Title

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Author

Revzan, K.L.

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K. L. Revzan

Building Ventilation and Indoor Air Quality Program
Lawrence Berkeley Laboratory
University of California
Berkeley, California, U.S.A. 94720

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Abstract

The effectiveness of range hoods and window fans in removing indoor pollutants is considered. Tests were conducted in a two-room test space with an infiltration rate less than 0.1 hr^{-1} using sulfur hexafluoride as a tracer gas. Range hood tests were carried out with heated and unheated tracer gas. In the former case, ventilation efficiency was roughly linear over a range of flow rates from 10.3 to 60.0 l/sec., the highest measured efficiency being 0.77. With unheated tracer gas, effectiveness was highly dependent on environmental conditions. Window fan tests were conducted with the source of tracer gas in each of the two rooms, the fan itself remaining fixed. With the source in the room without the fan, fairly good agreement with a mass-balance model was obtained. With the source in the same room as the fan, agreement with the model was poor. In all cases, the results suggest the importance of free convection in pollutant transport.

Introduction and Experimental Protocol

Range Hood Experiments

It has been observed (1) that significant amounts of pollutants generated by cooking may appear in rooms distant from the kitchen even when range hoods are in operation. Although hood configuration is important (2), the determination of the dependence of pollutant levels on fan flow rate is a useful first step in understanding the process of removal. Accordingly, range hood tests were carried out in the test space of Fig. 1 at flow rates of 10.3, 20.8, 32.2, 44.4, and 60.0 l/sec. At each flow rate, tests were made with and without a cooking burner in operation. SF_6 measurements were taken at the points labelled "B" in Figure 1 at all flow rates except 60.0 l/sec, for which the points labelled "A" were used.

Environmental data was collected at 30 min intervals. SF_6 concentration was measured at eight points using two Wilks Miran 101 analyzers. The interval between measurements was approximately 2 min., so that a complete sequence was performed every 8 minutes. The analyzers were recalibrated at 2 hour intervals, using secondary standards of approximately 0, 10, and 25 ppm SF_6, themselves calibrated against primary standards.

The tests were conducted as follows: At the beginning of each test the range hood was turned on, the flow rate of the fan measured, the injection of SF_6, diluted 20:1 with air, begun at a point 10 cm above the burner, and the burner turned on if required. After one hour, the hood was turned off and the mixing fans turned on for one hour to provide a measure of the average concentration in the entire space.

Window Fan Experiments

To study a more general case of local ventilation, tests were conducted with a fan exhausting from an opening in room 2 (Fig. 1). With the tracer gas source in room 1, tests were made at flow rates of 10.3 and 20.3 l/sec. Sampling was done at points "B" of Figure 1. Three tests were made at each flow rate. With the source in room 2, tests were made at flow rates of 10.3, 19.4, 31.7, 39.2, and 45.2 l/sec. Sampling was again at points "B" of Figure 1. Two tests were made at each of the four lower flow rates and one at 45.2 l/sec.

Each window fan test consisted of a three-hour injection at the center of the appropriate room, during which measurements of flow rate, concentration, and environmental parameters were carried out in the same manner as for the range hood tests.

Because our tests were conducted at relatively low flow rates, it is not suggested that they reflect strictly realistic configurations, particularly in the case of window fans. The results are intended to be taken as an indication of the kinds of mixing patterns that result from the combination of forced and free convection and of the changes in local ventilation efficiency that may be expected as flow rates and ambient conditions change.

Space limitations permit only a brief treatment of the results in this paper; the reader is referred to (6) for details.

Results and Discussion

Range Hood Experiments

We define range hood efficiency, η, by

$$\eta = \frac{C_0 - C}{C_0}, \tag{1}$$

where C_0 is the steady-state concentration which would obtain under conditions of perfect mixing and C is the measured steady-state concentration. In circumstances where steady-state has not been reached, the steady-state value of the measured concentration may be found by extrapolation provided that it increases exponentially at the air exchange rate, as was the case in all of our experiments.

The measure of efficiency provided by (1) affords no indication of the variation in concentration from point to point within the test space. The simple models that are available assume that perfect mixing obtains in each room, and are therfore inapplicable to circumstances in which the tracer gas concentration near the outlet is greater than that found elsewhere. No single number can represent the degree of mixing within a room or between rooms; examination of the data in each case is necessary.

We consider first the tests conducted with the burner on during the tracer gas injection period. It was found during preliminary work that results were highly repeatable, so that only a single test at each flow rate was used for analysis. The results demonstrate that ventilation efficiency, defined by Equation 1, increases roughly linearly with flow rate (Figure 2). If a straight line is fit to the data, using the simple least squares method, we find the best fit to be

$$\eta_c = 0.0611 + 0.0118\, F, \tag{2}$$

where η_c is the calculated efficiency and F the flow rate in l/sec; the correlation coefficient is 0.991. By extrapolation, we find that an efficiency of .90 would be reached at a flow rate of 71.1 l/sec, although it is possible that some levelling off would occur before reaching this point.

Figure 3 is illustrative of the results obtained. Three runs at a flow rate of 32.2 l/sec are shown: the first two, carried out with the burner off, are discussed below; the third run, with the burner on, shows the exponential buildup of the tracer gas during the injection period. Calculations made on the basis of this and the other experiments show that the rate of the buildup is sufficiently close to the air exchange rate to permit the use of equation 1.

Two additional indicators of local ventilation efficiency are the ratios between the post-injection concentration at the center of room 1 and those at the center of room 2 and in the outlet duct, respectively. It was found that the concentration in the outlet duct relative to that in the rooms increases with flow rate, which is indicative of the increasing local efficiency. The concentration in room 2 is comparable to that in room 1 until we reach a flow rate of 60.0 l/sec, at which rate the former concentration drops to ~25% of the latter; below this rate, the hood does not prevent the transport of pollutants from the source room to the remainder of the space, i.e., any pollutant that is not removed by the hood is likely to be distributed widely over any adjacent open space.

When the burner was not employed, results were highly variable. The first two runs shown in Figure 3 are representative: in the first run, we see an extremely high local efficiency, the post-injection concentration in the test space being <1 ppm; in the second, the concentration is higher than for the third run, during which the burner was on. It is inferred that free convection plays a much more important role in transport when the tracer gas lacks buoyancy.

Window Fan Experiments

Results with the injection in room 1 agree well with the mass-balance model of Sandberg (3), although his mixing factor was found to depend significantly on prevailing environmental conditions; these results will not be discussed further.

The results with the injection in room 2 are summarized in Table 1, in which the spatial average concentrations in the two test rooms and in the outlet concentration, all taken at the end of tracer gas injection, are shown; the time-average temperatures over the course of the injection are also tabulated. The distinctive result is the absence of any significant difference in the concentrations in the two rooms until a flow rate of 45.2 l/sec is reached. The increased ventilation efficiency at higher flow rates is reflected in the ratio between the measured concentration in the outlet duct and that in the test space, which is seen to increase sharply at a flow rate of 39.2 l/sec.

Figure 4 illustrates the time-dependent behavior. The several concentrations for two runs at 39.2 l/sec are shown; the temperatures of the three rooms and the outdoor temperature have been superimposed. The relatively small changes in the indoor-outdoor temperature difference do not appear adequate to account for the differences between the first and second runs, although it is possible that the effect of very small changes in the pattern of air movement, especially near the source, may be much greater than expected. In any case, it is clear that the similarity of the concentrations at the end of the injection period for the two runs gives a misleading picture of the actual situation. Integration of the central room concentrations over the time of the injection would be equally misleading, particularly in view of the large fluctuations seen in run 1.

The results of Table 1 do not agree well with the mass-balance model. We expect the concentrations in room 1 to be lower than those in room 2, with the ratios of the former to the latter diminishing as the flow rate increases, due to the effect of the fan in overcoming the naturally occurring transport of air from room 2 to room 1. Instead we find that, up to 31.7 l/sec, the concentrations are roughly comparable and that, in some cases, there is actually a greater concentration in room 1 than in either room 2 or the outlet. This situation might be accounted for by assuming that the infiltration rate of room 2 is much greater than that of room 1, in which case the concentrations predicted by the model become roughly equal, although there is no evidence to support such a assumption.

At the two highest flow rates, it is useful to compare the results with a model in which a small area near the outlet duct is treated as one of the two rooms and the remainder of the test space as the other. The principal assumption of this model is that perfect mixing prevails throughout much of the space; this assumption appears to be supported by the data taken at the two highest flow rates. The data at 39.2 l/sec proves to be consistent with a mixing factor (3) of ~0.75 and that at 45.2 l/sec with a factor of ~0.35. In particular, the second run at the former flow rate shows good agreement with the time-dependent predictions of the model. The fit of the remaining two runs, one at the former and one at the latter rate, is far less satisfactory; different ambient conditions may account for the discrepancy between theory and experiment.

Table 1. Fan experiments with tracer gas source in room 2: all concentrations are taken at the end of tracer gas injection; the room 1 and 2 concentrations are spatial averages; the temperatures are time averages over the injection period; the subscripts indicate rooms 1, 2, and 3, and the outlet.

Flow rate (l/sec)	C_1 (ppm)	C2 (ppm)	Cout (ppm)	T1 (oC)	T2 (oC)	T3 (oC)	Tout (oC)
10.3	26.28	33.04	32.44	21.4	21.9	18.4	18.4
	33.18	32.53	30.80	20.0	19.7	19.2	14.6
19.4	19.42	18.99	16.32	21.6	21.4	21.0	17.5
	23.26	22.32	21.87	19.2	18.8	18.4	13.0
31.7	12.15	12.07	13.23	19.4	19.2	17.9	17.8
	11.87	11.80	12.77	18.2	17.8	17.4	13.4
39.2	4.64	4.69	9.11	19.9	19.7	18.8	15.9
	4.62	4.99	10.71	18.0	17.6	17.1	12.8
45.3	1.56	2.64	10.53	19.8	20.2	16.6	19.1

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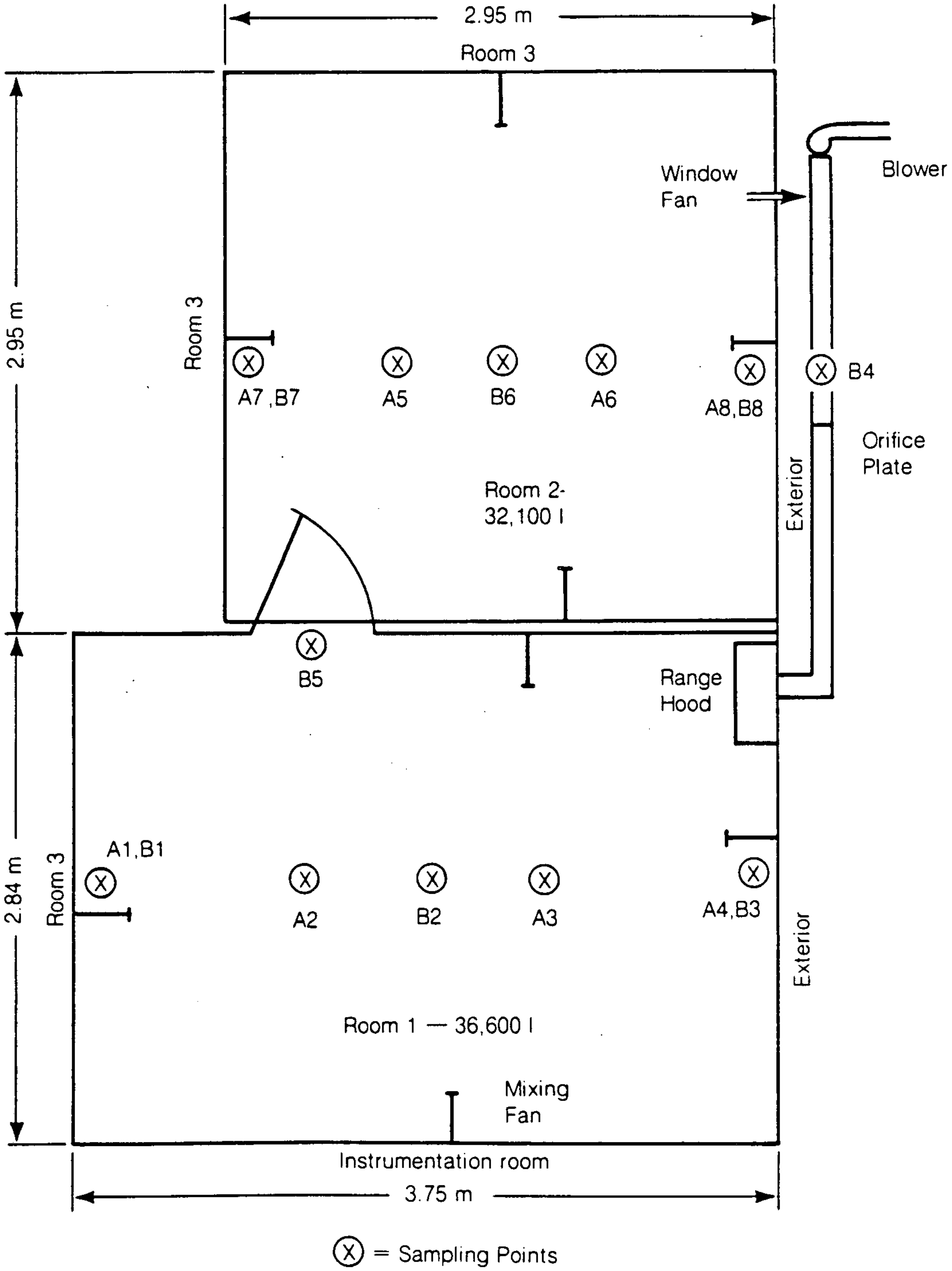

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Figure 1. Floor plan of the two test rooms, with sampling points, mixing fans, and experimental apparatus; room 3 was not used.

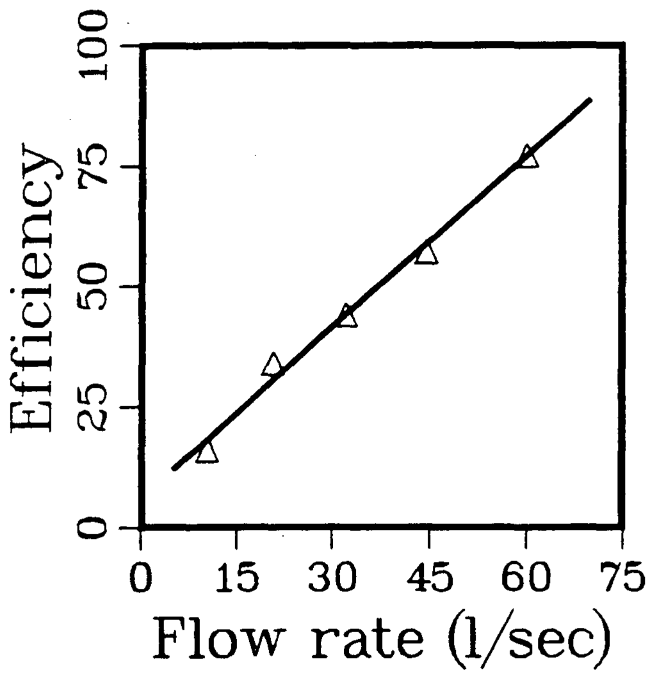

Figure 2. Range hood ventilation efficiency.

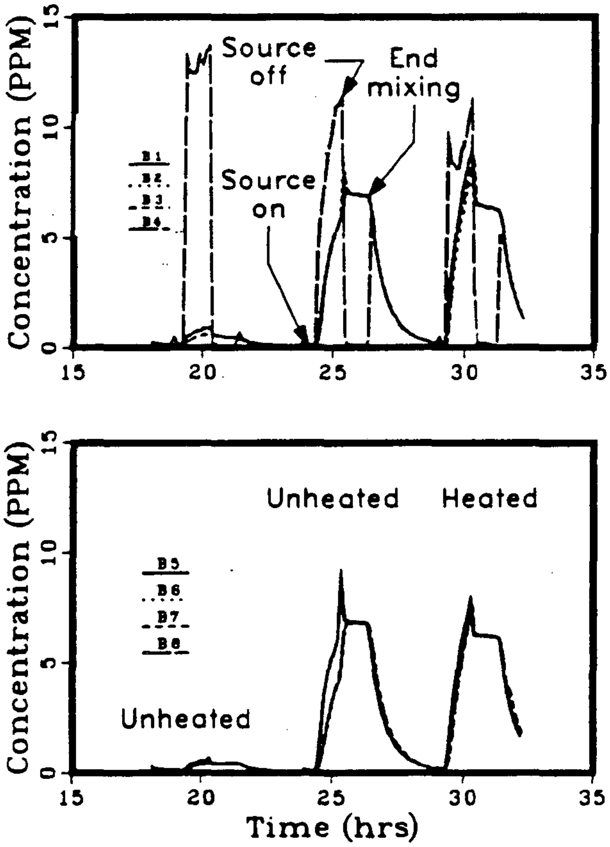

Figure 3. Typical range hood results with unheated and heated tracer gas. The sampling points are shown on Figure 1. The flow rate was 32.2 ℓ/sec.

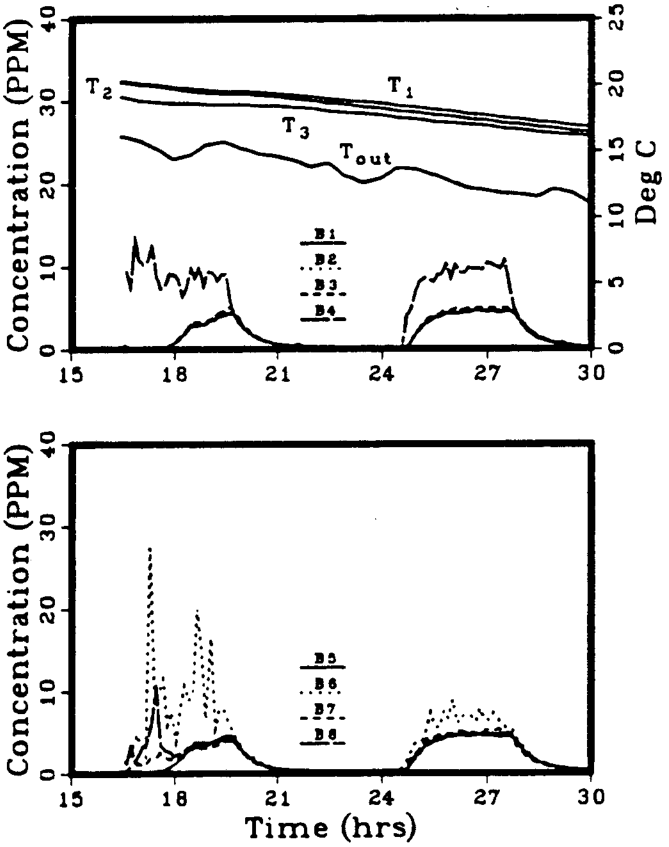

Figure 4. Typical window fan results. The sampling points are shown on Figure 1. The temperatures in rooms 1, 2, and 3, and outside are also shown. The flow rate was 39.2 ℓ/sec.

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UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720