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Summary. By an environmental chamber study the convective flow around a human being was simulated by a heated non-breathing thermal manikin. Following a simulated organic solvent spillage on the clothing the spatial uniformity of the breathing zone concentration of the manikin was described by simultaneous measurements of the concentration of volatile organic compounds at four positions within the breathing zone. This experiment was repeated at selected free field ait velocities (VF). The strongest concentration gradient measured was in calm air the concentration at the brest and at the lapel being 290 mg/m^3 and 3 mg/m^3, respectively. The non-uniformity of the concentration indicates a possible serious bias of the exposure estimate by the conventional sampling of the breathing zone concentration. The convective air velocity in calm air ranged 0,05-0,20 m/s within the breathing zone.

Introduction

The non-uniformity of indoor air pollution with time and spatial distribution is well recognized (13). Estimating human exposure by sampling of the breathing zone concentration is common practice of the occupational hygiene (11), and by convention (5) the breathing zone is the air volume of a 0.6 m diameter hemisphere centered at the midpoint of an imaginary line drawn from ear to ear. A recent field study (3) indicated that the micro environment of the breathing zone may exhibit strong concentration gradients of particulates leading to a possible serious bias of the exposure estimate. The reported concentration gradients may partly be explained (1, 3) if resuspended dust accumulated by the clothing is carried to the breathing zone by the convective flow generated by the human body. The air flow in the boundary layer around the human body is a complex phenomenon and presently difficult to describe (10). Consequently modeling the the breathing zone concentration caused by contamination liberated from clothing and by the convective flow carried to the breathing zone is also difficult. The purpose of the present environmental chamber study was to evaluate the potential exposure by inhalation of volatile organic compounds (VOC) evaporated from organic solvent spillage on the clothing. Additionally the purpose was to evaluate the spatial uniformity of the breathing zone concentration.

Materials and methods

The study was performed in a test chamber (6 x 7 x 2.6 m) with no mechanical ventilation and at basicly constant air temperature (17.8 - 20.0°C) with stratification ranging 1.0°C, and a steady surface temperature of 19.5°C. By an adjustable fan in the chamber the horizontal free field air velocity (VF) at the center of the chamber could be fixed at preselected levels (range 0 - 1.0 m/s), and the flow direction was from behind or from behind along the chamber diagonal. A heated non-breathing thermal manikin (9) having 1.75 m^2 surface area was normally dressed (0.8 clo) and seated at a table at the center of the chamber. The thermal input was adjusted establishing thermal comfort according to Fanger's equation, and the input ranged 120 - 150 W in dependence of VF. Organic solvent spillage on the clothing was simulated by applying 1 cm^3 of O-Xylen to a well defined minor area of the clothing at the right thigh. This area (0.1 x 0.1 m) consisted of a single layer of paper impermeably sealed on the back.

The surface temperature distribution of the heated manikin was compared to a human being (equally dressed, similar heat production) by means of an AGA-thermovision and documented by colour photos. The air velocity and temperature of the convective plume around the manikin was measured (by means of an Indoor Climate Analyzer, type 1213, Brüel & Kjær) at position A-D as indicated in fig. 1, at the selected levels of VF. The convective flow around the manikin was further visualized by smoke and documented by colour photos. The O-Xylen was applied to the clothing and the breathing zone concentration of VOC was measured simultaneously at the positions A - D. In the sampling period the air velocity and the air temperature was measured at position A. By standard Technique (12) the VOC was collected on charcoal (100 cm^3/min sampling rate, 15 min sampling periods) and analyzed by gas chromatography. The experiment was repeated at the selected levels of VF, allowing sufficient time between the experiments to wash out air pollution left in the chamber.

Results

A similar surface temperature distribution of the manikin compared to a human being was confirmed by the thermovision technique. The constant rising air movement of the convective flow around the manikin was visualized by smoke, and qualitatively the flow is described as a boundary layer which continues to accellerate and partially detaches at convexities of the body and the dress and becomes little by little turbulent. Quantitatively the air velocity and the gradient of the temperature at positions A -D ranged as shown by examples in table 1. The 15-min time weighted average of the O-Xylen breathing zone concentration at the positions A - D at the selected levels of VF are shown in table 2. The simultaneously measured air velocity at position A (flow direction along the diagonal) is shown in table 1.

Table 1

Air velocities, V, in the breathing zone at two different free field air velocities. The flow direction at VF=0.38 m/s was along the diagonal.

Position	VF m/s	V(x) m/s	Tu(y) %	dT(z) K	VF m/s	V(x) m/s	Tu(y) %	dT(z) K
A	0	0.20	20	2.2	0.38	0.31	39	1.4
B	0	0.17	24	1.5	0.38	0.19	32	2.8
C	0	0.08	60	2.0	0.38	0.08	80	3.1
D	0	0.05	61	2.3	0.38	0.25	24	0.7

x. avarage of a 3-min sampling period.
y. turbulent intensity
z. the temperature gradient, i.e. the difference between the temperature at the actual position and T1.

Table 2

The concentration (mg/m^3 of O-Xylen in the breathing zone at the selected levels of VF (m/s) and at the different flow directions.

	Flow direction from behind				Flow direction from behind along the diagonal			
Position	VF= 0	VF= 0.10	VF= 0.17	VF= 0.28	VF= 0	VF= 0.38	VF= 0.47	VF= 0.66
A	151	87	2(a)	44	130	2(a)	7	6
B	362	842	18	168	290	2(a)	28	8
C	16	62	27	11	3	10	11	7
D	8	44	2(a)	35	3	5	4	5

a. Detection limit

Discussion

In the present study the surface temperature distribution of the manikin was similar to that of a human being, and the results are in accordance with results obtained by previous examinations (9). The natural convection phenomenon around a non-breathing human being can be simulated by using the manikin. Qualitatively the convective flow around the seated manikin was similar to the flow (visualized by the Schlieren optics) around an undressed human being (7). The measured air velocity in the breathing zone of the seated manikin ranged 0.05 - 0.20 m/s in calm air, rising, as an example, to a range of 0.08 - 0.31 m/s in case of VF=0.38 m/s. When the heated undressed manikin is seated in calm air at 21.2 - 22.2°C. The peak velocity (6) of the chest boundary layer is 0.18 m/s. A maximum velocity of 0.5 m/s of the convective flow at the head has been reported for a standing undressed human being at 15°C ambient temperature (4).

Using a uniformly dispersed aerosol a recent (2) test chamber study has indicated a uniform breathing zone concentration of a non breathing unheated manikin. It is well recognized (1, 3) that the breathing zone concentration may be significantly influenced by redispersion of dust accumulated by the clothing. It has been reported (8) that pollution may accumulate in vortices in the wake of people, provided the pollution is emitted in the vortex area. Considering an air flow from behind the present study indicated that organic solvent spillage on the front of the clothing may cause a spatially non-uniform VOC breathing zone concentration. From table 2 the strongest concentration gradient was observed in calm air. At all the other investigated levels of VF the kinetic energy of the horizontal flow was sufficient to influence the convective flow around the manikin. As VF was increased the concentration gradient decreased. Considering the concentration level no obvious relationship to VF was observed. The respiratory cycle of a human being may to a yet unknown degree influence the mixing within the breathing zone (7), but the present study may indicate a possible serious bias of the exposure estimate obtained by the conventional sampling of the breathing zone concentration.

Conclusion

The convective flow around a human being may be simulated using a heated thermal manikin. The convective air velocity in the breathing zone of a non-breathing manikin seated in calm air ranged 0.05 - 0.20 m/s. The VOC breathing zone concentration due to organic solvent spillage on the clothing of the manikin was spatially non-uniformly distributed indicating a possible serious bias of the exposure estimate by the conventional sampling of the breathing zone concentration. In calm air the breathing zone concentration ranged 3 - 362 mg/m^3. The concentration level and the non-uniformity of the concentration distribution depended on the air velocity in the room.

Acknowledgement

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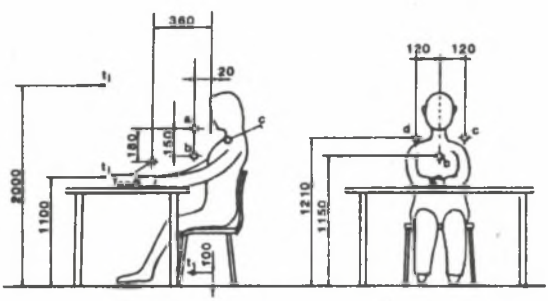

Fig. 1. Draft of the experimental set-up (not drawn to scale)

Rys. 1. Szkic stanowiska pomiarowego (bez zachowania skali)

Receneztn: Doc. dr inż. Jerzy Makowiecki

Wpłynęło do Redakcji 4.03.1988 r.

BADANIA ODDZIAŁYWANIA NA CZŁOWIEKA ROZLANEGO NA UBRANIE ROZPUSZCZALNIKA

S t r e s z c z e n i e

Przedstawiono wyniki badań przeprowadzonych w komorze klimatycznej, gdzie przepływ konwekcyjny wokół człowieka symulowano przy pomocy ogrzewanego, nie oddychającego manekina cieplnego. Po rozlaniu na ubranie manakina substancji symulującej rozpuszczalnik organiczny, opisano przestrzenną jednorodność stężeń w strefie oddychania manekina, za pomocą pomiarów stężeń lotnych związków organicznych równocześnie w czterech punktach w strefie oddychania. Eksperyment powtarzano dla różnych wartości prędkości powietrza nawiewanego. Największy, zamierzony gradient stężeń wystąpił w spokojnym powietrzu, gdzie stężenie na wysokości klatki piersiowej wynosiło 290 mg/m^3, a na wysokości kolan siedzącego manekina 3 mg/m^3. Niejednorodność stężeń wskazuje na możliwość poważnego błędu w oszacowaniu oddziaływania za pomocą konwencjonalnego próbowania stężeń w strefie oddychania. Konwekcyjna prędkość powietrza w spokojnym powietrzu zmieniała się w zakresie 0,05-0,20 m/s w obrębie strefy oddychania.

ИССЛЕДОВАНИЕ ВОЗДЕЙСТВИЯ НА ЧЕЛОВЕКА РАЗЛИТОГО НА ОДЕЖДУ РАСТВОРИТЕЛЯ

Р е з ю м е

В настоящей работе представлены результаты исследований, проведённых в климатической камере, в которой конвекционное течение вокруг человека имитировалось с помощью отапливаемого недышащего теплового манекена.

На одежду манекена было разлито вещество имитирующее органический растворитель, а потом была описана пространственная однородность концентрации в зоне дышания манекена с помощью измерений концентрации летучих органических соединений одновременно в четырёх точках в зоне дышания. Эксперимент проводился при разном значении скорости навеваемого воздуха. Наибольший измеренный градиент концентрации обнаружился в спокойном воздухе, где концентрация на уровне грудной клетки была 290 мг/м^3, а на уровне колен сидящего манекена - 3 мг/м^3.