INDOOR/OUTDOOR

AIR QUALITY RELATIONSHIPS

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The purpose of this study was to gather air quality data for four pollutants inside and outside of three pairs of structures for different seasons of the year. This paper presents results obtained during the summer, fall, and winter seasons of 1969–70. Suspended particulate, soiling particulate, carbon monoxide, and sulfur dioxide were measured at pairs of public buildings, office buildings, and private homes. A brief preliminary program was conducted during the winter of 1969 to verify our procedures and equipment and to assess the effects of heating and cooking systems in private homes on indoor levels of air pollutants. Two self-contained and portable instrument packages were constructed for the measurement program. The major components of each trailer package were a central vacuum pump for drawing air samples through particulate collection filters, four paper-tape soiling samplers, a conductimetric analyzer for sulfur dioxide, an infrared analyzer for carbon monoxide, a master control unit, and supporting apparatus to make the trailer self-contained. Each pair of buildings was sampled simultaneously for a two-week period. Four sampling points were selected at each structure, two outside and two inside. Suspended particulate samples were collected for 12-hr day and night periods, soiling particulate samples for 2-hr periods, and gaseous samples for 5-min periods. The results show the ease of penetration of particulate into private homes and the removal ability of air conditioning systems. Outdoor daily activity greatly influences particulate levels and urban carbon monoxide levels. Internal generation of pollutants was a significant factor in measured interior concentrations in some of the structures sampled.

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The exposure of a person to air pollutants does not stop as soon as he enters an enclosed space. Indoor atmospheres become contaminated through the penetration of outdoor pollutants into interiors and through the generation of a variety of pollutants within the interior space itself. The question of relative indoor/outdoor levels of air pollutants has been addressed by several earlier workers[1–6] but in view of the importance of this question, it is surprising how relatively little attention this area of research has received until recently.

This paper* describes a pilot study program whose objective was to obtain data on the quantitative relationship of indoor to outdoor air quality levels in terms of several pollutants. To satisfy the objective, a unique mobile equipment package was developed to permit simultaneous sampling of indoor and outdoor air for diverse building structures.

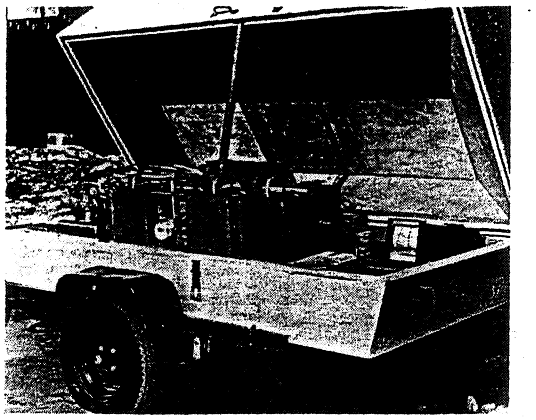

Figure 1. The TRC indoor/outdoor sampling system.

Sampling Plan

The program was conducted in two phases: The Preliminary Program and the Basic Program.

Preliminary Program

Prior to the initiation of the basic sampling program, a brief study of four private homes was conducted during the winter of 1969 to determine the effect of the heating and cooking systems on indoor levels of air pollutants. Two of the homes had gas-heating systems and stoves and two had coal-heating systems. Carbon monoxide was measured at the gas-heated homes and sulfur dioxide and soiling particulate as well as carbon monoxide were measured at the coal-heated homes.

Basic Program

Three pairs of buildings were selected in and around Hartford, Conn., for combinations of characteristics which are described later. Each pair of buildings was sampled simultaneously over a two-week period during the summer, fall, and winter seasons.

The four classes of pollutants described below were sampled at each structure at four sampling points as follows:

1. *Far Outside.* Representing ambient air quality in the area of the building.
2. *Near Outside.* Located next to a window separating the indoor from the outdoor environment.
3. *Near Inside.* Just inside from the Near Outside sample.
4. *Far Inside.* Located well inside the structure and representing levels of pollutants from outdoors or generated indoors to which the occupants are exposed.

Pollutants Measured

Four different types of pollutants were monitored, each of which is recognized as a component of urban atmospheres, each of which is expected to behave differently in penetrating structures, and each of which may be generated inside the structure.

Suspended Particulate Matter. A special 4-in. filter was developed by TRC for the collection of suspended particulate matter on Type A glass fiber filters. One filter was exposed for 12 hr (7 A.M. to 7 P.M.), after which another was exposed for the following 12-hr period (7 P.M. to 7 A.M.). Particulate matter concentrations were based on the weight accumulated on the filter papers during the 12-hr exposure periods (approximately 100 m³ of air is sampled in 12 hr).

Soiling Particulate Matter. Gelman tape samplers operating in the sampling trailers (one for each of the four sampling points) were used to determine the concentrations of soiling particulate matter based on light transmission through the exposed areas of the filter tapes. Two-hour sequential sampling periods were used.

Carbon Monoxide. An Intertech Infra-2 nondispersive infrared spectrophotometer was used for this measurement. Five-minute samples from the four sampling points were directed sequentially to this analyzer as well as the SO_2 analyzer by a time-controlled solenoid valve system.

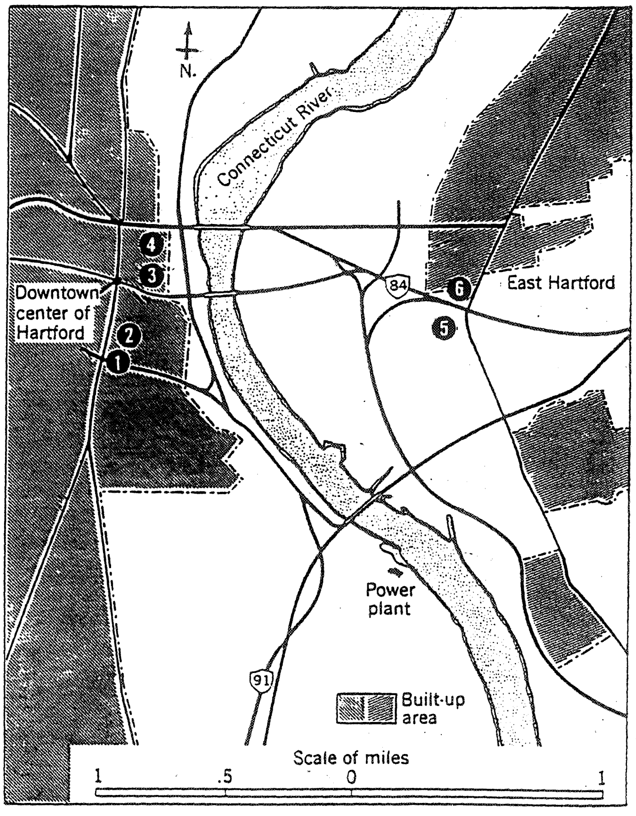

Figure 2. Map showing study area and approximate locations of test buildings.

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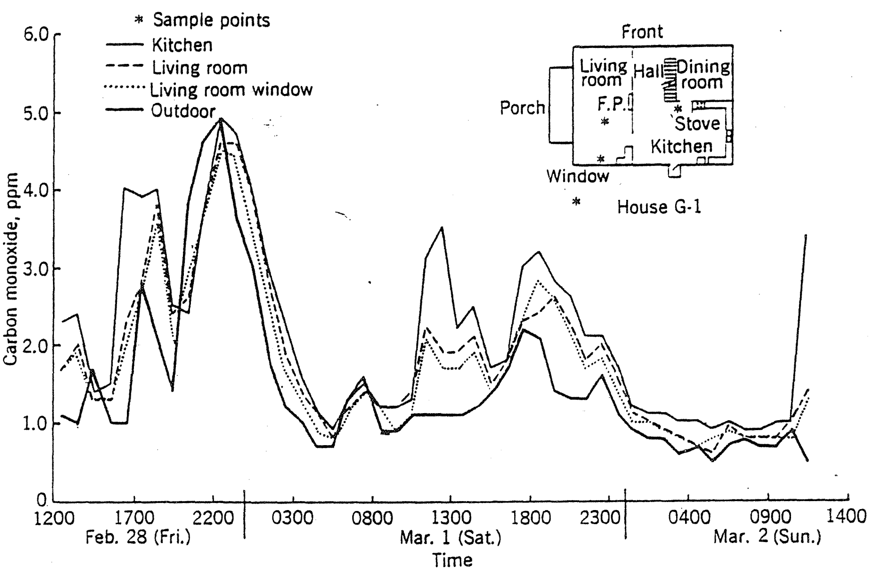

Figure 3. Time variation of carbon monoxide for house G-1.

Sulfur Dioxide. A Sign-X Model 604-B conductimetric SO_2 analyzer was used in this study. As pointed out above, the four sampling points were sampled sequentially on a 5-min basis.

Instrumentation

The requirements, as laid down in the sampling plan, called for simultaneous comparative measurements, at pairs of selected business and residential sites. The nature of the sampling plan dictated the use of portable equipment for rapid transport between site-pairs and the distance between the sites in each pair dictated the need for at least two instrumentation packages. We were sure that noisy air samplers, such as the standard HiVol sampler, would not be acceptable when placed inside buildings or near residences. Additionally, a high rate of sample flow taken from inside a residence would interfere by cleaning the air if discharged back into the residence, or by modifying the ventilation rate if discharged outside.

With these constraints in mind, and with the objective of creating a flexible monitoring package with the maximum usage of equipment in common, we developed two packages, making use in common of units such as pumps, analyzers, and recorders, and coordinating the operation through a central control unit in each package. Figure 1 is a photograph showing one of the trailer-mounted equipment packages developed.

Structures Samples

Three basic types of structures were used for the study: public buildings, office buildings, and private homes. A pair of buildings of each type was sampled simultaneously. Structures in each pair were essentially similar, except for one design feature which might affect the exposure to and the penetration of certain pollutants. The locations of the six structures are shown in Figure 2.

Public Buildings. The pair of public buildings used in the study were the Hartford Public Library, built as an air-rights structure over a four-lane highway, the Hartford City Hall, which is located to the north of the library and is separated from it by a heavily traveled street. Neither building is air conditioned, and both are of masonry construction.

Office Buildings. The pair of office buildings are located in Constitution Plaza, an urban renewal area in the center of Hartford. One of the buildings is a six-story structure at 250 Constitution Plaza (250 CP), built directly over a five-level, partially underground parking garage and connected to the garage by stairwells and elevator shafts. The other office building is a 16-story structure at 100 Constitution Plaza (100 CP), not built over a parking garage. Both buildings are air conditioned and therefore have no open windows. To prevent infiltration of air from the parking garage, an attempt is made to pressurize the smaller office building by returning or recirculating significantly less air than the air-conditioning system provides for the building.

Private Homes. Both homes are located in East Hartford, in the midst of a freeway interchange network. One home is located on Carroll Road, to the north of an Interstate Highway, and the other on Blinn Street, on the opposite side of the same east-west road. Neither house is air conditioned, nor do they have gas stoves which are a source of internal carbon monoxide.

Sampling Results

Preliminary Program

The emphasis in this preliminary study was on qualitative rather than quantitative indoor/outdoor differences, and the most interesting results are presented in terms of graphs showing the time history of pollutant concentrations at each of the four sampling points.

Gas-Heated Homes. Figure 3 is typical of the CO history of one of the gas-heated homes. It is evident that kitchen sources dominate the CO picture in the house between 1600 and 1800 on February 28. A small outdoor peak at 2.8 ppm during this period, undoubtedly the result of home-bound traffic, was insufficient to raise indoor concentrations above those caused by kitchen sources. However, at about 2000 outdoor CO levels exceeded those indoors, and indoor

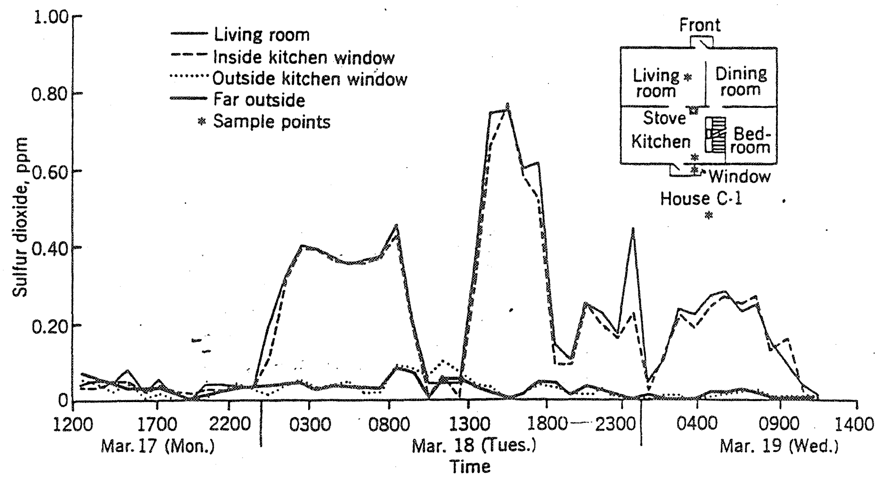

Figure 4. Time variation of sulfur dioxide for house C-1.

concentrations began to respond to the outdoor influence. The indoor/outdoor patterns in the remainder of this record also appear to be logical. The gradient between the various sampling points usually shows the point nearest the window to be at an intermediate value between the kitchen and outdoors.

In tests at another gas-heated home, the attached garage was a far greater source of indoor CO levels than the gas stove.

Coal-Heated Homes. Figure 4 is the concentration history for SO_2 in one of the coal-heated homes. The most striking features of this record are the high indoor concentrations of SO_2. It is clear that indoor sources completely dominate the indoor levels of SO_2. A leaky furnace is the only logical source of these high concentrations, since the periods of high concentration coincide with stoking periods, and carbon monoxide patterns were essentially the same as those for SO_2 with only a different scale necessary to reproduce its record.

Basic Program

Suspended Particulates. Results are presented for suspended particulate, soiling particulate, and carbon monoxide. Sulfur dioxide values were too low and variable during the measurement programs to provide any insight into indoor/outdoor relationships and are not presented in this paper.

Table I summarizes the data obtained on total suspended particulates. Average seasonal particulate concentrations are shown for each of the four sampling points at each of the structures. We have also shown indoor/outdoor ratios based upon data for the "far indoor" and "far outdoor" values to show the relative penetration of outdoor particles indoors and/or the generation of particles indoors. A number of interesting observations can be made on these data:

1. In some cases (notably at the Public Buildings), a gradient in particulate levels exists with respect to distance from the building. Yet, there is little or no gradient of particulate levels within the structures tested based on the sampling configurations used. See Figure 5 for indoor/outdoor profiles for winter data.

2. Daytime levels of particulates, both indoors and outdoors, are higher than nighttime levels, undoubtedly because of the higher levels of human activity during the day, both indoors and outdoors.

3. Except for one set of values at one of the private homes, indoor/outdoor ratios are less than 1.0, indicating a substantial removal of particulates in the penetration process.

4. Indoor concentrations in the air-conditio are uniformly low, indicating that the roughing part of the air-conditioning system are at lea effective in removing suspended particulates.

In addition to the above rather obvious po parent that indoor/outdoor ratios are related t of building, air conditioning or lack thereof, outside particulates.

In connection with the last mentioned item, for the winter at the Library.

Figure 6 shows graphically the change in in ratios with season for one each of the three diff buildings. Note that for the two non-air-cond tures (public building and private home) there decrease in ratio from summer to winter. Thi of the gradual closing up of the buildings wi temperatures and the relatively higher conc larger (non-penetrating) particulates during seasons. Note that the indoor/outdoor ratios f homes during the summer exceeded 1.0, indic stantial indoor generation of particulate matte tern for the air-conditioned building is especiall The peak in indoor/outdoor ratio in the Fall results from the high make-up air ratio during t compared with summer and winter which w drive the indoor/outdoor ratio upwards towards

Organic particulate matter was measured by benzene extractable content of suspended partic Table II presents data on indoor/outdoor leve soluble material based upon the far indoor and values. We have also shown indoor/outdoor r zene extractable particulates based upon weight for this type of material and "enrichment facto the ratios of indoor/outdoor values of the frac particulate matter which is benzene extract "enrichment factors" show the extent to which p the structure have become enriched with sol material, either through selective removal in th process of larger inorganic particles or through soluble organic particles inside the structures. comparing Table II with Table I that indoor/o for benzene soluble materials are consistently indoor/outdoor ratios for total particulate matte on benzene soluble enrichment factors clearly s tive enrichment of indoor particulate matter wi soluble organic material as a result of the genera

Table I. Summary of suspended particulate matter results. (Concentration, $\mu g/m^3$, indoor/outdoor ratio, dimensionless.)

Location	Sampling point	Summer Day	Summer Night	Fall Day	Fall Night	Winter Day	Winter Night
Library	Far Outdoor	132	82	150	100	425	189
	Near Outdoor	98	66	115	77	293	130
	Near Indoor	70	45	61	46	74	51
	Far Indoor	66	43	57	44	67	45
	Indoor/Outdoor	0.50	0.52	0.38	0.44	0.16	0.26
City Hall	Far Outdoor	153	78	133	94	327	168
	Near Outdoor	145	76	128	83	285	147
	Near Indoor	78	52	87	50	107	53
	Far Indoor	78	49	82	50	87	51
	Indoor/Outdoor	0.51	0.63	0.62	0.53	0.27	0.30
100 CP	Far Outdoor	104	93	48	38	124	81
	Near Outdoor	118	98	47	40	137	89
	Near Indoor	49	49	34	24	39	41
	Far Indoor	50	46	36	27	38	39
	Indoor/Outdoor	0.48	0.49	0.75	0.71	0.31	0.48
250 CP	Far Outdoor	124	109	66	46	183	97
	Near Outdoor	115	102	58	44	163	98
	Near Indoor	57	67	38	24	57	31
	Far Indoor	56	60	38	23	60	32
	Indoor/Outdoor	0.45	0.55	0.58	0.50	0.33	0.33
Blinn Street	Far Outdoor	79	65	96	74	114	86
	Near Outdoor	87	65	93	70	109	79
	Near Indoor	67	51	52	42	45	32
	Far Indoor	70	56	54	45	49	35
	Indoor/Outdoor	0.87	0.86	0.56	0.61	0.43	0.41
Carroll Road	Far Outdoor	66	56	78	61	103	85
	Near Outdoor	60	49	81	60	116	81
	Near Indoor	73	47	73	37	44	32
	Far Indoor	76	47	76	38	53	33
	Indoor/Outdoor	1.15	0.84	0.97	0.62	0.51	0.39

Table II. Summary of data on the benzene soluble content of suspended particulates, concentration $\mu g/m^3$. (Indoor/outdoor ratio and organic enrichment factor, dimensionless.)

Location	Sampling point	Ratios	Summer Day	Summer Night	Fall Day	Fall Night	Winter Day	Winter Night
Library	Far Outdoor		9.8	7.0	16.1	13.6	29.5	14.2
	Far Indoor		6.6	11.9	11.7	12.1	13.9	6.0
		Indoor/Outdoor	.67	1.70	.73	.89	.47	.48
		Enrichment Factor	1.24	3.12	1.57	1.82	3.12	2.16
City Hall	Far Outdoor		21.8	10.5	22.8	21.8	25.3	10.9
	Far Indoor		17.1	12.3	23.3	11.3	24.6	5.5
		Indoor/Outdoor	.78	1.17	1.02	.52	.97	.50
		Enrichment Factor	1.66	2.00	1.61	.94	3.23	1.77
100 CP	Far Outdoor		19.0	14.0	6.2	5.5	13.0	19.9
	Far Indoor		20.5	20.6	16.5	5.0	10.2	8.7
		Indoor/Outdoor	1.08	1.47	2.66	.91	.78	.73
		Enrichment Factor	2.44	3.13	3.04	1.09	3.08	1.62
250 CP	Far Outdoor		17.0	12.3	7.8	7.8	21.9	16.7
	Far Indoor		17.4	11.9	12.1	5.2	14.5	8.6
		Indoor/Outdoor	1.02	.97	1.55	.67	.66	.51
		Enrichment Factor	2.99	1.86	2.40	1.20	2.44	1.50
Blinn Street	Far Outdoor		18.4	11.5	16.7	16.9	11.0	12.7
	Far Indoor		—	17.3	13.9	16.3	11.8	5.5
		Indoor/Outdoor	—	1.50	.83	.96	1.07	.43
		Enrichment Factor	—	1.66	1.43	1.60	2.70	1.17
Carroll Road	Far Outdoor		13.5	19.8	12.7	11.9	9.1	10.5
	Far Indoor		18.7	17.8	22.9	9.5	25.6	5.3
		Indoor/Outdoor	1.39	.90	1.80	.80	2.81	.50
		Enrichment Factor	1.32	.92	2.16	1.49	2.56	1.15

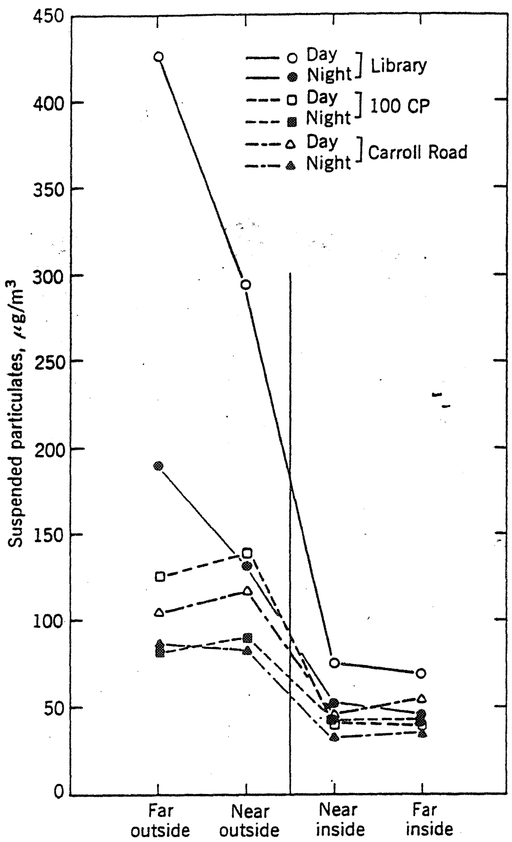

Figure 5. Indoor/outdoor profiles for winter suspended particulate data.

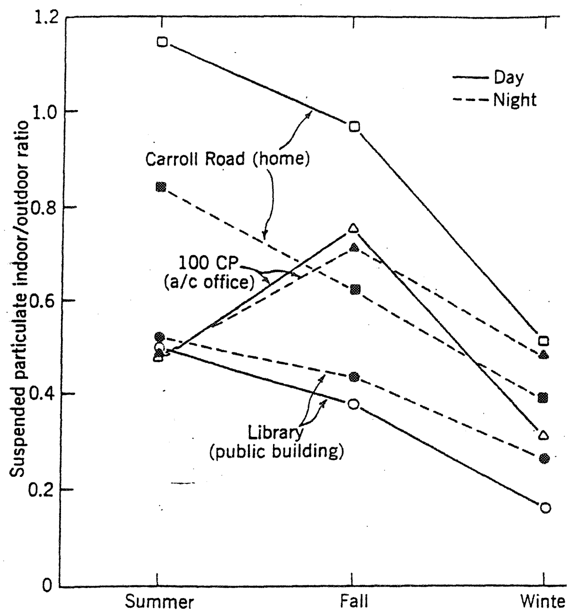

Figure 6. Seasonal suspended particulate indoor/outdoor r three types of structures.

of these soluble organic particles and/or the presence of sources of such materials indoors (smoking and cooking).

The organic particulate enrichment factors for the air conditioned buildings appear to be uniformly high, indicating a significant contribution from smoking and a low collection efficiency of the air-conditioning filters for soluble organic particulate matter.

Inorganic lead particulates were measured by nitric acid extraction of the total suspended particulate samples and an analysis of the extract for lead by atomic absorption. Table III is similar in structure to Table II, but is based on the inorganic lead content of the particulate matter. The indoor/outdoor ratios and lead enrichment factors for lead particulates are generally lower than these same factors for benzene soluble material which indicates that lead particulates are removed to a greater extent in the penetration process than benzene soluble material. In addition, the lack of lead sources inside structures contributes to the differences in these relationships. The indoor/outdoor ratios and enrichment factors for lead for the two air-conditioned buildings are not significantly different. Recall that one of the buildings (250 CP) is built over a parking garage. Thus, the operation of the ventilation system on 250 CP with a slight positive pressure is effective in preventing the penetration of auto exhaust (and lead) into the building's indoor atmosphere.

Soiling Particulate. Table IV presents a summary of data on soiling particulate matter showing the seasonal values both day and night for the four sampling points at each of the six structures tested. As in the case of suspended particulate matter (Table I) we show the indoor/outdoor ratios based on far indoor and far outdoor ratios based on far indoor and far outdoor measurements. A number of observations are immediately apparent from this table:

1. Soiling particulate values in the Hartford Area ar low, when compared with other larger and more industrialized eastern cities.
2. In general, a gradient exists between outdoor and values, but except for the public buildings, is not parti steep. See Figure 7 for winter data on three of the buil
3. Daytime and nighttime soiling index levels appea roughly the same with no consistent difference betw two values, whereas with suspended particulates, d levels were consistently greater than those measured a Nighttime difference in behavior can probably be attrib the small size of the soiling particulates which tend suspended at night, after the activities of the day ha sided while the larger particles contributing to the pended particulate" measurement tend to settle out at
4. Indoor/outdoor ratios are higher than those fo suspended particulate matter which also points to the size of the soiling particulate matter.
5. Indoor/outdoor ratios for the air-conditioned bu do not appear to be significantly different from the n conditioned structures indicating that soiling parti are not effectively removed by the filters in the air-con ing system.
6. The City Hall in the fall and the Carroll Road h summer have indoor/outdoor ratios exceeding 1.0. Alt the levels of soiling are low, it would appear that unde conditions there was some indoor generation of soiling ulates in these structures.

Carbon Monoxide. Table V presents a summary of se indoor/outdoor CO values. From this table, it is ap that:

1. Outdoor levels of CO were greatest near the City L which confirms the significant auto traffic contribution air rights structure.
2. Outdoor levels of CO near 250 CP are significantly than those at 100 CP because of its closer proximity to downtown street.
3. In general, very shallow or even slightly positive gra for CO exist from outdoors to indoors, confirming th servative nature of CO in its penetration of structure possible internal generation. See Figure 8, showing w time indoor/outdoor profiles.

Table III. Summary of data on inorganic lead concentration of suspended particulate matter. (Concentration $\mu g/m^3$, indoor/outdoor ratio and lead enrichment factor, dimensionless.)

Location	Sampling point	Ratios	Summer Day	Summer Night	Fall Day	Fall Night	Winter Day	Winter Night
Library	Far Outdoor		1.58	0.72	3.78	3.44	3.44	1.68
	Far Indoor		0.77	0.39	2.04	1.68	1.40	0.44
		Indoor/Outdoor	0.49	0.54	0.54	0.49	0.42	0.26
		Enrch. Fctrs.	0.92	0.99	1.18	1.00	2.77	1.16
City Hall	Far Outdoor		0.87	0.48	[a]	3.68	2.71	1.61
	Far Indoor		0.92	0.44	1.62	2.04	1.85	0.99
		Indoor/Outdoor	1.06	0.92	[a]	0.55	0.67	0.61
		Enrch. Fctrs.	2.23	1.58	[a]	1.01	2.33	2.16
100 CP	Far Outdoor		0.46	0.36	1.19	0.86	1.68	1.98
	Far Indoor		0.18	0.27	0.46	[a]	0.59	1.26
		Indoor/Outdoor	0.39	0.75	0.39	[a]	0.35	0.64
		Enrch. Fctrs.	0.89	1.61	0.41	[a]	1.37	1.42
250 CP	Far Outdoor		0.38	0.55	2.04	1.13	2.72	1.83
	Far Indoor		0.35	[a]	0.72	0.46	0.86	1.26
		Indoor/Outdoor	0.92	[a]	0.35	0.41	0.32	0.69
		Enrch. Fctrs.	2.67	[a]	0.55	0.73	1.61	0.85
Blinn Street	Far Outdoor		1.86	2.68	3.94	2.79	2.42	1.19
	Far Indoor		1.59	1.75	1.54	1.33	1.26	0.77
		Indoor/Outdoor	0.85	0.65	0.39	0.48	0.52	0.71
		Enrch. Fctrs.	0.86	0.72	0.67	0.79	1.30	1.75
Carroll Road	Far Outdoor		0.75	1.66	1.68	2.19	1.19	0.57
	Far Indoor		0.75	1.20	0.93	1.33	0.47	[a]
		Indoor/Outdoor	1.00	0.72	0.55	0.61	0.40	[a]
		Enrch. Fctrs.	0.94	0.74	0.66	1.13	0.50	[a]

[a] Questionable data.

Table IV. Summary of soiling particulate matter results. (COH/1000 ft, indoor/outdoor ratio, dimensionless.)

Location	Sampling Point	Summer Day	Summer Night	Fall Day	Fall Night	Winter Day	Winter Night
Library	Far Outdoor	0.42	0.31	0.36	0.34	0.58	0.49
	Near Outdoor	0.38	0.30	0.33	0.32	0.49	0.42
	Near Indoor	0.34	0.25	0.32	0.31	0.31	0.26
	Far Indoor	0.34	0.25	0.33	0.32	0.29	0.24
	Indoor/Outdoor	0.81	0.81	0.92	0.94	0.50	0.49
City Hall	Far Outdoor	0.41	0.30	0.33	0.29	0.52	0.44
	Near Outdoor	0.42	0.31	0.31	0.30	0.63	0.54
	Near Indoor	0.39	0.28	0.42	0.37	0.61	0.52
	Far Indoor	0.40	0.30	0.38	0.33	0.49	0.41
	Indoor/Outdoor	0.98	1.00	1.15	1.14	0.9[illegible]	0.93
100 CP	Far Outdoor	0.30	0.36	0.27	0.24	0.41	0.38
	Near Outdoor	0.45	0.45	0.34	0.28	0.49	0.47
	Near Indoor	0.27	0.31	0.23	0.24	0.39	0.42
	Far Indoor	0.26	0.30	0.19	0.19	0.35	0.34
	Indoor/Outdoor	0.87	0.83	0.69	0.79	0.85	0.89
250 CP	Far Outdoor	0.46	0.52	0.28	0.25	0.72	0.64
	Near Outdoor	0.50	0.56	0.28	0.26	0.67	0.62
	Near Indoor	0.32	0.39	0.23	0.22	0.45	0.41
	Far Indoor	0.26	0.32	0.22	0.21	0.42	0.35
	Indoor/Outdoor	0.57	0.62	0.79	0.84	0.58	0.55
Blinn Street	Far Outdoor	0.44	0.53	0.33	0.35	0.40	0.50
	Near Outdoor	0.43	0.53	0.36	0.38	0.41	0.50
	Near Indoor	0.44	0.52	0.36	0.36	0.33	0.38
	Far Indoor	0.39	0.45	0.30	0.31	0.33	0.37
	Indoor/Outdoor	0.89	0.85	0.88	0.89	0.82	0.74
Carroll Road	Far Outdoor	0.32	0.38	0.34	0.36	0.29	0.36
	Near Outdoor	0.35	0.40	0.33	0.36	0.30	0.36
	Near Indoor	0.33	0.37	0.26	0.23	0.22	0.25
	Far Indoor	0.38	0.42	0.26	0.24	0.27	0.30
	Indoor/Outdoor	1.19	1.10	0.80	0.67	0.93	0.83

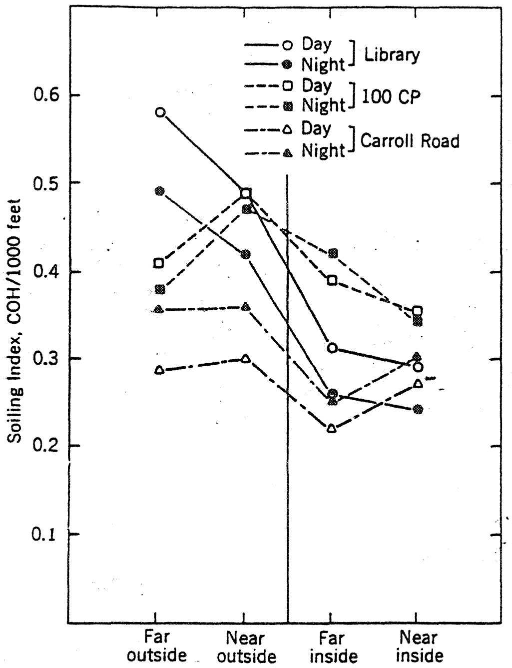

Figure 7. Indoor/outdoor profiles for winter soiling particulate data.

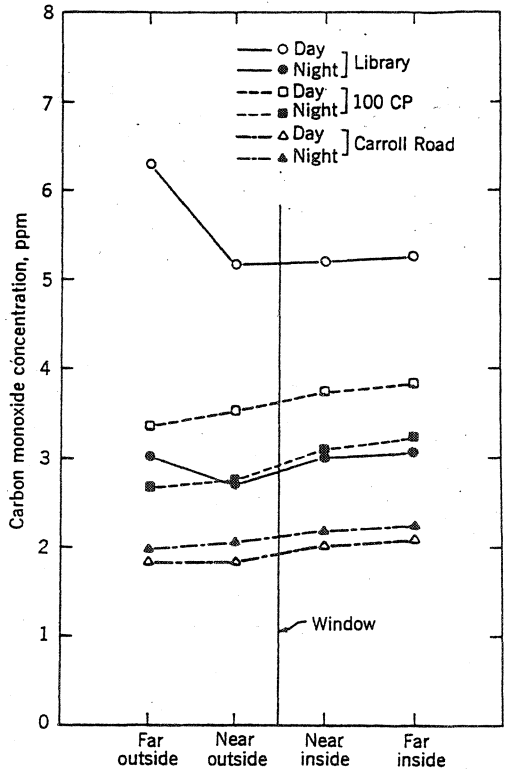

Figure 8. Indoor/outdoor profiles for winter CO data.

Table V. Summary of carbon monoxide results, ppm. (Indoor/outdoor ratio, dimensionless.)

Location	Sample point	Summer Day	Summer Night	Fall Day	Fall Night	Winter Day	Winter Nig
Library	Far Outside	3.73	2.17	6.14	4.72	6.32	3.0
	Near Outside	3.17	2.09	4.86	4.23	5.20	2.7
	Near Inside	3.12	2.08	4.67	4.50	5.22	3.0
	Far Inside	3.24	2.17	4.76	4.52	5.28	3.0
	Indoor/Outdoor	0.87	1.00	0.78	0.96	0.84	1.0
City Hall	Far Outside	3.40	1.97	4.90	3.78	7.50	3.7
	Near Outside	3.05	1.87	4.43	3.58	6.44	3.4
	Near Inside	3.04	2.00	4.38	3.85	6.02	3.4
	Far Inside	3.04	2.00	4.35	3.83	6.02	3.4
	Indoor/Outdoor	0.89	1.02	0.89	1.01	0.80	0.9
100 CP	Far Outside	2.55	2.80	2.72	1.99	3.39	2.6
	Near Outside	2.68	2.90	2.98	2.08	3.55	2.7
	Near Inside	3.38	2.80	3.53	2.48	3.79	3.2
	Far Inside	3.34	2.81	3.58	2.48	3.82	3.2
	Indoor/Outdoor	1.31	1.00	1.32	1.25	1.13	1.2
250 CP	Far Outside	3.26	3.11	4.01	2.92	4.26	2.4
	Near Outside	3.29	3.18	3.77	2.87	3.77	2.3
	Near Inside	3.38	3.04	3.82	3.07	3.21	2.3
	Far Inside	3.42	3.18	3.83	3.05	3.23	2.3
	Indoor/Outdoor	1.05	1.02	0.96	1.04	0.76	0.9
Blinn Street	Far Outside	2.52	3.14	3.06	3.21	2.05	2.0
	Near Outside	2.43	3.08	3.08	3.23	2.15	2.1
	Near Inside	2.53	3.32	3.11	3.37	2.15	2.1
	Far Inside	2.57	3.36	3.17	3.48	2.21	2.2
	Indoor/Outdoor	1.02	1.07	1.03	1.08	1.07	1.0
Carroll Road	Far Outside	2.06	2.70	3.33	2.70	1.84	1.9
	Near Outside	2.06	2.72	3.16	2.75	1.86	2.0
	Near Inside	2.12	2.74	3.33	2.93	2.02	2.2
	Far Inside	2.15	2.75	3.20	2.94	2.07	2.2
	Indoor/Outdoor	1.04	1.02	0.96	1.08	1.12	1.1

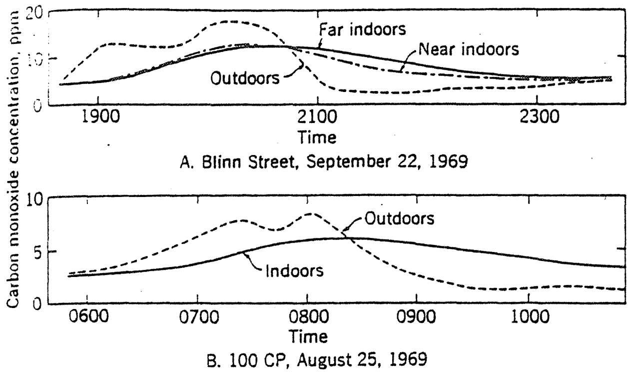

Figure 9. Typical time history of CO concentrations at a private home and an air conditioned office building.

4. Far indoor/far outdoor ratios taken on the average for all structures approximate 1.0.

5. Based upon indoor/outdoor ratios, the ventilation system at 250 CP appears to eliminate any significant contribution of the parking garage to indoor CO levels.

The essentially simultaneous indoor/outdoor measurements of CO permitted us to make direct comparison of relatively short term average indoor and outdoor concentrations. We evaluated a large number of interesting episodes of which the two shown in Figure 9 are typical. Figure 9A shows an episode at the Blinn Street residence where one outdoor value was plotted along with the two indoor values. The outside CO went through a cycle of high concentration for 2 hr followed by a period of low concentration. The response to outdoor concentrations was sluggish, indicating that the house was closed up.

We had previously measured the exponential decay constant* of both private homes in a closed up mode to be about 90 minutes. We measured these constants by "spiking" the indoor atmosphere with CO and measuring the change in concentration with time. The pattern in Figure 9A confirmed the measured decay constant for this house while closed up. The two indoor curves give an idea of the relative indoor gradient for CO during periods when there is a difference between indoor and outdoor concentrations.

Figure 9B is a time history at 100 CP. Normally, such an ir-conditioned building reacts extremely slowly to changes n outdoor concentrations, but starting about 0700, the indoor oncentration rises relatively sharply in response to outdoor evels, but the decay indoors does not drop off as rapidly as he buildup. In this building, make up air is introduced to he system about 0700 which in this and many other instances oincides with significant outdoor concentrations. Later in e morning after the traffic induced outdoor peak has passed d the system has started operating on a minimum make up r mode, indoor CO concentrations remain well above outor concentrations for a considerable period.

xponential decay constant is based on the equation: $C = {}^{-t/T}$ where C is concentration, t is time over the interval in stion, and T is the decay constant.

Conclusions

This program has shown that portable instrument trailers designed as multiport samplers are well suited to the conduct of indoor/outdoor sampling programs. Using common sampling instruments for the collection of data on gaseous pollutants at a number of sampling points operated sequentially provides an accurate assessment of pollutant profiles even when point to point differences in concentration are extremely small.

The salient conclusions we have drawn from the data collected in this program are;

1. In homes with gas heating and cooking, the heating systems has no effect on CO levels; however, the gas stoves had a significant effect on indoor CO levels.

2. In one house with a coal-fired hot air heating system which had apparent leaks, indoor concentrations of CO and SO_2 approached levels of concern as to possible adverse health effects.

3. Suspended particulate matter readily penetrated the private homes in this study in the summer. Penetration was more of the order of 50% in other buildings and other seasons, decreasing to as low as 20% at one public building in the winter.

4. Normal daily activity, traffic and seasonal factors greatly influenced the measured levels of suspended particulates, both outdoors and, to a lesser extent, indoors.

5. The organic fraction of suspended particulates readily penetrated all structures and significant quantities may have been generated indoors.

6. The lead fraction of suspended particulates outdoors was strongly dependent upon traffic factors and penetrated structures only marginally better than the parent particulate.

7. Soiling index measurements showed low soiling potential in the Hartford area, with 80 to 90% of outdoor levels appearing indoors, except at one public building in winter when indoor concentration dropped to 50% of outdoors.

8. Carbon monoxide readily penetrated all the structures. Anomalies were readily relatable to source and ventilation variables. In air-conditioned buildings, the indoor concentration of CO may be altered by properly phased adjustments in external ventilation.

9. From carbon monoxide measurements there appeared to be little detectable influence of a submerged roadway upon indoor air quality in an air rights structure, other than through its contribution to general pollutant concentration outdoors. In addition, an underlying parking garage had little effect upon indoor air quality in an air-conditioned building located above the garage.

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