EVALUATION OF INDOOR AIR QUALITY BY A PERCEIVED COMFORT EQUATION

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ABSTRACT

Research has been carried out to study local comfort in an office with displacement ventilation. The discomfort due to air quality is calculated by the olf and decipol, the new units for perceived air quality, and due to draft by a new comfort equation including turbulence intensity. The distributions of decipol and draft are computed by an air flow computer program based on a low-Reynolds-number k-ε model. It has been found that the distribution of percentage dissatisfied occupants for air quality is different from the distribution of smoke concentration. The olf and decipol units are recommended to be used for evaluating indoor air quality. The thermal comfort in the office is acceptable for this ventilation system though fresh but colder air is supplied directly to the occupied zone.

INTRODUCTION

Energy conservation measures, resulting in tighter building envelopes and use of the materials with better thermal insulation, increase the concentrations of internally-generated contaminants in offices. Displacement ventilation systems have been therefore introduced to remove the contaminants more effectively. For evaluation of indoor air quality with displacement systems, the odour sources from wall materials, furniture, systems, etc. should be accounted for in addition to bioeffluents and smoking caused by occupants. This can be accomplished by the olf and decipol, the new units for perceived air quality [1]. It will be the main aim of the present paper to evaluate indoor air quality in an office with displacement ventilation by a perceived comfort equation. Thermal comfort in the office would also be quantitatively analyzed since fresh but colder air is supplied directly to the zone of occupation.

RESEARCH APPROACH

The application of the olf and decipol units makes it possible to establish an odour balance for the air in a room. If the room air is well mixed, the perceived indoor air quality, C_i, can be determined from [1]:

$$C_i = C_o + 10 \frac{G}{Q} \quad \text{(decipol)} \qquad (1)$$

where C_o is perceived outdoor air quality (decipol), G is total odour sources (olf) and Q is ventilation rate (l/s). Then the percentage dissatisfied persons in the room, PD, can be calculated by [1]:

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$$PD = e^{5.98-(112/C_i)^{0.25}} \quad (\%) \tag{2}$$

For an office with a displacement ventilation system, the room air is not well mixed. The assumption of an uniform concentration distribution of odours cannot be accepted. The field distribution of perceived indoor air quality should be predicted for finding local air quality.

The development of computational fluid dynamics allows us to compute the field distributions of air velocity, air temperature, perceived air quality/contaminant concentration, and turbulence intensity. The air flow program PHOENICS-84 [2] has been employed to calculate the air distribution in the office. The computations involve the solution of three-dimensional equations for the conservation of mass, momentum (u, v, w), energy (H), perceived air quality or contaminant concentration (C), turbulence energy (k), and the dissipation rate of turbulence energy (ε). The turbulence model used is a low-Reynolds-number k-ε model [3] which has been implemented in PHOENICS-84. This model has been verified to be more suitable for indoor air flow simulations, and a better agreement between computation and experiment has been found with respect to velocity and turbulence energy distributions and heat exchange through solid walls [3]. The governing equations of the model can be expressed in a standard form:

$$\mathrm{div}\,(\rho \vec{V} \phi - \Gamma_\phi\, \mathrm{grad}\, \phi) = S_\phi \tag{3}$$

where ρ is the air density (kg/m³), $\vec{V}$ is the air velocity vector (m/s), Γ_ϕ is the diffusive coefficient (N s/m²), S_ϕ is the source term of the general fluid property, and ϕ can be any one of 1, u, v, w, k, ε, H, or C. When $\phi = 1$, the equation changes into the continuity equation.

With the distributions of air velocity, air temperature, and turbulence intensity, percentage dissatisfied people due to draft, PD, can also be calculated via the new thermal comfort equation [4]:

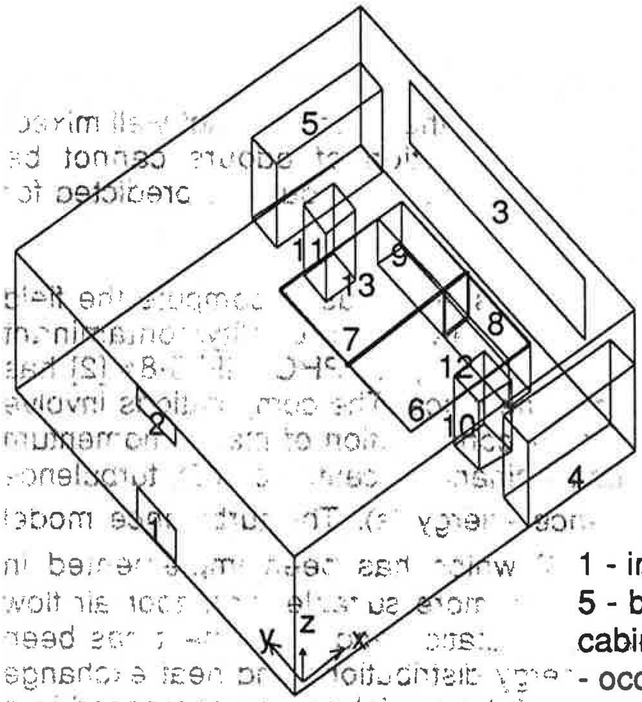
$$PD = (34 - T_a)(V - 0.05)^{0.62}\,(3.14 + 0.37\,V\,I) \quad (\%) \tag{4}$$

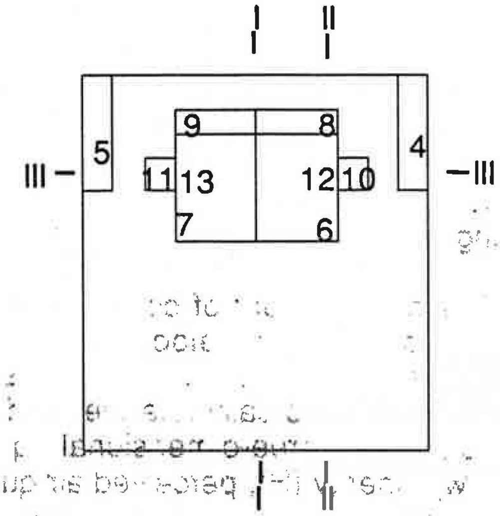
for $V < 0.05$ m/s insert $V = 0.05$ m/s, for $PD > 100\%$ use $PD = 100\%$, where T_a is the local air temperature (°C), V is the mean velocity (m/s), and I is the turbulence intensity (%). The turbulence intensity is defined as the velocity fluctuation over the mean velocity. The relationship between the turbulence intensity, I, and turbulence energy, k, can be written as:

$$I = 100\,(2k)^{0.5} / V \quad (\%) \tag{5}$$

RESULTS & DISCUSSIONS

Research has been conducted for a new office room as shown in Fig. 1. The room is 4.5 m long, 4.5 m wide, and 2.5 m high with some furniture, two computers, and two occupants. For simplicity, no flow blockage is used for the computers. The odour from the floor is assumed to be 0.5 olf, from the walls and ceiling 0.5 olf, from the books in each bookshelf 1.0 olf, from the smoking person (occupant a) 5.0 olf, and from the non-smoking person (occupant b) 1.0 olf. The ventilation system and furniture are





1 - inlet; 2 - outlet; 3 - window; 4 - bookshelf a; 5 - bookshelf b; 6 - table a; 7 - table b; 8 - filing cabinet a; 9 - filing cabinet b; 10 - occupant a; 11 - occupant b; 12 - computer a; 13 - computer b.

Fig. 1. Sketch of an office with displacement ventilation system.

supposed to get appropriate maintenance such that no odour sources are assumed. This implies that it is a low-olf office with a total 0.15 olf/m^2 of odour load from materials, furniture, books, and ventilation system. The surface temperatures of the enclosures are 22.3°C. The convective heat gain from the window is 150 W due to solar radiation. The heat source from each occupant is 80 W and from each computer 120 W. The inlet size is 0.6 m x 0.6 m with an air velocity of 0.20 m/s which corresponds to a 5 times of air-change-rate or 70 l/s. The temperature of the air supplied is 19.0°C and the turbulence intensity is 40%.

The computed distributions of air velocity, smoke concentration/perceived air quality, and percentage dissatisfied people due to indoor air quality are shown in Fig. 2. Figs. 2c and 2d are the distributions of the perceived air quality due to 1.0 olf smoke odour or the distributions of the smoke concentration caused by 0.01 ml/s smoke source. The application of dual units is necessary. This is because not all pollutants can be perceived, such as radon; the concentration of the pollutants should be determined by unit ppm or Bq/m^3. From Fig. 2d we can see that the smoke concentration is low in the left part of the office although there is a smoker on the right side of the tables. It is obvious since the room geometry and heat sources are symmetrical. Adding all the values of perceived air quality caused by different odour sources together, the distribution of percentage dissatisfied people can be calculated as shown in Figs. 2e and 2f. The distributions of the percentage dissatisfied people are different from those of smoke. It is because the smoke is not the only odour in the room. The odours from materials, books, and bioeffluents from human bodies have a significant contribution on perceived air quality.

It should be noted that the air change rate for the room is considerably high (5 ach). The percentage dissatisfied people due to air quality in the part of the room with the smoker is about 15% in 1.1 m height, or 20% in 1.7 m. In a well-mixed situation, the average perceived air quality C$_i$ is 1.286 which corresponds to an average PD of 18.6%. The PD values in standing level (1.7 m height) in the office are higher in a well-mixed system. This can be explained from the air flow field as illustrated in Fig.

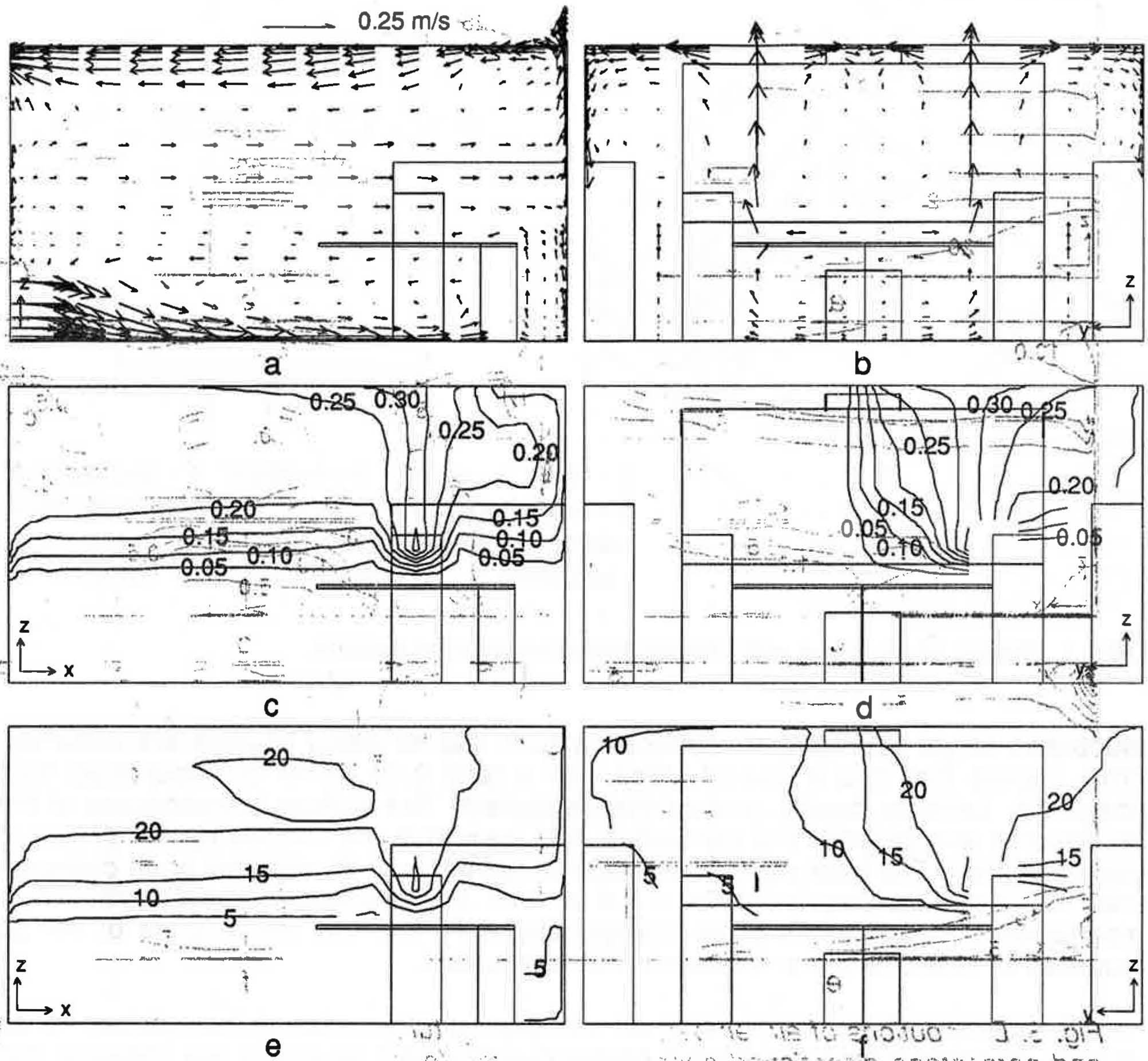


Fig. 2. Distributions of air velocity (a, b), perceived air quality/smoke concentration (c, d) [decipol or ppm], and percentage dissatisfied people due to indoor air quality (e, f) [%] in different sections of the office. (a) section I-I, (b) section III-III, (c) section II-II, (d) section III-III, (e) section II-II, (f) section III-III.

2b. The heat sources from the computer and human body induce a large amount of air together with the smoke up to the ceiling. This air forms a large eddy which brings contaminated air downwards along the side wall. There are three large eddies as shown in Fig. 2a. It is different from the assumption that there is only one eddy in an office with displacement ventilation system. The complex flow pattern will mix the air better such that it results in a higher contaminant concentration in the upper part of the occupied zone of the office. However the air quality in the room is certainly much better than in a conventional "well-mixed" system as reported by Chen [5]. The contaminant concentration in a actual conventional "well-mixed" system is even higher than the mathematically averaged one because it is hard to mix room air perfectly.

For an overall evaluation of indoor air quality due to odours, the olf and decipol should be used. The results indicate that a large amount of fresh air is required to meet the requirement of comfort. For the office presented here, the air supply is much

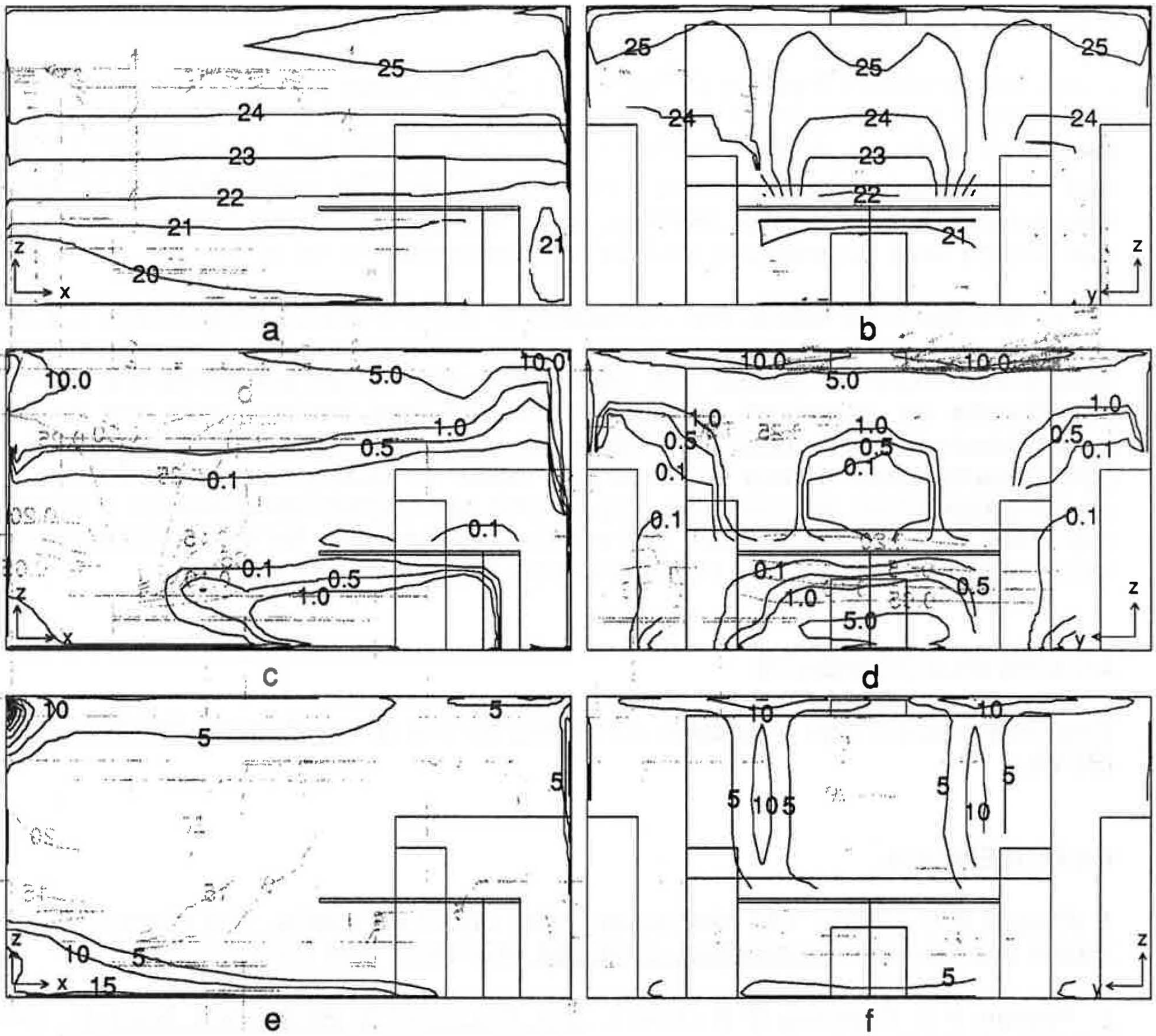


Fig. 3. Distributions of air temperature (a, b) [°C], turbulence energy (c, d) [$10^{-4}m^2/s^2$], and percentage dissatisfied people due to draft (e, f) [%] in different sections of the office: (a) section I-I, (b) section III-III, (c) section I-I, (d) section III-III, (e) section I-I, (f) section III-III.

higher than that given in most existing standards. But such a high air-change-rate is not recommended because of the cost of energy for ventilation. It is preferable to reduce the odour sources as by prohibiting smoking and using low-olf materials.

Fig. 3 shows the distributions of air temperature, turbulence energy, and dissatisfied people due to draft. The values of dissatisfied people due to draft in the room is less than 20% even near the inlet. In the present study, the air velocity in the inlet is low (0.2 m/s) and the temperature is rather high (19.0°C). Those conditions are certainly in favour of comfort. Figs. 3a and 3b indicate that there is a large temperature stratification in the room. The discomfort due to draft shown in Figs. 3e and 3f does not include the influence of the temperature stratification. Olesen [6] pointed out that a 3°C of temperature difference between head (1.1 m) and ankles (0.1 m) will lead to a 6% of dissatisfaction. However, the thermal comfort is still acceptable under the current situation.

CONCLUSIONS

It can be concluded that the perceived comfort equation can be applied to evaluate local indoor air quality in an office with displacement ventilation. The distributions of perceived air quality and concentrations of contaminants can be computed by an air flow program with a low Reynolds number k-ε model. The distributions of air velocity, temperature, and turbulence intensity, which are also computed by the flow program, can also be used to determine the local thermal comfort in the office.

In this particular office, the distribution of percent dissatisfied people due to air quality is different from the distribution of smoke concentration. This is because the odours from materials, books, and bioeffluents from human bodies have a significant contribution on perceived air quality. The olf and decipol units are therefore recommended to be used for evaluating indoor air quality due to odours. For contaminants which cannot be perceived, indoor air quality can be evaluated by the concentration of the contaminants. The comfort due to draft has also been analyzed for this office. The thermal comfort in the office is acceptable for the ventilation system though fresh but colder air is supplied directly to the occupied zone.

ACKNOWLEDGMENTS

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