

# A DETAILED STUDY OF THE EFFECTS OF VENTILATION, FILTRATION AND OUTDOOR AIR ON THE COMPOSITION OF INDOOR AIR AT A TELEPHONE OFFICE BUILDING

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## ABSTRACT

Sensors installed at a telephone office building in Neenah, WI continuously monitor twenty-four parameters related to the operation of the building's heating, ventilation, and air conditioning (HVAC) system. This data is stored in a dedicated minicomputer and can be retrieved, in various formats, for subsequent analyses. For more than a year we have conducted detailed chemical analyses of indoor and outdoor samples collected at this same location. Using the above data, we have examined the composition of the indoor air as it correlates with the composition of the outdoor air and the various HVAC operating parameters.

## INTRODUCTION

Starting in the mid-70's, the rising costs of fuel and electricity provided strong incentives for the pre-divestiture Bell System to reduce its energy usage. This usage had reached  $8.4 \times 10^{13}$  BTU's by 1980. By the end of 1981, a building energy conservation program had been implemented in about 40% of the Bell System's 16,000 telephone office buildings across the United States. This translated to a total annual energy cost savings of about 38 million dollars, based on 1981 energy costs (2). However, there was concern that this program might lead to increased concentrations of contaminants within the building. It was recognized that changes in the composition of the indoor air and deterioration in indoor air quality could prove costly in terms of extra monitoring and maintenance of both switching and computing equipment. Money saved on energy might be lost to increased costs associated with diagnosing and repairing failures in the sensitive electronic equipment housed within these buildings. The present study has evolved from these initial concerns. Its major goal is to assess the effects of ventilation, filtration, and the composition of outdoor air on the composition of indoor air at representative telephone office buildings. This study provides direction so that energy conservation measures can be implemented in such a way as to minimize consequent environmentally related failures and the labor needed to correct such failures.

## EXPERIMENTAL

Details on the sampling and analyses of condensed phase and vapor phase species are discussed elsewhere (3-8). Briefly, fine and coarse airborne particles are collected indoors and outdoors using automatic dichotomous samplers. The sampling interval is one week. Organic compounds associated with these particles are analyzed by gas chromatography - mass spectrometry (GC/MS). Water soluble anions and cations are measured using ion chromatography (IC). Twenty four different elements contained in the particles are determined by proton induced x-ray emission (PIXE) analysis. Volatile organic compounds (VOCs) are collected (four week sampling interval) using a passive sampling technique (3). The VOCs are then analyzed using standard GC/MS procedures.

The telephone building at Neenah is equipped with sensors that continuously monitor fan starts, minutes of fan operation, % outside air, volume of air flow in the system, and duct velocities. Sensors also monitor the temperature and relative humidity of the indoor, outdoor, return, supply, and mixing air. Every eighth of a second this data is stored in a dedicated microcomputer, and can be subsequently retrieved from a terminal in a remote location. The stored data is polled five times a week.

The Neenah office has a variable volume air handling system ( $34 - 184 \text{ m}^3/\text{min}$ ) and a total internal volume of  $3925 \text{ m}^3$ . This office does not prefilter the makeup air; the air handling plenum contains roll type low efficiency filters followed by bag filters that have an ASHRAE Dust Spot rating of 85%.

## RESULTS AND DISCUSSION

Samples have been collected at the Neenah location for more than 12 months. The results presented in Tables 1-3 are representative data from a two month subset - 4/7 to 6/2/86. Table 1 lists weekly summaries of the status of the HVAC system at the Neenah building.

Table 1 : Status of the HVAC system at Neenah, WI from 4/7-6/2/86.

Week	Sampling Interval (hours)	Fans Off (hours)	Fans On (hours)	Outside Air (hours)
4/7-4/14	168	39.21	128.79	62.09
4/14-4/21	168	19.25	148.75	99.18
4/21-4/28	168	53.21	114.79	73.27
4/28-5/5	146.1	5.46	140.64	104.39
5/5-5/12	168	39.45	128.55	96.14
5/12-5/19	168	26.28	141.72	102.17
5/19-5/26	168	16.86	151.14	76.24
5/26-6/2	164	44.83	123.17	48.75

These weekly summaries have been assembled from the daily data, and the time intervals have been chosen to match the actual periods that the dichotomous units were sampling. Hence, for the week 4/28 - 5/5, the interval is only 146 hours since the samplers were turned off and reloaded before the standard 168 hours had elapsed. During these eight weeks, the fans at the Neenah building were on from 115 hrs/wk to 151 hrs/wk and the outside air introduced each week varied from 49 to 104 hours.

Table 2 presents the indoor and outdoor concentrations of fine and coarse particles, as well as the sum of these two modes ("Total"), from 4/7 to 6/2/86.

Table 2 : Indoor and Outdoor Concentrations of Fine, Coarse and Total Suspended Particles at Neenah, WI from 4/7 - 6/2/86.

Week	Fine ( $\mu\text{g}/\text{m}^3$ )		Coarse ( $\mu\text{g}/\text{m}^3$ )		Total ( $\mu\text{g}/\text{m}^3$ )	
	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor
4/7 - 4/14	0.85	7.41	< 0.05	17.61	0.85	25.02
4/14 - 4/21	1.22	10.33	< 0.05	13.38	1.23	23.71
4/21 - 4/28	3.05	17.85	0.97	31.36	4.02	49.21
4/28 - 5/5	0.67	7.80	0.66	24.58	1.33	32.38
5/5 - 5/12	3.50	16.62	0.21	32.75	3.71	49.37
5/12 - 5/19	4.12	17.59	1.39	18.36	5.51	35.95
5/19 - 5/26	2.41	12.40	0.78	18.63	3.19	31.03
5/26 - 6/2	3.12	20.24	0.28	24.53	3.40	44.77

Indoors, the concentration of fine particles is greater than the concentration of coarse particles, while outdoors the reverse is true. For the fine mode particles, the indoor concentration rises and falls with the outdoor concentration (they "track"). Although indoor sources are present, a large fraction of the indoor fine particles come from outdoor sources. For the coarse mode particles, the indoor concentration does not track the outdoor concentration. Most of the coarse particles collected indoors come from indoor sources. These observations are consistent with the building's filtration system; as outlined above, the air handling plenum contains roll filters followed by 85% bag filters. The fraction of coarse particles removed by these filters,  $F_s(\text{coarse})$ , is approximately 0.995 (1). The fraction of fine particles removed by these filters,  $F_s(\text{fine})$ , is approximately 0.75 (1). Consequently, the fraction of fine particles entering the building through the filters is far greater than the fraction of coarse particles.

Examination of the ionic species associated with these particles (8) indicates that far more water soluble ions are associated with fine particles than coarse particles. The major water soluble ions contained in the fine particles, both outdoors and indoors, are sulfate and ammonium. In the outdoor coarse particles the major ions are calcium, nitrate, magnesium, and sulfate; indoor coarse ionic species have relatively small concentrations. At Neenah almost all of the indoor fine mode sulfate has infiltrated from outdoors. The same is true for fine mode ammonium, sodium, magnesium and calcium ions.

PIXE results reveal the major contribution soil derived elements such as aluminum, silicon, calcium and iron make to the outdoor coarse mode particles. The data also shows how few of these soil derived coarse mode particles enter the building (there is an indoor source of iron). In the fine mode, sulfur (presumably sulfate) dominates both indoors and outdoors. Although there may be minor indoor sources, none of the indoor fine mode trace elements have dominant indoor sources.

The concentrations of the nonpolar organic compounds associated with the Neenah particles, especially the indoor particles, are lower than those observed in earlier studies at Wichita, Lubbock and Newark (5,6). Preliminary analyses have identified long chain alkanes and alcohols as well as several phthalate esters. However, there was insufficient material for detailed quantitative measurements. The GC/MS procedures will have to be modified, perhaps incorporating selected ion monitoring, to quantitate the particulate organics at such low levels. Indoor sources of particulate organics are much less dominant at the Neenah site than at earlier sites (5,6). This reflects a conscious effort to eliminate or reduce major organic sources within the Neenah office, coupled with judicious operation of the HVAC system (see Table 1).

The major volatile organic compounds detected indoors and outdoors at Neenah (Table 3) include toluene, xylene isomers, trimethylbenzene isomers, selected alkyl benzenes, and both branched and linear alkanes between C<sub>9</sub> and C<sub>13</sub>. The compounds listed in Table 3 are relatively inert species, in the sense that they are unlikely to react with the building filters or surfaces within the air plenum or office. Consequently, these compounds should all have indoor/outdoor (I/O) ratios of one or greater. Inspection of Table 3 reveals that this is generally the case. Of the listed compounds, several have I/O ratios substantially greater than one, indicating an indoor source. The most striking example is dimethyl phthalate, a common plasticizer, that is consistently detected indoors but not outdoors. Ethyl benzene and 1,3,5-trimethyl benzene have elevated I/O ratios during the period from 5/5 - 6/2, but this is less pronounced from 4/7 - 5/5. The opposite is true for the xylene isomers, which display higher I/O ratios from 4/7 - 5/5 than from 5/5 - 6/2. However, most of the compounds in Table 3 do not exhibit a dominant indoor source. As stated above, this is the result of deliberate actions calculated to minimize the concentrations of organic species in the office. It is worth noting that the volatile organic compounds have concentrations in the microgram per cubic meter range while the particulate organic compounds have concentrations in the low nanogram per cubic meter range.

Table 3 : Indoor and Outdoor Concentrations for Volatile Organic Compounds,  $\mu\text{g}/\text{m}^3$

Compound	4/7 - 5/5/86		5/5 - 6/2/86	
	Indoors	Outdoors	Indoors	Outdoors
Toluene	0.65	0.50	0.93	0.80
Branched Octane	0.03	0.04	0.09	0.08
Tetrachloroethylene	0.11	0.10	0.13	0.07
Octane	0.02	0.01	0.05	0.04
Chlorobenzene	0.08	0.07	0.13	0.10
Ethyl benzene	0.19	0.15	0.31	0.19
Xylene(m&p)	0.52	0.35	0.46	0.38
Xylene (o)	0.38	0.24	0.40	0.33
Nonane	0.10	0.09	0.26	0.22
Branched C <sub>10</sub>	-	-	0.28	0.30
1,3,5-Trimethyl benzene	0.44	0.33	0.48	0.17
Branched C <sub>10</sub>	-	-	0.20	0.21
1,2,4-Trimethyl benzene	0.45	0.32	0.60	0.55
Decane/C <sub>3</sub> -benzene	-	-	0.73	0.67
Decane/C <sub>3</sub> -benzene/ dichlorobenzene	0.37	0.26	-	-
Branched Undecane/ C <sub>4</sub> -benzene	0.55	0.37	1.12	0.76
C <sub>4</sub> -benzene	0.40	0.25	0.69	0.56
Undecane/C <sub>4</sub> -benzene	0.31	0.19	0.60	0.44
Dodecane	0.18	0.13	0.20	0.13
Tridecane	0.37	0.38	0.32	0.27
Tetradecane	0.08	0.09	0.08	-
Dimethyl phthalate	0.26	-	0.33	-
Pentadecane	0.11	0.07	0.23	0.09
Hexadecane	-	0.32	0.35	-
Heptadecane	0.68	0.66	0.30	0.35

## CONCLUSIONS

Within the telephone office building at Neenah, WI the majority of the volatile organic compounds have infiltrated from outdoors. The same is true for fine mode particles and their chemical constituents (organics, ionics and trace elements). This reflects a conscious effort to limit indoor sources at the Neenah site. Conversely, most of the indoor coarse mode particles and their chemical constituents have been generated indoors; their concentrations are relatively low. There is very little infiltration of outdoor coarse mode species, consistent with the efficiency of the building filters.

The steady state concentration of indoor species at the Neenah site can be explained using a mass balance model presented in detail elsewhere (8). The successful application of this model depends on the detailed HVAC information available at this building, as well as appropriate data regarding the composition of the outdoor air. Such modeling not only promotes understanding and control of the factors responsible for the composition of the indoor air, but also allows one to predict this composition as a function of outside conditions and HVAC operation.

The results presented in this report are, due to space constraints, abbreviated. The tables present only two months out of more than twelve months of data, and measurements on particulate organics, ionics and trace elements have been omitted. More detailed results and interpretations will follow.



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## A QUANTITATIVE METHOD FOR MEASURING AIR RECIRCULATION

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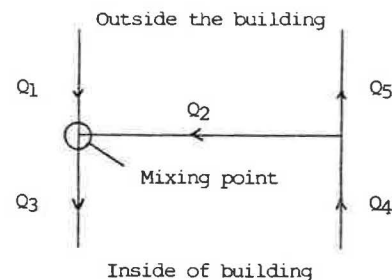
Abstract

There are both technical and medical-hygienic needs of accurate and useful methods to measure air recirculation in ventilation systems. This is possible by analysis of the CO<sub>2</sub>-concentrations in outdoor air (C<sub>1</sub>) and at two well-defined points before (C<sub>2</sub>) and after (C<sub>3</sub>) the mixing point for recirculated and fresh air. The percentage of recirculated air in the mixed inlet air to the interior of the building is represented by the quotient  $100 \times (C_3 - C_1)/(C_2 - C_1)$ . The accuracy of the method is excellent when the CO<sub>2</sub>-concentrations are determined with a sensitive instrument, such as an IR-spectrophotometer. However, detector tubes for CO<sub>2</sub>-analysis obtainable on the market today are not usable in this situation. Air recirculation in peopled spaces could result in CO<sub>2</sub>-concentrations in the inlet air which are considerably higher than 500 ppm.

Introduction

Air recirculation is used to an ever increasing extent to save energy. In the Scandinavian countries during wintertime, up to 80 percent of the exhaust air could be recirculated in office buildings. In addition, non-intentional air recirculation could occur due to inappropriate locations of air inlets and outlets.

Air recirculation can be determined by measuring the concentration of a suitable tracer, e.g., carbon dioxide (CO<sub>2</sub>) emitted from residents and indoor activities. The accuracy of this method is excellent when the tracer is precisely determined with a sensitive instrument, such as an IR-spectrophotometer (1,2). In screening situations and for routine tests, more simple methods for tracer analysis would be useful. The purpose of the present study has been to examine if commercially available detector tubes for CO<sub>2</sub>-analysis could be used in such situations.

Method

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