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Authors
Hodgson, A.T.
Daisey, J.M.
Grot, R.A.

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A.T. Hodgson, J.M. Daisey, and R.A. Grot

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SOURCES AND SOURCE STRENGTHS OF VOLATILE ORGANIC COMPOUNDS IN A NEW OFFICE BUILDING

October 1990

Alfred T. Hodgson and Joan M. Daisey
Applied Science Division
Lawrence Berkeley Laboratory
Berkeley, CA 94720

and

Richard A. Grot
Center for Building Technology
National Institute of Standards and Technology
Washington, D.C. 20899

Currently with:

Lagus Applied Technology, Inc.
18159 Village Mart Drive, Suite 242
Olney, MD 20832

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ABSTRACT: This study was conducted at a newly constructed Federal office building in Portland, OR. The primary objectives were to identify the major sources of volatile organic compounds (VOC) in the building and to measure both long-term (one year) and short-term (several day) variations in source strengths. Samples for VOC were collected on four occasions over a period of 14 months starting with the first month of occupancy. During the final sampling period, samples were collected over four days (Friday - Monday). The samples were analyzed for individual compounds and for total VOC (TVOC). The results were expressed as specific source strengths, as well as concentrations, to facilitate comparisons of measurements made under different ventilation conditions.

The primary source of VOC in the building was identified as liquid-process photocopiers and plotters which emitted a characteristic mixture of C_{10}-C_{11} isoparaffinic hydrocarbons. The specific source strength of TVOC, which was dominated by the office-machine emissions, remained relatively constant over the course of the study. During the final four-day sampling period, the specific source strength of TVOC varied by about a factor of six with occupancy. The source strengths of many other compounds during those four days were also related to occupant activities. Motor vehicles in the below-ground parking garage were implicated as another major source of hydrocarbons in the building.

INTRODUCTION

Conditioning of ventilation air for office buildings consumes considerable energy. Consequently, recent construction practices have attempted to minimize the amount of conditioned air used for ventilation while still maintaining adequate indoor air quality. At the same time, there have been an increasing number of complaints among workers about nonspecific health problems associated with office environments. Although the etiological agents responsible for these complaints remain largely unknown, it has been hypothesized that volatile organic compounds (VOC) may play a role in producing symptoms such as mucous membrane irritation, headache, nausea, and dizziness.[1]

There are many sources of a large variety of VOC in office buildings (*e.g.*, building and interior finish materials, furnishings, office products, cleaning products and office machines). If it is determined that the concentrations of any VOC which are emitted within a building constitute a potential health problem, the concentrations can be reduced to some extent by increasing the ventilation rate. However, in many cases, source control would be a more effective and energy-efficient strategy. A major impediment to implementing source control measures is that it is first necessary to identify and understand the significant sources of VOC in a building.

This paper presents results from a detailed study of a large, newly constructed, Federal office building.[2,3] The overall study was designed to develop methods for evaluating the thermal and environmental performance of advanced technology buildings. The specific objectives of this portion of the study were to identify the major sources of VOC in the building and to measure both long-term (one year) and short-term (several day) variations in concentrations and source strengths in order to define the emission patterns of those sources.

EXPERIMENTAL

Description of the Building

The study was conducted at a new, Federal office building in Portland, OR. The building was constructed during 1986-1987 and was first occupied in August, 1987. The building has seven above-ground office floors and three basement levels. The basement contains a loading

dock and two and one-half floors of parking garage. A vertical cross section of the building is schematically shown in Figure 1. The building has about 46,000 m^2 of occupied floor space, with approximately 2,000 employees.

A penthouse on the roof of the building houses the air intakes, exhausts and mechanical equipment for the seven office floors. There are three main HVAC systems which serve the east, center and west cores of the building. Each of these systems has a vertical return air shaft connected to the ceiling plenums on all floors. Offices are predominantly open plan with 1.5-m high partitions separating work spaces. However, most floors have some enclosed conference rooms and offices. An enclosed computer facility is located on the second floor. The ventilated volume of the office floors is estimated to be 134,000 m^3 (85 percent of the total volume). The basement floors have their own mechanical systems with air intakes and exhausts at ground level. The basement floors are connected to the office floors by several elevator shafts and stairwells.

Investigators from the National Institute of Standards and Technology (NIST) installed a diagnostic center in the basement connected by a network of cables and sampling tubes to over 100 monitoring points throughout the building.[2] This system was used to monitor wind speed and direction, outdoor temperature, indoor temperature and humidity, indoor and outdoor levels of carbon dioxide (CO_2) and carbon monoxide (CO), and indoor levels of respirable particles in six size ranges. In addition, continuous ventilation rate measurements were made using an automated tracer-gas decay system.[2] The system injected sulfur hexafluoride into the building supply fans every two or three hours, allowed the tracer gas to mix and then monitored the decay in tracer-gas concentrations typically on each office floor and in the return-air shafts. Average ventilation rates calculated for the building had coefficients of variation of about ten percent.

The NIST investigators also conducted a questionnaire survey of a sample of the occupants after their move into the building.[3] The purpose was to determine the effects of office design features on job performance and satisfaction. About 20 percent of the respondents rated "air quality" in the building as poor. Almost 30 percent were disturbed by air "stuffyness". Odors did not seem to be a problem. The most frequent health-related worker complaint was difficulty in concentration. Complaints of eye irritation, headache and sleepiness were additionally elevated over estimated neutral responses.

Sampling and Analysis for VOC

Samples of VOC in indoor and outdoor air were collected during four periods over 14 months. The first samples were collected in August, 1987 just as building occupancy began. Subsequent samples were collected in October, 1987, January, 1988, and October, 1988. In October, 1988, samples were periodically collected over a four-day period from Friday through Monday.

The details of the sampling and analysis methods for VOC have been previously described.[4,5] In brief, air samples for VOC analysis were collected on multisorbent samplers (Part No. ST032, Envirochem, Inc., Kemblesville, PA) which are packed in series with Tenax-TA, Ambersorb XE-340 and activated charcoal. These samples were collected in duplicate or triplicate from the return air shafts at the penthouse level, from office spaces and from outdoor air on the roof of the building. The volumes of indoor samples were typically 1-3 L collected at a rate of 100 cm^3 min^{-1}.

Samples were thermally desorbed with a UNACON Model 810A (Envirochem, Inc.) sample concentrating and inletting system and introduced into a capillary gas chromatograph (GC) connected via a direct interface to a Series 5970B Mass Selective Detector (MSD, Hewlett

Packard Co.). For quantitative analyses, the MSD was operated to monitor multiple, individually selected ions. Concentrations are given as mass of compound per m^3 (20° C, 1 atm). During the thermal desorption procedure, eight percent of each sample was split off and analyzed directly, without chromatographic separation, by a flame-ionization detector (FID) to give a measure of the total of C_4 and higher molecular weight hydrocarbons in the sample. This measure has been termed total volatile organic carbon (TVOC), and results are given as mass of carbon per m^3 (20° C, 1 atm). The FID was calibrated with a mixture of C_9-C_{11} normal alkane hydrocarbons. Coefficients of variation for the quantitative measures of individual compounds and TVOC were typically better than ten percent.

Source Strengths of VOC

To facilitate comparisons of measurements made at definite times under different ventilation conditions and comparisons between this and other buildings, results have been expressed as apparent specific source strengths, S/V (mg/m^3-h), as well as concentrations. Apparent specific source strengths were calculated using a single-equation, steady state mass-balance model.[5] This model assumes perfect mixing of air in an enclosed volume. It was also assumed that removal processes other than ventilation were negligible. At steady-state conditions, the source strength, S (mg h^{-1}), of a pollutant is:

$$S = V a (C - C_o), \qquad (1)$$

where V is the ventilated volume (m^3), a is the ventilation rate (h^{-1}), and C and C_o are the indoor and outdoor concentrations (mg m^{-3}), respectively.

MAJOR SOURCES OF VOC

Potential sources of VOC were identified by a walk-through survey. Some of the sources thus identified were building interior finish materials (carpet tiles, carpet spray adhesive, vinyl base cove molding and adhesive, rubber floor tile and adhesive), furnishings, office products, and liquid-process photocopiers and plotters. In October, 1988, 26 copiers and three plotters were observed throughout the building with three or more machines on each of the seven floors. Some of the machines were located in small rooms in the core of the building. Many, however, were located in open office areas.

Both the copiers and the plotters use a common solvent as a clear dispersant and in their toner premixes. A major manufacturer's trade name for this solvent is Isopar G (Exxon Corp.). It is a manufactured product consisting of a mixture of C_{10} and C_{11} isoparaffinic hydrocarbons with a specific gravity of 0.75 and a boiling point range of 155-176°C. The GC-MSD scan analysis of plotter dispersant presented in Figure 2 shows that this product contains at least 20 major compounds. The figure also compares the composition of a portion of an indoor air sample collected in the building to the composition of the dispersant. All of the peaks in the air sample between 33.8 and 37.2 minutes correspond to the peaks in the dispersant based on matching retention times and mass spectra. There is, however, an unexplained difference in the ratios of the peak areas of the individual compounds to the total peak areas of the two samples between 33.8 and 37.2 minutes. That is, the lower molecular weight compounds were depleted in concentration in the air sample relative to the dispersant fluid. This difference may be due to processes that occur within the machines.

A supplies inventory indicated that 147 L of copier dispersant and toner premix were used in the building over a period of about 55 working days. This suggests that the average solvent

usage for copiers alone was approximately 2.7 L day^{-1} or 2 kg day^{-1}. Thus, copiers and plotters were found to be a major source of VOC in this building.

Motor vehicles were another probable source of the VOC in the office levels. The basement loading dock and parking garage levels are served by their own air-handling systems. However, during the fall and winter of 1987-1988, occasional incidents of significantly elevated CO concentrations (>10 ppm) from vehicle exhaust were measured in the upper building due to the flow of air from the basement levels up the elevator shafts and stairwells.[2] Subsequently, control of the garage exhaust fans was modified so that the fans operated continuously during occupied hours rather than intermittently as before. This reduced, but did not completely eliminate, the transport of CO to the upper building.

A number of light hydrocarbons (C_5-C_8) and aromatic hydrocarbons which are characteristic components of vehicle exhaust (2-methylbutane through 2,2,4-trimethylpentane and toluene through trimethylbenzene in Table I)[6-8] were identified and quantified in the building. Table I shows that the relative composition of these compounds in indoor air remained approximately constant throughout the study. The indoor composition of these compounds was similar to the composition in outdoor air sampled on the roof, although indoor concentrations were distinctly higher (Table II), indicating an indoor source.

Samples of new, unused interior finish materials (carpet tiles, carpet spray adhesive, vinyl base cove molding and adhesive, and rubber floor tile) were obtained from the building at the end of the construction period. The emissions of VOC from these materials were qualitatively determined using small-volume chambers. The dominant compounds emitted by these materials were not major constituents of the indoor air samples. Consequently, the contributions of these sources to concentrations of TVOC in the building appeared to be minor relative to liquid-process office machines and motor vehicles.

LONG-TERM TEMPORAL VARIATIONS

Variations in indoor concentrations and specific source strengths of individual compounds on the four sampling periods over the 14-month study are presented in Table I. The concentrations of Isopar "2", a C_{10} branched-chain alkane which is one of the more than 20 components of Isopar G, was estimated as n-decane and was used as a tracer for the entire Isopar mixture. (The many isoparaffinic hydrocarbons in the mixture could not be accurately quantified due of the lack of authentic standards for such compounds.) Concentrations of VOC in those samples which were collected after the regular work day may be less than the maximum values for those days, since the major sources of VOC were related to occupant activities (*e.g.*, use of photocopiers). Temporal variations in the concentrations and specific source strengths of TVOC are shown in Figure 3, and temporal variations in the major classes of compounds are shown in Figure 4.

In general, there was an inverse relationship between concentrations and ventilation rate with the highest concentrations of individual compounds, classes of compounds and TVOC most often occurring in January, 1988, when the ventilation rate was the lowest (0.24 h^{-1}). The concentration of TVOC on this date was 11 mg m^{-3}.

Specific source strengths of TVOC were nearly identical in the first three sampling periods and were somewhat higher in the final sampling period. This pattern of long-term variation in specific source strengths indicates that the major sources of VOC were regular occupant activities rather than building interior finish materials whose source strengths would be expected to decrease with time. Since the chromatograms clearly showed that TVOC was dominated by the Isopar mixture, this similarity in source strengths suggests fairly uniform use of copiers and plotters over the course of the study. Assuming that these values were typical

for an eight-hour work day, the range of source strengths would be 2.6 to 4.6 kg day^{-1} which is consistent with the estimated solvent usage rate for copiers alone of 2 kg day^{-1}.

The C_5-C_8 aliphatic hydrocarbons and the aromatic hydrocarbons had higher specific source strengths in the two October sampling periods when the ventilation rates were highest, as shown in Figure 4. It is probable that this was due to an increased flow of air from the basement levels into the office levels at this ventilation condition. There are often large stack effects in multi-story buildings, which can lead to depressurization at lower levels. This depressurization can provide a strong driving force for transport of pollutants from the parking garage into the office levels.

The source strength of C_9-C_{14} straight-chain aliphatic hydrocarbons was highest in January, 1988 (Figure 4). From Table I, it can be seen that this increase was due largely to increased source strengths of n-undecane (C_{11}) and n-dodecane (C_{12}). These are not components of the Isopar mixture and the reason for the increased source strengths is not known and could not be determined. The elevated source strengths of oxygenated and chlorinated compounds in the final sampling period (Figure 4) were due to 2-propanol, 2-propanone and trichloroethylene (see Table I) whose sources may have been products used in the building. With the exceptions of 2-butanone and dichloromethane, there was no general decrease in source strengths with increased building age as would be expected if building and interior finish materials and furnishings were the dominant sources of VOC.

SHORT-TERM TEMPORAL VARIATIONS

Short-term variations in concentrations of VOC were investigated over the four-day period (Friday - Monday) from 28-31 October, 1988. Data for individual compounds are presented for Friday afternoon in Table II as an example of the samples collected over this period. The concentrations of four individual Isopar compounds (Isopar "1-4") were estimated as n-decane or n-undecane. The variation in the average ventilation rate during this period is shown in Figure 5. The maximum ventilation rate was approximately 2 h^{-1}, which is near the maximum design value for the building.[2] When the ventilation system and other exhaust fans were off at night, the ventilation rate decreased to about 0.2 h^{-1}, which represents infiltration through the building shell. During this period, the ventilation system was operated on Friday evening until midnight and for 6-8 hours during the day on Saturday and Sunday, which was atypical.

The variations over the four-day period in the specific source strengths of TVOC, the sum of the individual compounds, and the sum of the four Isopar compounds whose concentrations were estimated are shown in Figure 6. These source strengths were calculated using concentrations measured in the central return-air shaft and on the roof. Since the chromatograms were dominated by the Isopar mixture, much of the difference in source strengths between TVOC and the sum of the individual compounds was due to the more than 16 Isopar compounds which were not individually quantified. The data show that the source strengths on Friday were at a maximum and approximately equal in mid-morning and mid-afternoon. On the following Monday, the mid-morning source strengths significantly exceeded the afternoon values. Source strengths were lowest at night and during the weekend reflecting the low level of occupancy and activity in the building at these times. The specific source strength of TVOC during the weekend averaged about 1 mg/m^3-h which is equal to a source strength of about 3 kg per 24 hours. This compares to an estimated total source strength on Friday of about 9 kg and demonstrates that the major sources of VOC were associated with occupant activities. Since there was no major qualitative difference between weekday and weekend emissions, emissions during the weekend may have been primarily due to the re-emission of VOC sorbed onto surfaces in the building.

Variations in the specific source strengths of the other major classes of compounds over the four-day period are shown in Figure 7. The C_9-C_{14} straight-chain aliphatic hydrocarbons and the chlorinated hydrocarbons had emission profiles which were similar to TVOC, suggesting that their sources were also related to occupant activities. The source strengths of the C_5-C_8 aliphatic hydrocarbons and the aromatic hydrocarbons had somewhat different profiles with elevated mid-morning and low mid-afternoon values on both Friday and Monday. The observed short-term temporal variations are consistent with motor vehicle exhaust from the garage as a source of these compounds. The high source strength of oxygenated compounds on Sunday was due solely to 2-propanone (acetone) whose source was not identified.

SPATIAL VARIATIONS

Spatial variations in the concentrations of individual compounds and TVOC in the building on Friday, October 28, 1988, are shown in Table II. Samples were collected in the three return-air shafts and in an office cubicle on the fifth floor over a period of about one hour with the building operating at a ventilation rate of 2 h^{-1}. Coefficients of variation for concentrations of individual compounds in the three air shafts were, with several exceptions, less than ten percent. Coefficients of variation for the sum of the compounds and TVOC were seven and eight percent, respectively. Concentrations in the office were in good agreement with average concentrations in the air shafts. This uniformity of concentrations indicates that the air in the building was well mixed at this ventilation condition. This mixing was aided by the mechanical recirculation of air among the office floors. Mixing at lower ventilation rates would be expected to be as good or better since a larger percentage of air would be recirculated among the floors under such conditions.

SUMMARY AND CONCLUSIONS

This study demonstrated the utility of a mass-balance model for evaluating sources of VOC in office buildings. Because indoor and outdoor concentrations of VOC and ventilation rates were concurrently measured, it was possible to express the results for VOC as apparent specific source strengths. This allowed comparisons to be made over both long and short time periods even though the ventilation rates at the times of measurement varied considerably.

The major sources of VOC in this building were found to be related to occupant activities. Therefore, the source strengths of most VOC did not decrease as the building aged as would be expected if building and interior finish materials and furnishings were the major sources of these compounds. The dominant source of VOC was liquid-process photocopiers and plotters which emitted a characteristic mixture of C_{10}-C_{11} isoparaffinic hydrocarbons. Tsuchiya also found exhaust vapors from liquid-process photocopiers to be a common and major source of these VOC in office buildings.[9] Vehicles operating in the basement levels were the probable major source of the aromatic hydrocarbons and the other predominant aliphatic hydrocarbons in the building.

It is not known if the air quality and health complaints recorded for this building are atypical for office buildings in the U.S. or if they are related in anyway to concentrations of VOC.

In general, the light hydrocarbons such as the dominate VOC in this building are considered to have low toxicity. For example, the occupational threshold limit values for exposures to nonane and gasoline are 200 ppm (1050 mg m^{-3}) and 300 ppm (900 mg m^{-3}), respectively.[9] The toxicological data for isoparaffinic hydrocarbons recently have been

summarized.[10] These data indicate that both the acute and chronic toxicity of isopariffins in animals and humans are very low.

In one human inhalation exposure study, 12 volunteers were exposed for six hours to 100 ppm (~600 mg m^{-3}) C_8-C_{11} isoparaffins.[11] Sensory perception was evaluated by a questionnaire. No symptoms associated with solvent exposure were observed, including dryness of mucous membranes, headache, fatigue, or nausea.

In another study of human reactions, the effects of inhalation exposure to n-decane were investigated.[12] This study demonstrated measurable effects at concentrations that were an order of magnitude lower. Sixty-three randomly selected subjects were exposed in double blind experiments to concentrations of 0, 10, 35 and 100 ppm (1 ppm = 5.82 mg m^{-3}). A significant dose-effect relationship was found in all exposed groups for questions concerning air quality. The effect decreased during the exposure period indicating adaptation. Tear-film stability, an indicator of eye dryness, also showed decreasing values with increasing exposure.

If it is determined that concentrations of VOC in a building should be limited to some maximum level for health and comfort reasons, identification of the sources of VOC is the necessary first step in developing appropriate control strategies. Since the sources in this building were occupant related, increasing the minimum ventilation during occupied hours without modifying the source activities would reduce maximum concentrations. A more energy-efficient strategy for maintaining low concentrations would be to alter the way the building's systems handle sources. Since the air in the building is well mixed, this might mean establishing enclosed locations for essential liquid-process office machines with exhaust ventilation directly to the outside. The feasibility and cost of such a retrofit approach has not been studied. A practical, energy-efficient strategy for reducing the transport of pollutants from the garage to the office floors is less obvious.

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Table I. Long-term variations in the concentrations and specific source strengths of individual VOC.

		CONCENTRATION ($\mu g/m^3$) *				SP. SOURCE STRENGTH ($\mu g/m^3$-h)			
	Date:	8/4/87	10/14/87	1/13/88	10/28/88	8/4/87	10/14/87	1/13/88	10/28/88
	Time:	20:00	17-19:00	15-17:00	15-17:00	20:00	17-19:00	15-17:00	15-17:00
Vent.	Rate:	0.5	1.36	0.24	1.99	0.5	1.36	0.24	1.99
COMPOUND									
Oxygenated									
2-Propanol		14.8	20.2	137.2	26.5	5.8	21.9	31.6	52.6
2-Propanone (acetone)		50.1	28.8	66.6	32.4	22.1	27.0	14.9	49.7
2-Butanone		40.9	6.2	15.3	5.7	19.0	2.5	2.0	7.6
Chlorinated									
Dichloromethane		32.4	2.6	13.4	2.7	15.9	1.3	2.7	5.4
1,1,1-Trichloroethane		13.5	13.8	119.7	17.1	5.4	13.6	27.5	27.0
Trichloroethene		16.4	7.2	58.2	14.8	8.2	9.7	11.0	27.6
Aliphatic									
2-Methylbutane		31.9	53.8	81.6	26.2	13.1	31.7	16.1	44.7
n-Hexane		11.3	10.0	24.0	9.2	5.7	6.7	3.7	14.6
Cyclohexane		5.7			2.7	2.4			4.2
n-Heptane		4.8	3.1	12.6	3.6	2.0	2.7	0.2	5.5
3-Methylhexane		6.0	4.0	14.7	3.5	2.4	3.1	0.0	5.2
Methylcyclohexane		5.1			1.7	2.4			2.5
2,2,4-Trimethylpentane		2.4	1.8	8.0	3.0	1.0	1.3	0.7	6.0
1,4-Dimethylcyclohexane		3.1				1.6			
n-Nonane		39.6	10.6	149.1	33.9	19.7	11.4	35.3	63.0
2,2,5-Trimethylhexane		2.4				1.2			
Isopar "2" **		147.0	82.5	638.7	95.4	72.8	104.2	151.7	179.7
n-Undecane		115.6	57.3	831.3	48.3	55.2	71.3	196.8	85.7
n-Dodecane		49.1	10.6	280.8	10.9	21.8	5.9	67.0	17.6
n-Tridecane			6.0	111.9	8.5		5.8	26.2	13.8
n-Tetradecane			36.1	245.3	27.0		43.0	57.9	49.5
Aromatic									
Toluene		60.4	81.3	91.0	33.1	22.7	80.9	13.7	50.2
Ethylbenzene		11.8	7.0	18.7	7.5	5.3	4.9	2.3	11.4
1,2-Dimethylbenzene		17.2	8.7	25.8	8.1	7.6	5.8	4.1	12.0
1,3-,1,4-Dimethylbenzene			18.1	54.5	18.3		11.7	8.8	26.6
1,3,5-Trimethylbenzene		4.1				1.6			
TOTALS									
Sum of Individual VOC		685	470	2998	440	315	466	674	762
TVOC		5200	1900	11000	2300	2500	2400	2500	4300

* Average concentration for return-air shafts

** Estimated concentration using n-decane as standard

Table II. Concentrations of VOC in mechanical system air, indoor air and outdoor air on the afternoon of Friday, October 28, 1988.

	Concentration ($\mu g/m^3$)					
	Return Fans					
Time:	East 15:51	Center 15:16	West 16:25	Return Fan Average	Floor 5 15:38	Roof 14:42
COMPOUND						
Oxygenated						
2-Propanol	38.8	19.1	21.5	26.5	13.1	0.0
2-Propanone (acetone)	33.9	31.2	32.2	32.4	27.9	7.4
2-Butanone	5.2	5.3	6.6	5.7	5.0	1.9
Chlorinated						
Dichloromethane	2.8	2.7	2.6	2.7	2.0	0.0
1,1,1-Trichloroethane	15.8	18.3	17.2	17.1	15.0	3.5
Trichloroethene	16.0	15.4	13.1	14.8	15.9	0.9
Aliphatic						
2-Methylbutane	30.2	30.2	18.3	26.2	35.8	3.8
n-Pentane	13.2	17.8	11.5	14.2	21.1	2.7
n-Hexane	9.4	9.7	8.4	9.2	10.9	1.8
Cyclohexane	2.8	2.8	2.4	2.7	3.2	0.6
n-Heptane	3.7	3.8	3.3	3.6	3.6	0.8
3-Methylhexane	3.6	3.5	3.3	3.5	5.1	0.9
Methylcyclohexane	1.8	1.8	1.6	1.7	2.0	0.4
2,2,4-Trimethylpentane	3.1	3.1	2.8	3.0	4.4	0.0
n-Nonane	33.2	40.4	28.0	33.9	37.2	2.2
Isopar "1" *	133.6	155.4	134.3	141.1	139.5	7.7
Isopar "2" *	94.5	110.5	81.1	95.4	98.0	5.1
Isopar "3" *	221.1	240.9	198.2	220.1	250.6	11.1
Isopar "4" *	278.5	297.6	248.1	274.8	306.1	13.9
n-Undecane	52.9	47.7	44.5	48.3	56.2	5.3
n-Dodecane	9.9	12.2	10.6	10.9	13.3	2.0
n-Tridecane	7.3	7.6	10.5	8.5	9.5	1.6
n-Tetradecane	28.3	27.4	25.2	27.0	62.3	2.1
Aromatic						
Benzene	15.3	15.0	15.0	15.1	18.7	4.7
Toluene	33.4	34.8	31.1	33.1	41.0	7.9
Ethylbenzene	7.3	7.8	7.3	7.5	7.8	1.8
1,2-Dimethylbenzene	8.2	8.2	7.9	8.1	10.0	2.1
1,3-,1,4-Dimethylbenzene	18.7	18.2	18.0	18.3	24.0	4.9
Methylethylbenzene	11.4	11.1	11.2	11.2	13.6	2.9
1,2,4-Trimethylbenzene	10.6	10.7	10.5	10.6	12.6	2.7
1,4-Diethylbenzene	8.6	8.7	8.5	8.6	9.1	2.1
TOTALS						
Sum of Individual VOC	1153	1219	1035	1136	1275	105
TVOC	2348	2537	2061	2315	2163	143

* Estimated concentration using n-decane or n-undecane as standards

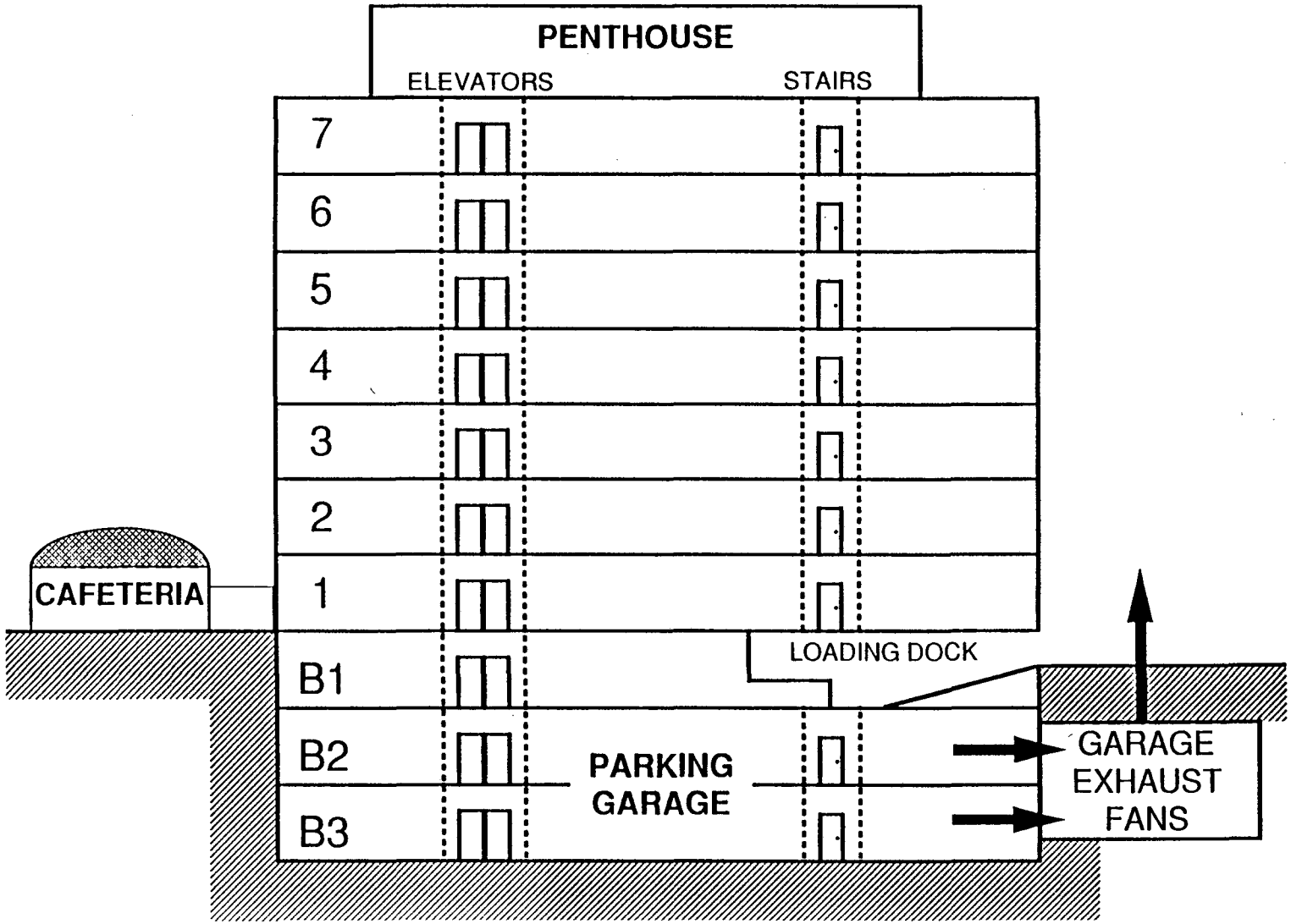

Figure 1. Schematic of a vertical cross section of the building.

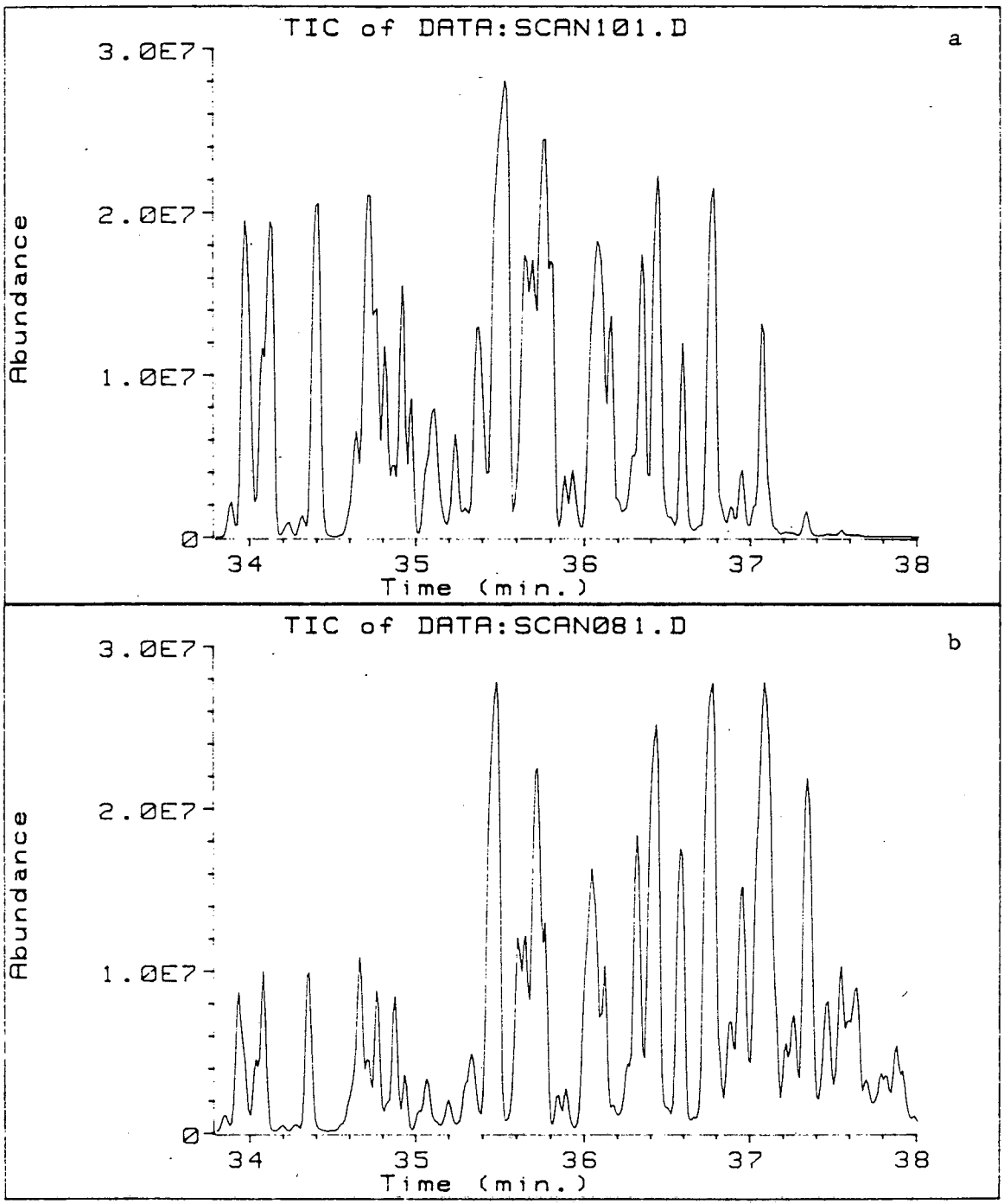

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Figure 2. Comparison of a portion of the total ion chromatogram for a dispersant from a liquid-process plotter (a) with a corresponding portion for an indoor air sample (b).

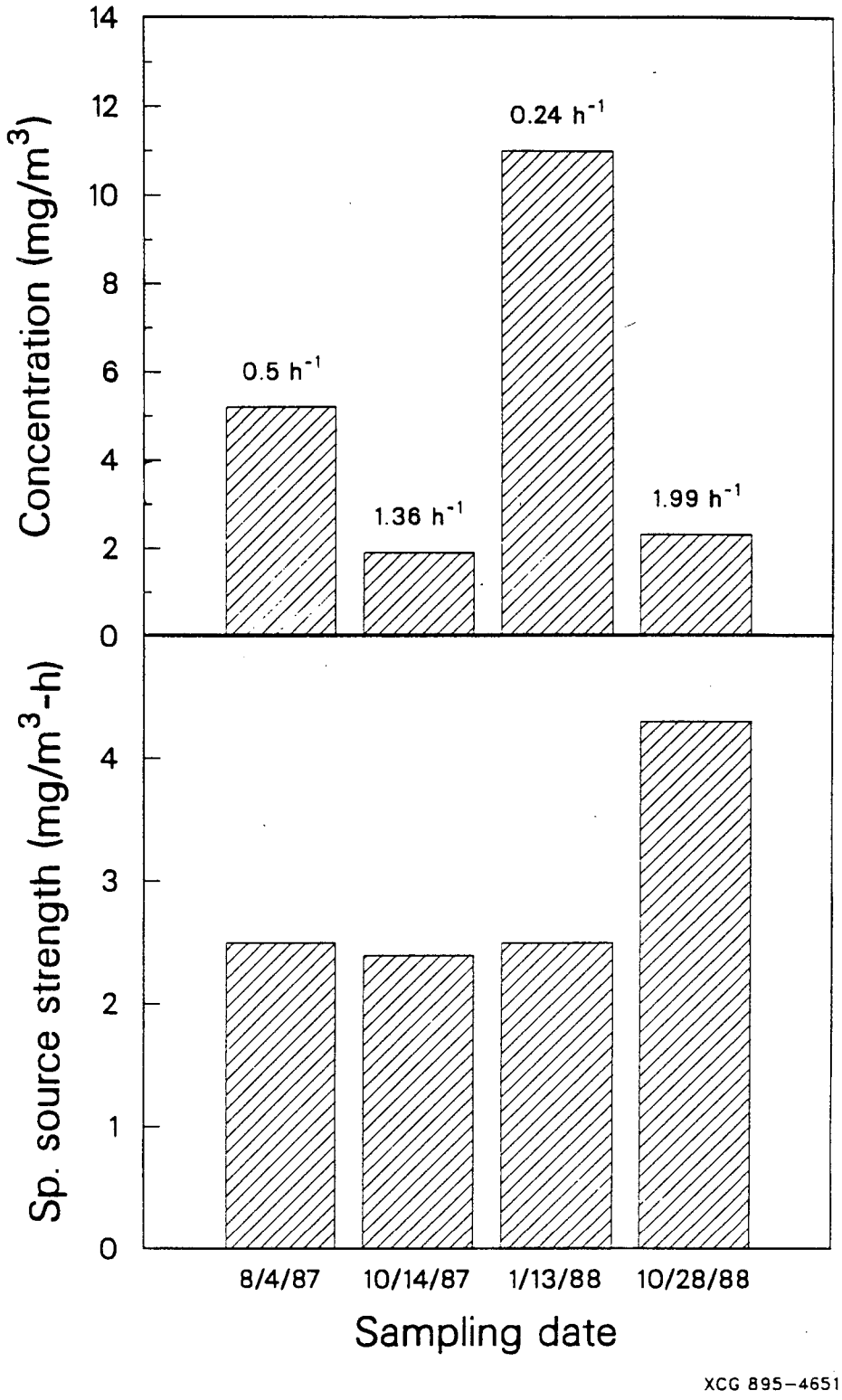

Figure 3. Long-term variations in the concentration and specific source strength of TVOC. Ventilation rates are shown above the concentration bars.

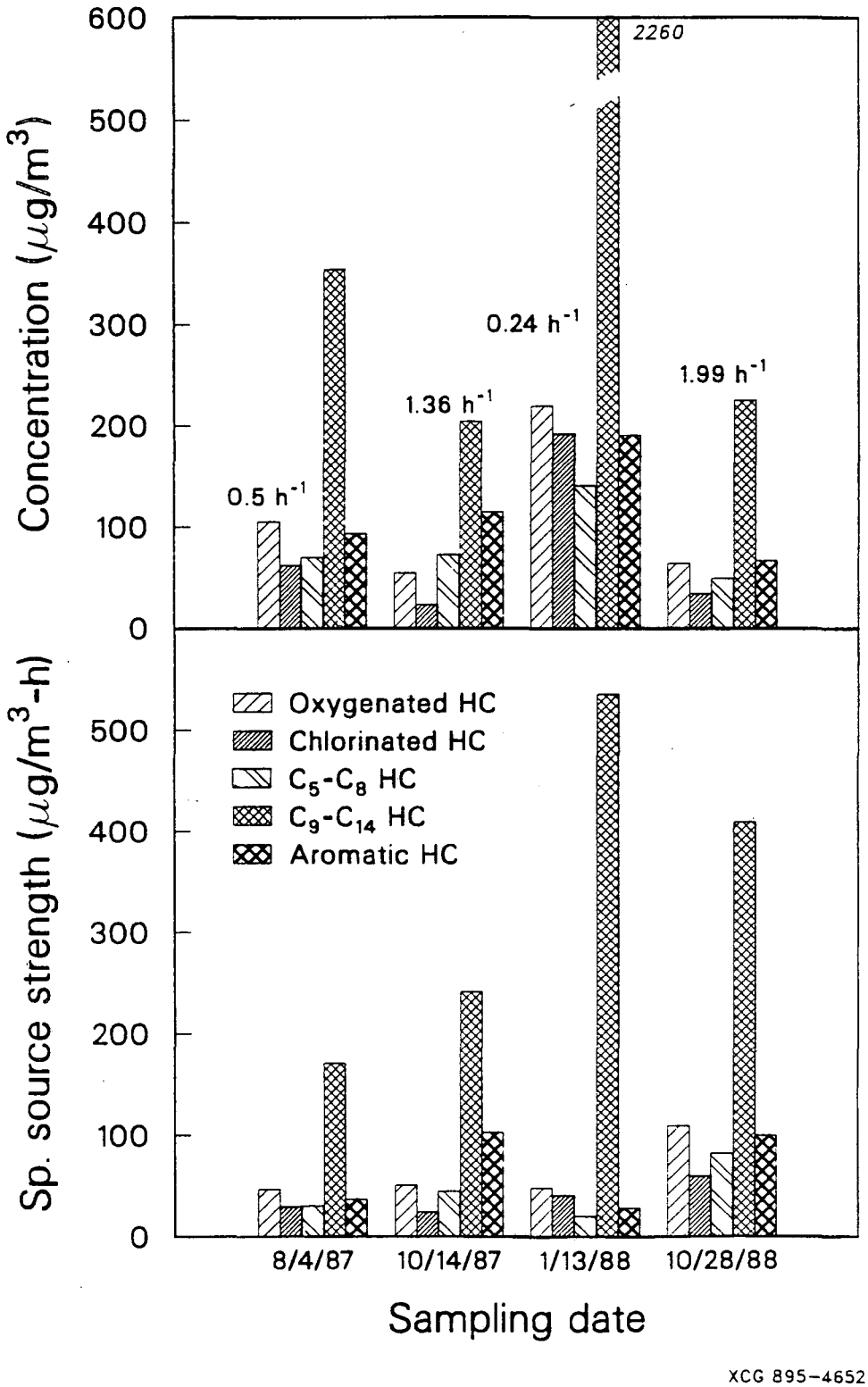

Figure 4. Long-term variations in the concentrations and specific source strengths of the major classes of VOC. Ventilation rates are shown above the concentration bars.

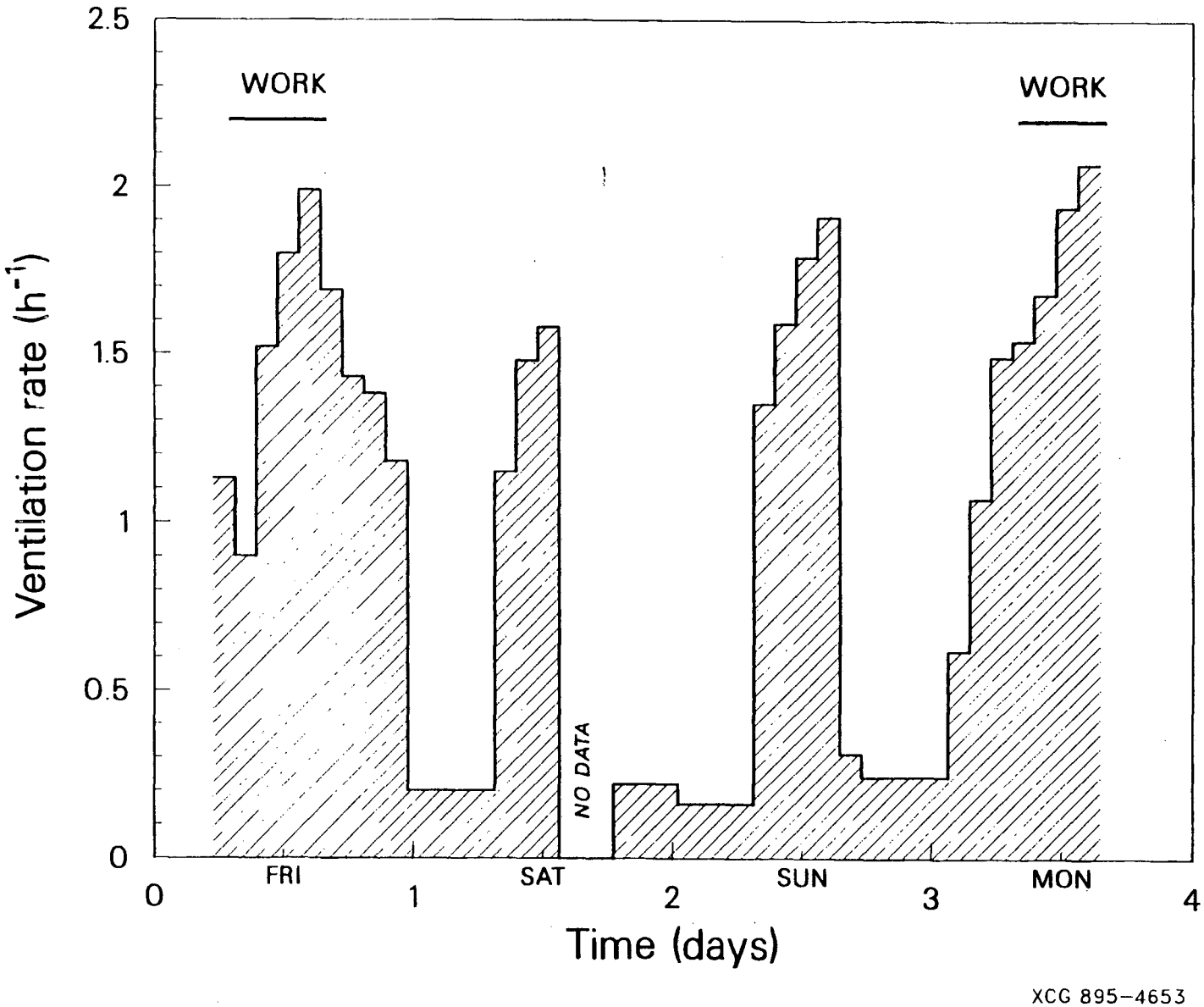

Figure 5. Average ventilation rate over a four-day period (Friday - Monday). Work-day durations are shown as horizontal bars.

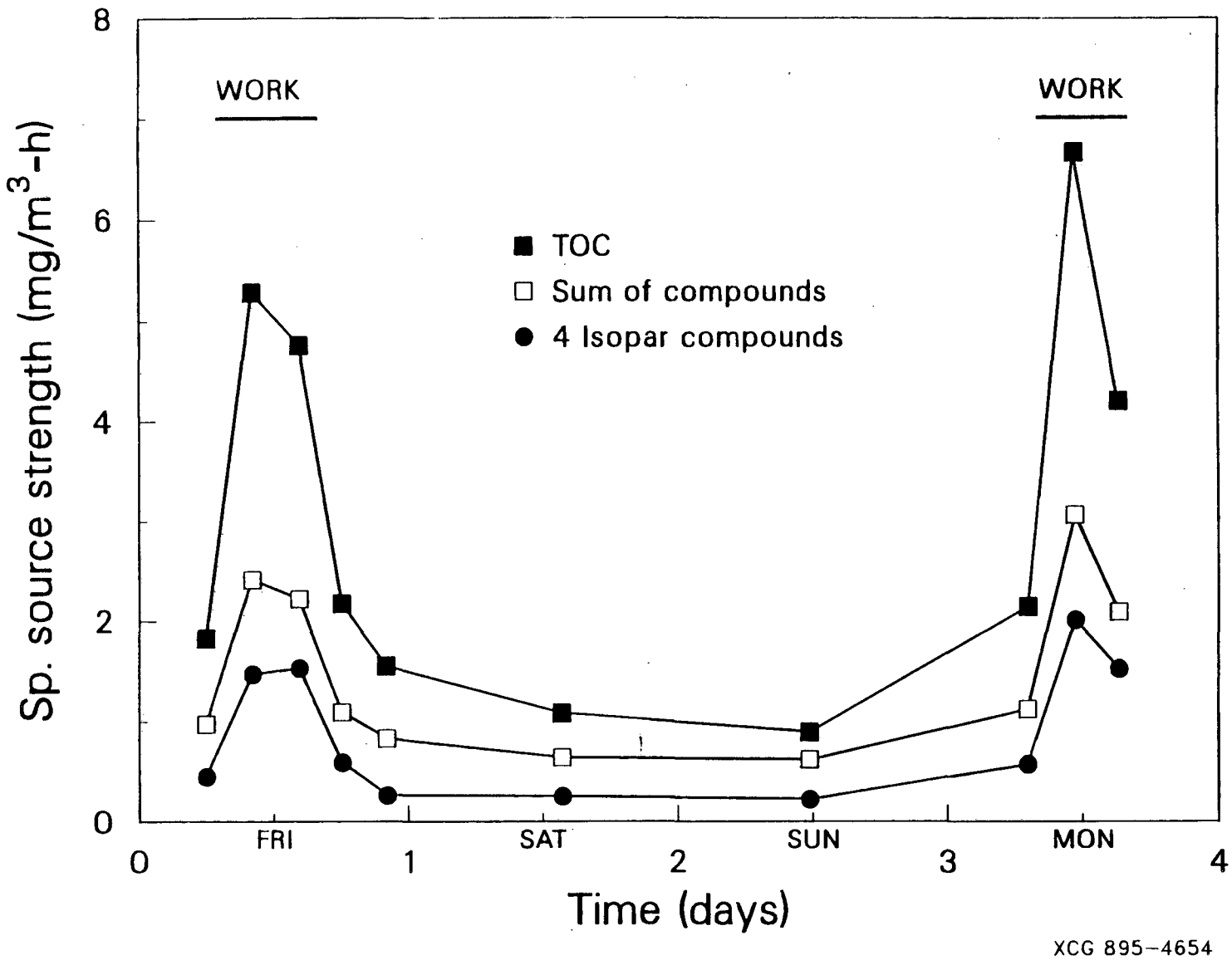

Figure 6. Variations in the specific source strengths of TVOC, the sum of individually quantified VOC, and four Isopar compounds over a four-day period. Work-day durations are shown as horizontal bars.

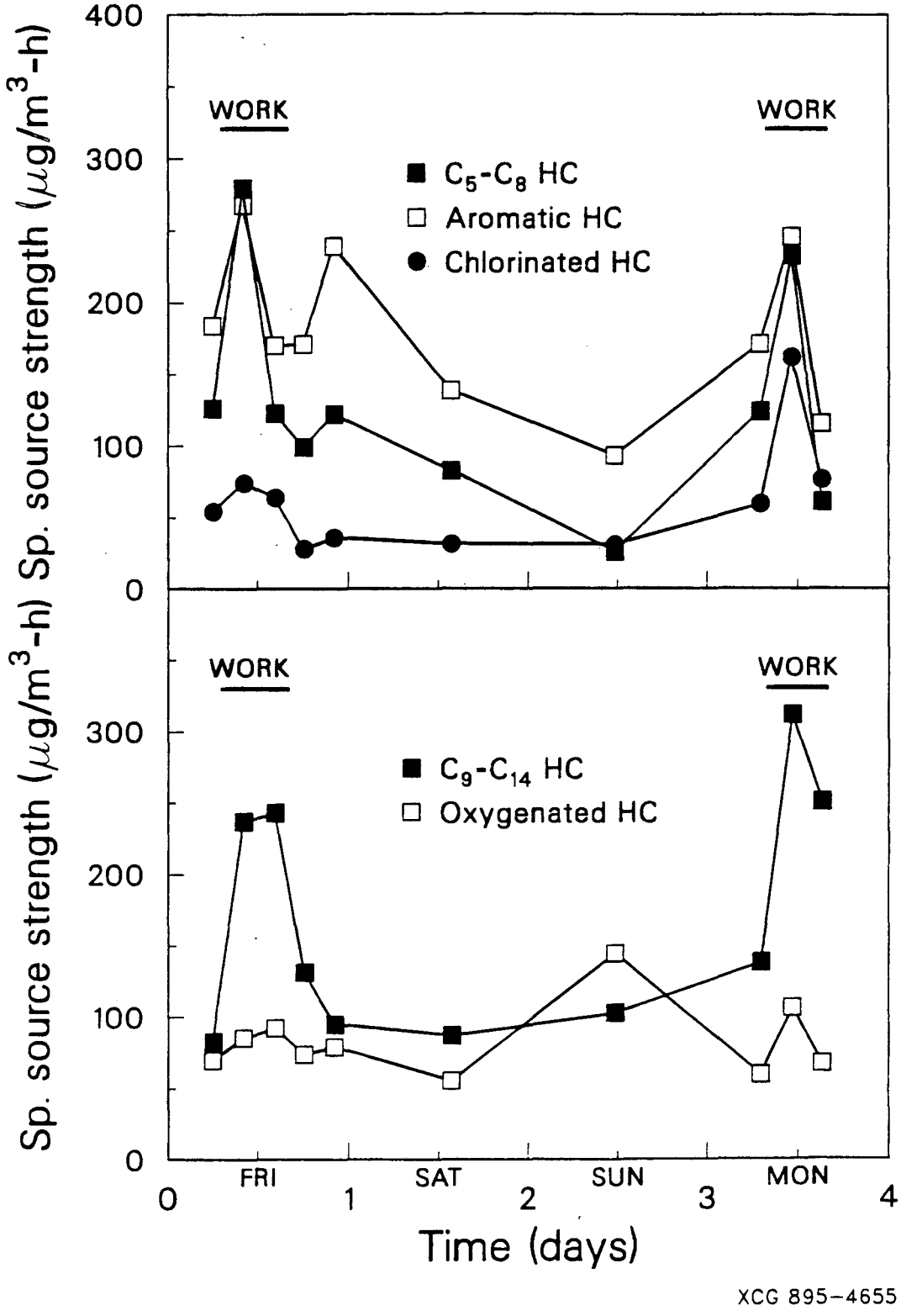

Figure 7. Variations in the specific source strengths of the major classes of VOC over a four-day period. Work-day durations are shown as horizontal bars.

LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
INFORMATION RESOURCES DEPARTMENT
BERKELEY, CALIFORNIA 94720