AIR VELOCITIES INSIDE DOMESTIC ENVIRONMENTS: AN IMPORTANT PARAMETER FOR PASSIVE MONITORING*

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Abstract

Air velocities have been measured in the master bedroom, kitchen, and basement of six occupied homes plus the dining/living room area of one unoccupied house. Median air velocities of 5.3 and 12.4 cm/s† in the occupied and unoccupied houses raise concern that inadequate air movement may sometimes exist for accurate passive monitoring of pollutant vapors. Central-air circulation systems had a variable impact on air velocity. Median velocities increased from 5.8 to 6.2, 3.2 to 5.7, 1.5 to 8.1, and 4.4 to 15.5 cm/s in three occupied and one unoccupied houses, respectively. Median velocities of 4.2, 4.3, and 10.2 cm/s in the master bedroom, basement, and kitchen, respectively, are consistent with increased occupant activities and use of ceiling and/or exhaust fans in or near the kitchen.

Introduction

Passive monitoring of pollutants in indoor air is widely used because time-weighted-average concentrations can be obtained at low cost. A fundamental assumption for most applications is an adequate velocity of air across the opening of the sampler to prevent depletion of monitored vapors (2). Such depletion increases the effective sampling length of the passive monitor, thus reducing the molecular sampling rate. Considering an open, tubular monitor of conventional Palmes Tube design, the increase, i, in pathlength must be small with respect to the length of the monitor (1) to prevent significant reductions in performance. The added boundary layer of effective thickness i represents a convective resistance to sampling, which must be small in comparison to the internal diffusion resistance for quantitative measurement. The quantity i may be modeled as a function of sampling tube diameter (d) and air velocity (v),

$$i = k * d^m * v^{-n} \qquad (1)$$

where m and n are reported as about 0.6 and 0.4, respectively, and k depends on geometric factors and molecular properties of air and sampled pollutant. With a prudent selection of d, i can be kept small with respect to 1, thus minimizing the impact of low air velocity on molecular sampling rate. With contemporary monitors, minimum air velocities for quantitative sampling will vary by at least tenfold from 7 cm/s to <0.7 cm/s (2). Protocols for

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†1 cm/s = 0.01 m/s = 0.033 ft/s = 1.97 ft/min

evaluation of diffusive samplers also include the air velocity parameter (1). For conventional industrial hygiene applications, minimum air velocities of around 25-40 cm/s result in insignificant i values. However, for fixed point monitoring inside residences, near stagnant air conditions are possible; air drift velocities of 1-20 cm/s have been measured with smoke sticks (3). In this research, indoor air velocities and selected factors influencing movement of indoor air were measured in one unoccupied and six occupied homes.

Experimental Methods

All air velocity measurements were made using an omni-directional field anemometer manufactured by TSI Inc. (Model 1620). Laboratory calibration was performed in an approximate 10 cm I.D., 5 m long tube with near-laminar air flow. The measured response (mv) for 18 calibration points ranging from 0.2 to 30 cm/s were fit to a second-order linear model.

$$v\ (cm/s) = -8.27 * mv^2 + 90.53 * mv + 1.15 \qquad (2)$$

An r^2 coefficient of 0.97 and root mean square error of 1.7 cm/s were achieved. Detection limits of <1 cm/s were easily achieved in laboratory calibrations. Field calibration consisted of daily zero measurements.

Air velocity was measured for one week periods in six occupied homes in East Tenneessee as part of a multipollutant study. Measurements were taken sequentially in master bedroom, kitchen, and basement locations at distances typically 0.9 to 1.4 m from the floor, 0.3 to 1.2 m from the nearest wall, and >2-3 m from the nearest floor register of the central, forced-air HVAC system. Air velocity data were also taken for three months near the geometric center of a dining/living room area of an unoccupied research house as part of ductwork leakage and ventilation study. Data acquisition intervals ranged from 3 to 20 minutes.

Results and Discussion

The frequency distribution of air velocities measured in the six occupied homes had a maximum at 0-2.5 cm/s and decayed rapidly to insignificant levels at velocities >25 cm/s (Figure 1). The median velocity of 5.3 cm/s indicates the strong bias of the data to low velocities. The small, -2.5 to 0 component of the distribution is an indication of the lower resolution limits for the probe in field use and is presumably caused by heating effects local to the sensor at very low air velocities. These negative deviations are temporary and most evident after central HVAC operation (Figure 2).

The impact of central, forced-air HVAC systems on air velocities varied greatly between the occupied houses. In House 936, a fivefold increase in median velocity from 1.5 to 8.1 cm/s was observed with HVAC operation shifting the peak of the velocity distribution from 0-0.25 to 7.5-10 cm/s (Figure 3). The predominant impact of the HVAC is illustrated in a 14 hour segment of data from the master bedroom (see Figure 2), where HVAC operation was determined from a temperature probe in a floor register. In contrast, the median air velocities for house 917 and 958 show only twofold and minimal increases in velocity, respectively, with HVAC operation (Figure 3).

Some systematic variation in air velocity was also noted between rooms in the occupied houses (Table 1), potentially reflecting occupant activity. The largest air velocities in the complete six-house data base were observed in the kitchen, consistent with the presence of exhaust and/or nearby ceiling fans and common occupant activity. Considering a subset of three houses where HVAC operation was intermittent and successfully monitored, higher velocities were also generally observed in the kitchen under both HVAC on and off conditions. The exception was a small basement data set (i.e., 132 points) under HVAC on conditions that were limited to one house. The master bedroom had consistently the lowest air velocities in the three house subset, especially under HVAC off conditions. Data from house 936 under HVAC off conditions provides the clearest evidence of occupant activity. The six resident children who were home for summer vacation were excluded from the master bedroom, but active in the kitchen and basement areas.

Table 1: Median Air Velocities (cm/s) in Six Occupied Homes By Location. Number of Data Points Indicated In Parentheses

House	HVAC	Master Bedroom	Basement	Kitchen
All 6 Houses	On&Off	4.3 (5115)	4.2 (2260)	10.2 (2265)
3 Houses	Off	1.8 (1846)	4.2 (648)	5.3 (108)
	On	6.1 (1967)	15.0 (132)	7.3 (301)
House 936	Off	1.1 (767)	8.3 (206)	8.0 (38)

The data from the unoccupied research house (Figure 3) were generally consistent with the results from the occupied homes. The median velocities of 4.4 and 15.0 cm/s under HVAC off and on conditions are (somewhat surprisingly) near the upper range of data observed in the occupied homes and demonstrate a strong influence of the central HVAC circulation system.

Conclusions

The very low air velocities measured in one unoccupied and six occupied houses (particularly without forced-air circulation systems) emphasize the need to characterize the velocity-dependent sampling rates of passive monitors used for measurements of indoor air quality. The location and HVAC dependence of ambient air velocities should be considered in the development of passive monitoring protocols.

References

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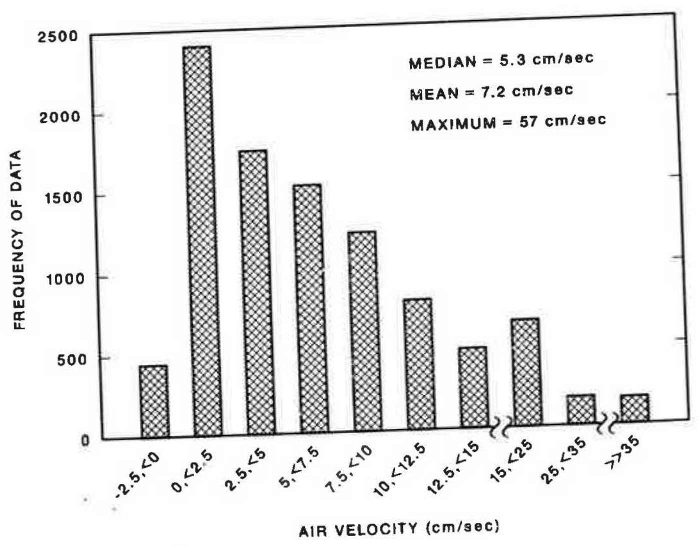

Figure 1: Distribution of air velocities in six occupied homes.

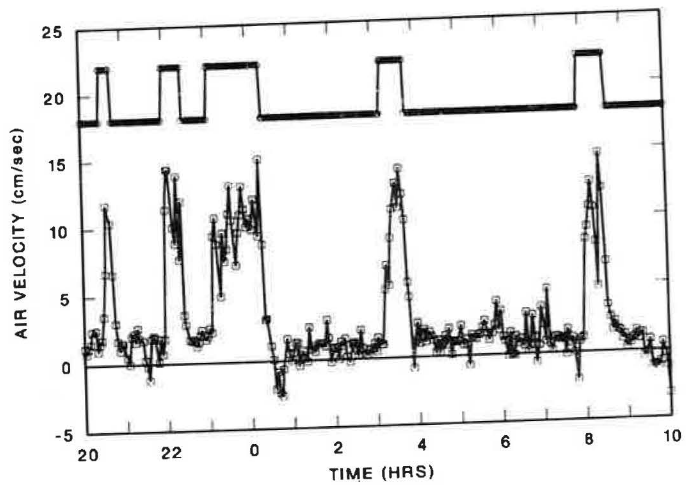

Figure 2: Temporal dependence of air velocity in the master bedroom of house 936. Operation of HVAC indicated in upper graph.

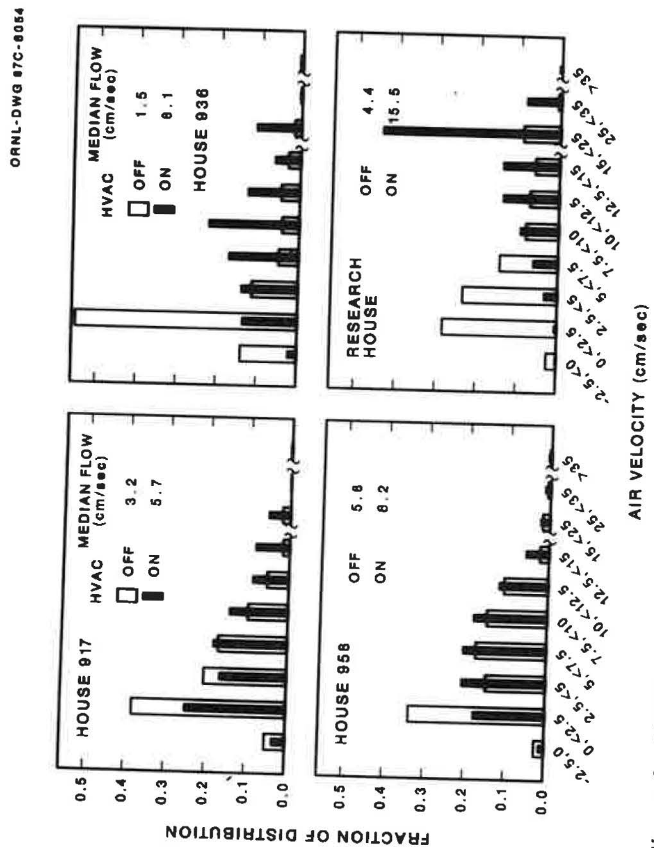

Figure 3. Distribution of air velocities in 1 unoccupied and 3 occupied houses as a function of HVAC operation.

PERSONAL EXPOSURE DUE TO SOLVENT SPILLAGE ON CLOTHING

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Abstract

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 air 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