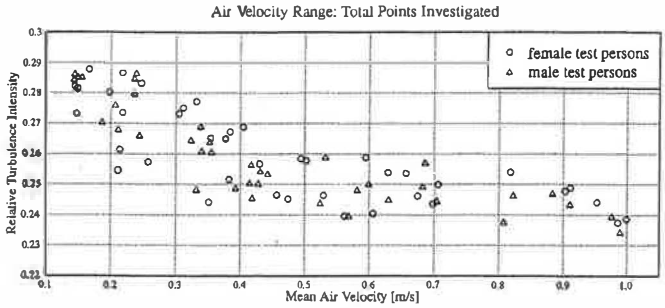

Fig. 2 Relative turbulence intensity versus mean air velocity in each test

adjacent room doing some reading, or study activity for around 40–50 min. Then, he started again the test with another jet flow condition. Every test person performed six/seven tests, but he was never allowed to perform more than three tests per day. The number of subjects participating at each test and the corresponding range of air velocity are indicated in Table 2. The mean initial skin temperature of the neck just before the jet started to blow is also listed. Figure 2 shows the relative turbulence intensity (R.T.I.) versus the mean air velocity recorded in every test, measured in the centre-line of the jet flow 20 cm behind the neck. Indeed, along the cross section of the jet, mean air velocity and relative turbulence intensity were not uniform: moving away from the centre-line, the mean value slightly decreases while turbulence increases.

Sensitivity to Air Movements

All data obtained from the impressions of test persons were analysed separately for each gender. Only results from people feeling in thermal comfort during the whole test were considered.

For every one of the seven tests, the mean vote of human responses was calculated and referred to the average mean air velocity of the corresponding test. For each gender, were obtained seven mean votes for every one of the three impressions, at the average mean air velocity of the corresponding test. In this way it was drawn a trend for every one of the three impressions of air movement versus mean air velocity, with duration exposure as a parameter. Based upon these results, the time history trends for all the three impressions were evaluated.

Figure 3 shows the results dealing with the sensitivity to air velocity intensity after 2, 10 and 20 min of exposure to draught, versus mean air velocity. At the beginning of the exposure, this sensitivity to air movement is practically the same for female and male test persons. As the exposure continues, at the highest velocities investigated, women show a slightly higher sensitivity, i.e. a higher mean vote. From the graphs dealing with the sequence of the vote of air velocity intensity in Figures 6 and 7, for both females and males we can distinguish two trends. At air velocities lower than 0.25 m/s the mean vote decreases only slightly with time; at higher velocities, the decrease is larger. The vote 1.0, which corresponds to a *very slightly* perception of air movement, was found to be nearly independent of the gender during all the exposure. We can observe that this limit happens at a mean air velocity of around 0.26–0.27 m/s, after 2 min exposure, and moves towards air velocities of 0.44–0.46 m/s, after 20 min exposure. In the higher mean velocity range, women are more sensitive than men. A vote of 2 (perception of a continuous and slow air movement), has already a different trend between women and men. After 20 min exposure, a vote of 2 happens at a mean

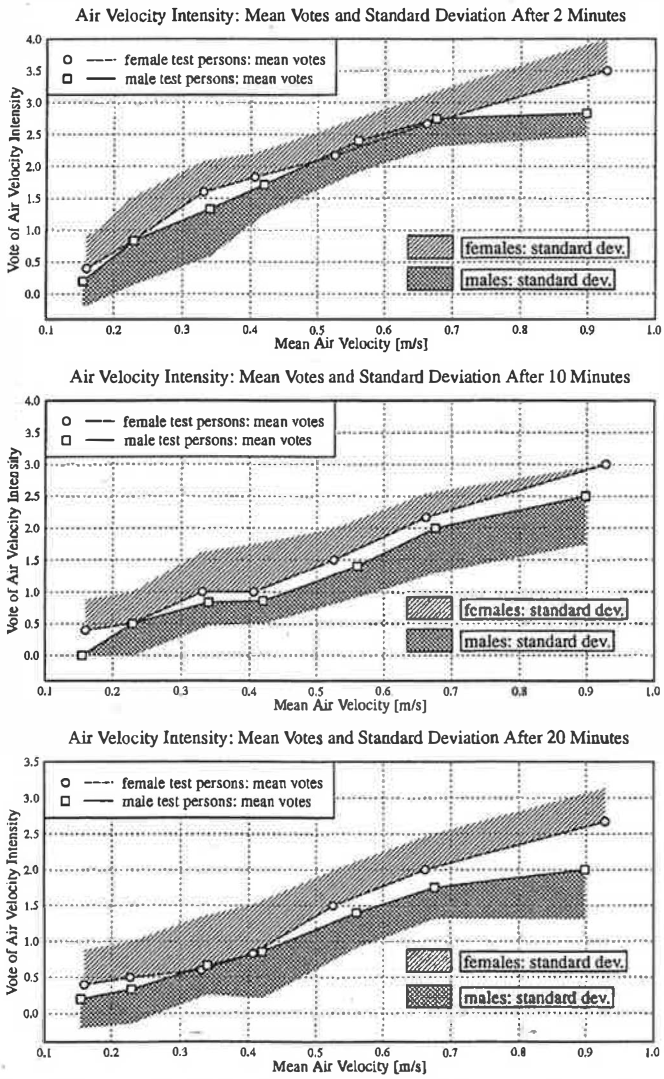

Fig. 3 Mean vote of air velocity intensity. Only one side standard deviation is drawn

air velocity of 0.53 m/s for women, and 0.61 m/s for men. As a general trend, we can also notice that the decrease of sensitivity is more pronounced in the first ten min exposure, for both women and men.

Figure 4 shows the mean vote of air temperature versus air mean velocity. In the beginning of the exposure, men and women have the same sensitivity to the air flow temperature, for all the air velocity range. As the exposure duration increases, women and men start to have different sensitivities. We can easily observe a higher sensitivity for women: in all the air velocity range the female votes are always lower than the men's ones. The corresponding sequences are shown in Figures 6 and 7. The constant-vote lines show a trend nearly independent of time for men. Only some lines indicate a weak decrease in sensitivity: votes −1.0, −1.5 and −2.5. Women, instead, seem to have a sudden increase in sensitivity between 2 and 5 min of exposure, after which the sensitivity remains nearly constant with time. The vote −1, which corresponds to the impression of slightly cool air behind the neck, indicates the condition at which the test person starts to feel the cooling effect of draught. This vote, after 2 min of exposure, occurs at mean air velocity of 0.37 m/s for both female and male test persons. After 20 min of exposure, we have 0.29 m/s for women and 0.45 m/s for men.

The results dealing with the pleasantness are shown in Figure 5. In the first 2 min of the exposure, females and males have an identical sensitivity in the whole velocity range. For longer exposures, the results indicate a constant and more unpleasant situation for female test persons. At mean air velocities lower than 0.6 m/s, the constant-vote lines, (lower graph of Figure 6), are nearly independent of the exposure duration. For men instead, Figure 7, we have an irregular trend with

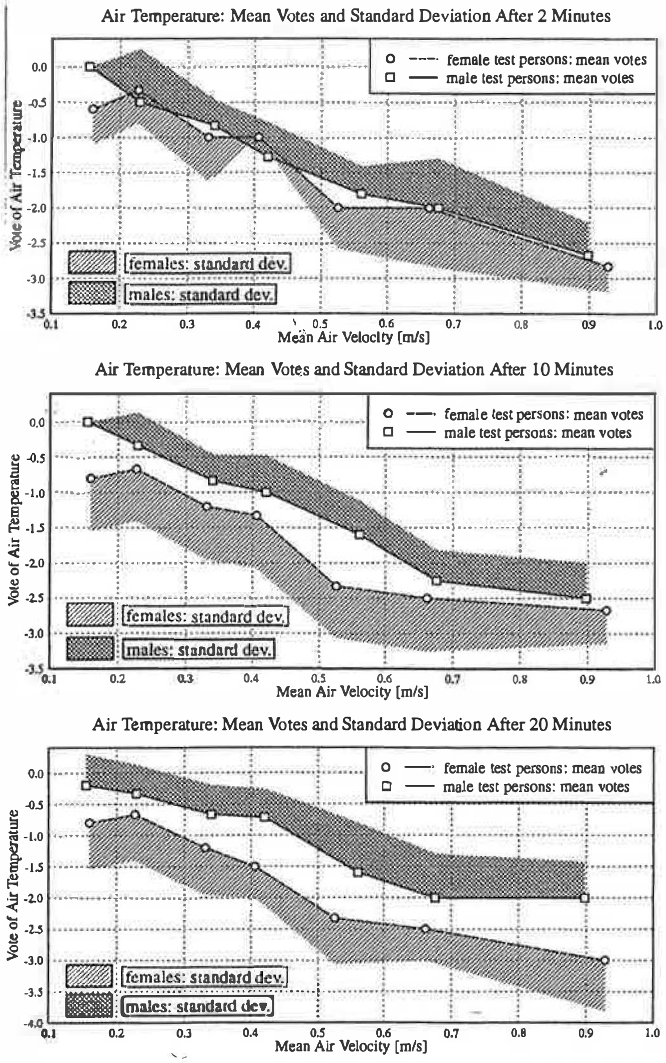

Fig. 4 vote of air temperature. Only one side standard deviation is drawn

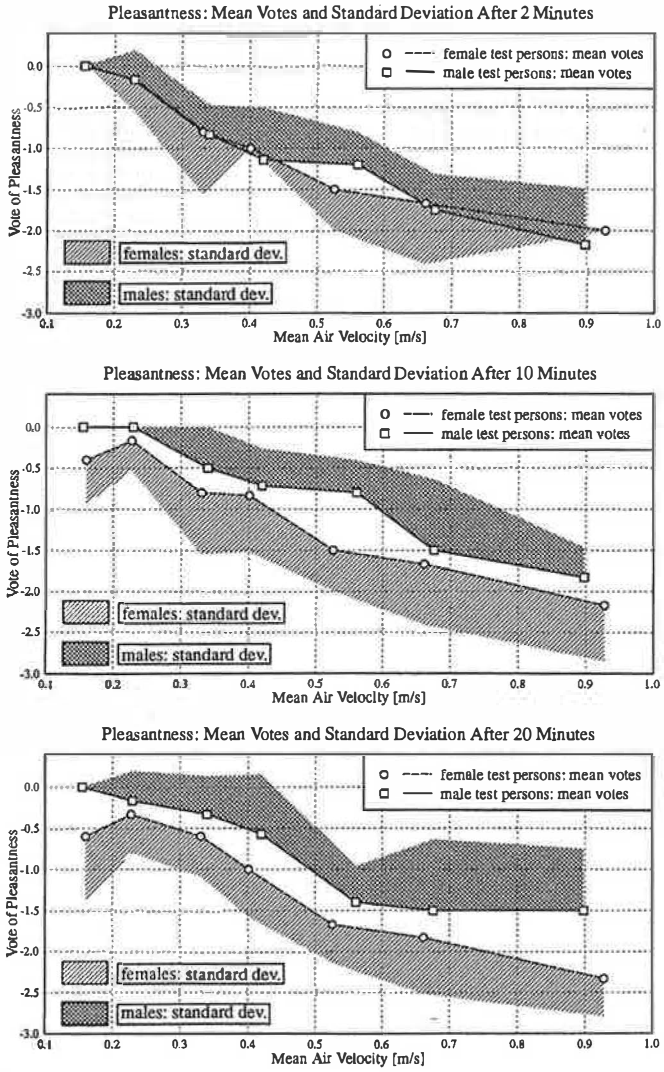

Fig. 5 Mean vote of pleasantness. Only one side standard deviation is drawn

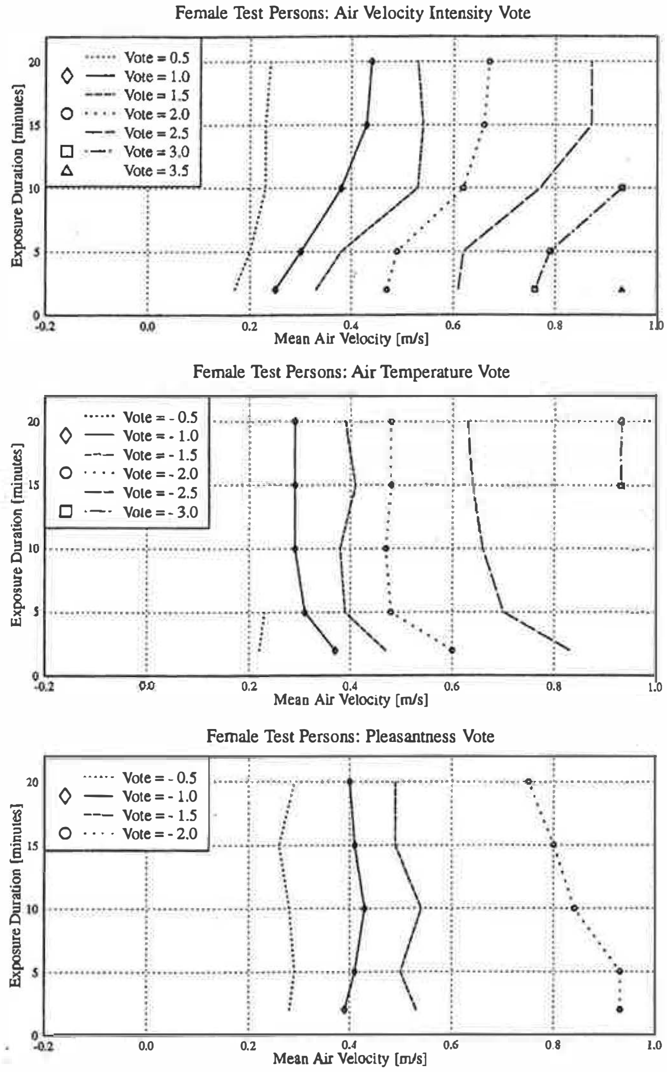

Fig. 6 Female test persons: time history of the votes for air movement impressions

a weak decrease of unpleasantness vote as the exposure duration increases. More precisely, we have a constant decreasing trend at mean air velocities lower than 0.40 m/s. At higher mean air velocities, the lines of constant vote are quite irregular. Furthermore, as the mean air velocity increases, the difference between women and men reactions becomes more evident.

In the work of McIntyre (1979), we can find that an air jet flow at 23°C doesn't raise any sensation of discomfort in the first 2 min of exposure for air velocities up to 0.25 m/s. This finding is in good agreement with the graphs of Figures 6 and 7, dealing with the pleasantness votes. Still in the findings of McIntyre, we have that feeling of discomfort remains constant during the exposure duration. In the current work, this trend has been observed only with female test persons at mean air velocities up to 0.6 m/s. From a qualitative point of view, the results dealing with the sensitivity to the strength of air velocity are in good agreement: the air velocities are perceived with less intensity as the exposure continues. A similar behaviour was found by McIntyre also for the feelings of coolness. This aspect is in disagreement with the current results, especially for the votes observed with female test persons.

Skin Temperature

The skin temperature at the back of the neck was recorded before the jet started to blow air, and is referred to as the initial skin temperature, I.S.T. (see Table 2). To determine the eventual impact of I.S.T on draught sensitivity, the mean votes of air movement sensitivity were evaluated according to test persons having lower and higher I.S.T. than the average. Only a very slight difference in sensitivity between these two groups was observed, and there were no well defined trend hold-

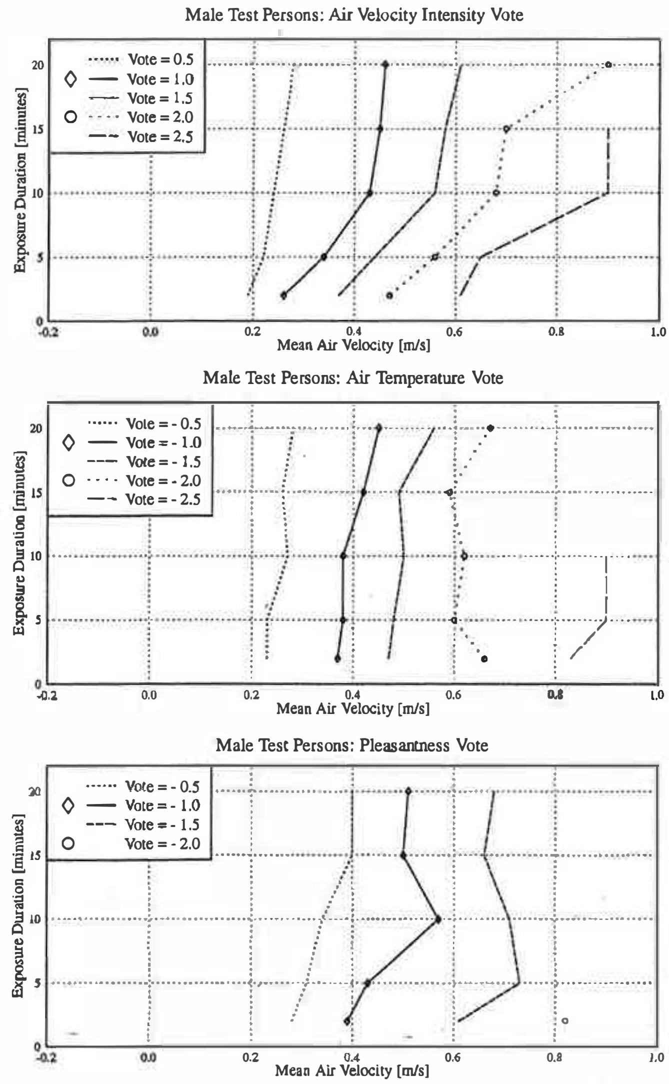

Fig. 7 Male test persons: time history of the votes for air movement impressions

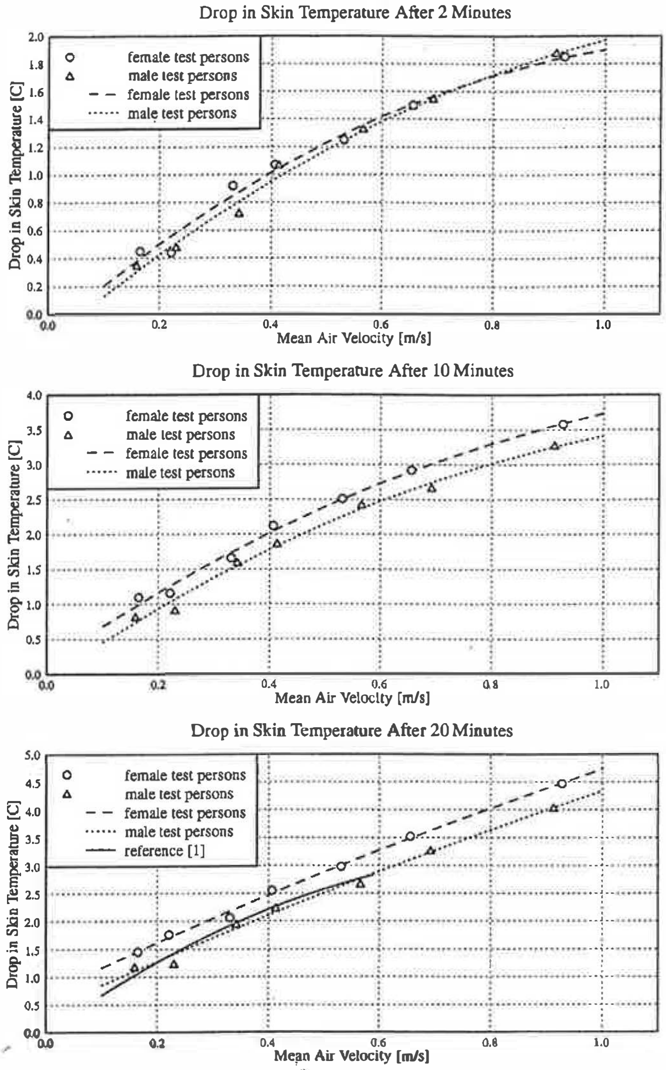

Fig. 8 Drop of skin temperature versus mean velocity

ing for the whole mean velocity range and exposure duration as well. During the exposure to draught, the neck skin temperature was recorded as well. Figure 8 shows the mean skin temperature drop from the I.S.T. in every test, versus mean air velocity, for females and males. At the beginning of the exposure females and males had similar drop of skin temperature. As the exposure duration increases, females had a larger drop in skin temperature for the entire velocity range investigated.

In the graph dealing with the drop of skin temperature after 20 min exposure, the line from the data of Houghten (1938) is also plotted. More precisely, this line corresponds to the drop of skin temperature after 30 min exposure to draught at an air temperature of 21.1°C, which is the closest situation investigated in this reference with the current experiment. Moreover, this line was obtained with only male test persons, for an air temperature of around 1°C lower, and exposure duration of 10 min longer than in the current investigation. Even though, the mentioned curve fits quite well with the results dealing with male test persons. Also from the results of Houghten (1938), a drop in the neck skin temperature close to 1.8°C determines the limit between comfortable and uncomfortable draught based on the condition of 10% dissatisfied to the air movement. In Figure 9, we can observe that a drop of 1.8°C in the neck skin temperature, after 20 min exposure, corresponds to a mean vote of pleasantness −0.4, for both females and males. From the lower graph of Figure 8, a drop in skin temperature of 1.8° was observed at mean air velocities of around 0.25 and 0.32 m/s for females and males respectively, after 20 min exposure. Considering the lower graph in Figure 5, we can easily notice how these velocities are very far from satisfying the requirement of 10% dissatisfied to the air movement: mean value of pleasantness nega-

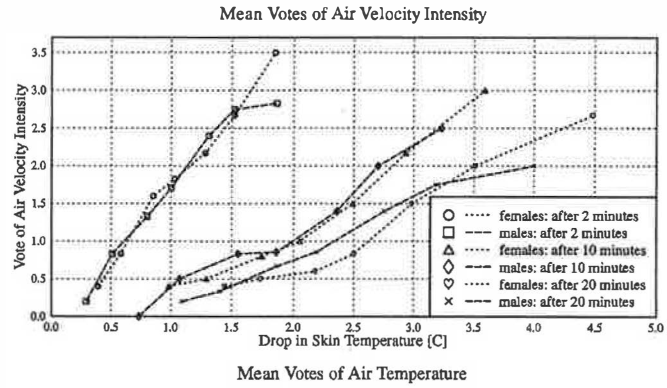

Fig. 9 Vote of draught versus drop of skin temperature

tive (−0.4) and standard deviation span of around 0.5 vote, i.e. most of women and men dissatisfied.

Effects of Turbulence Intensity

A small investigation was designed to provide qualitative ideas of the effects of R.T.I., on draught sensitivity. The experiment was developed with four test persons, two females and two males, randomly selected from the previous twelve test persons. The procedure was identical to the first experiment, with a shorter exposure to draught (10 min). A total of 44 single tests were analysed in the mean velocity range between 0.08 and 0.42 m/s. Two levels of air velocity turbulence were maintained: a low level of around 23% and a high level of around 52%. A high level of R.T.I. was generated by means of two rotating wells (with three blades), inside the nozzle, and by grid screens at the inlet section of the nozzle to destroy large scale vorticity. Test persons were allowed to express their votes with a higher resolution than in the previous experiment. In all tests the air temperature was kept between 22.2 and 22.5°C. The results showed an impact of R.T.I. on draught discomfort. This aspect is in qualitative agreement with the work of Fanger et al., (1988). For all the three impressions of air movement, the observed votes corresponding to high R.T.I. denoted a higher sensitivity than the ones at lower R.T.I. The difference was particularly pronounced at the higher mean air velocity range. With high turbulence, the votes of air velocity intensity remained constant with exposure duration, while at low turbulence the sensitivity decreased rapidly with time. The results for the air temperature sensitivity indicated that after 10 min exposure, the mean air velocity corresponding to vote −0.5 and −1 at low turbulence level is around double the one at high turbulence. Also for the pleasantness vote, the effect of R.T.I. of air velocity is remarkable. Table 3 shows the values of mean air velocity corresponding to the votes 0.5 and 1.0 at the beginning of the exposure and after 10 min, for all the three impressions, at low and high R.T.I.

Table 3 Mean air velocity corresponding to the votes 0.5 and 1.0 at the beginning and the end of the draught exposure, 10 minutes, for all the three impressions, at low and high R.T.I.

Impression	R.T.I.	Vote	Mean air velocity After 2 min [m/s]	Mean air velocity After 10 min [m/s]
Air Vel. Intensity	23%	0.5	0.16	0.24
Air Vel. Intensity	52%	0.5	0.10	0.14
Air Vel. Intensity	23%	1.0	0.22	0.39
Air Vel. Intensity	52%	1.0	0.17	0.20
Air Temperature	23%	0.5	0.18	0.24
Air Temperature	52%	0.5	0.13	0.12
Air Temperature	23%	1.0	0.30	0.35
Air Temperature	52%	1.0	0.22	0.20
Pleasantness	23%	0.5	0.26	0.30
Pleasantness	52%	0.5	0.15	0.12
Pleasantness	23%	1.0	0.34	0.41
Pleasantness	52%	1.0	0.22	0.24

Conclusions

The experiments were developed exposing the neck of test persons to a turbulent air flow where large-scale vortices have decayed. Only results from test persons in perfect thermal neutrality during the entire experiment were considered. All test persons were sitting with the same posture and performed light activity (reading) at the same level. From the mean values and standard deviation of the human response, calculated at prescribed mean air velocity ranges, and from the skin temperature measurements, the following conclusions were drawn.

- The sensitivity to draught was observed to depend on the exposure duration, especially in the higher range of mean air velocity investigated.
- With the exception of the initial period of exposure for all three draught sensitivities, the female test persons mean votes were more severe than males and, in some cases, were also outer the standard deviation range of males results.
- At the beginning of the exposure, females and males had the same drop in skin temperature. As the exposure continued, females revealed a greater drop than men, along all the mean air velocity domain investigated. The initial skin temperature didn't show a relevant impact on draught perception and sensitivity.
- At the beginning of the exposure, the strength of the air flow was detected at lower mean air velocities than the cooling effect was. Female test persons decreased the sensitivity to air velocity intensity, mostly in the first ten minutes, while in the first five minutes of exposure, the thermal sensitivity was observed to increase. Male test persons revealed a large decrease of sensitivity to air velocity intensity during all the exposure duration, while thermal sensitivity to air temperature was nearly constant.
- A vote of unpleasantness was always associated with a vote of coolness. For both females and males it was never found a negative vote of pleasantness without a negative vote of air temperature.
- A vote of pleasantness was more stable with exposure duration for women than for men. Women

were more severe for the pleasantness vote in the whole velocity range investigated.

- R.T.I of air velocity had an impact on the sensitivity to air movement.
- High R.T.I. increased the sensitivity to draught. In the experiments at high R.T.I., the mean votes of all the three impressions were observed to be more constant and regular with exposure duration than at lower R.T.I.

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References

Abramovich, G.N. (1963) *The theory of turbulent jets*, Cambridge, MA, The Massachusetts Institute of Technology.
Becker, H.A. and Massaro, T.A. (1968) "Vortex Evolution in a Round Jet", *Journal of Fluid Mechanics* **31**, 435–448.
Fanger, P.O. and Christensen, N.K. (1986) Perception of draught in ventilated spaces, *Ergonomics*, **29**, 215–235.
Fanger, P.O., Melikov, A.K., Hanzawa, H. and Ring, J. (1988) "Air turbulence and sensation of draught", *Energy and Buildings*, **12**, 21–39.
Crow, S.C. and Champagne, F.H. (1971) "Orderly Structure in Jet Turbulence", *Journal of Fluid Mechanics*, **48**, 547–591.
Houghten, F.C. (1938)"Draught temperatures and velocities in relation to skin temperature and feeling of warmth", *ASHVE Transactions*, **30**, 193–212.
Hyldgaard, C.E. (1998) "Thermal plumes above a person". In: *Roomvent '98*, Stockholm, Vol. 1, 407–413.
Mayer, E. and Schwab, R. (1988) "Direction of low turbulent airflow and thermal comfort". In: *Healthy Buildings '88*, Stockholm, Sweden, Vol. 2, pp. 577–582.
McIntyre, D.A. (1979) "The effect of air movement on thermal comfort and sensation. Indoor Climate" In: Fanger, P.O. and Valbjørn, O. (eds), Copenhagen, Danish Building Research Institute, pp. 541–560.
Rajaratnam, N. (1976) *Turbulent jets, Developments in water science*, Amsterdam, Elsevier.
Rodi, W. (1982) *Turbulent buoyant jets and plumes*, New York, Pergamon Press.
Tennekes, H. and Lumley, J.L. (1990) *A first course in turbulence*, Cambridge, MA, M.I.T. Press.
Todde. V. (1997) "Draught sensitivity for hands in turbulent air flows". In: Woods, J.E., Grimsrud, T. and Boschi, N. (eds) *Proceedings of Healthy Buildings/IAQ '97*, Washington, Vol. 2, pp. 201–207.
Todde, V., Linden, E. and Sandberg, M. (1998) " Indoor Low Speed Air Jet Flow: Fiber Film Probe Measurements", *Roomvent '98*, Stockholm, Sweden, Vol. 2, pp. 585–592.
Toftum, J., Zhou, G. and Melikov, A. (1997) "Effect of air flow direction on human perception of draught", *Clima 2000*, in press.
Zukauskas, A. (1985) "*Heat transfer in crossflow of a cylinder*", New York, Springer-Verlag.