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SUMMARY

On May 8, 1990, the National Institute for Occupational Safety and Health (NIOSH) received a request for a Health Hazard Evaluation (HHE) from employees of the AMP Incorporated facility in Berwyn, Pennsylvania, who alleged that some of the workers in the Sales-Service office area of the facility's 400 Building had often complained of excessive headaches and upper respiratory symptoms which, in many cases, resolved upon leaving work. The requestors, who also complained about thermal comfort and air circulation in the area, asked NIOSH to determine if the building had indoor environmental quality (IEQ) problems which could account for the complaints. On February 6 and 7, 1991, NIOSH investigators conducted an IEQ survey in the building.

A visual inspection of the building and of the heating, ventilation, and air-conditioning (HVAC) systems serving its northern portion (where the relevant areas are located), and an evaluation of the HVAC design specifications and features, revealed environmental tobacco smoke (ETS) in the cafeteria (the designated "smoking" area at the time of the survey) and the possibility that ETS-containing air may be recirculated by the systems from the cafeteria to the other areas in the northern portion. The HVAC-design evaluation also revealed that the existing design-specified minimum ventilation (outside-air exchange) rates were insufficient under most operating conditions, compared to current, recognized ventilation standards, for the occupied spaces in the northern portion. The actual ventilation effectiveness of the HVAC systems at the time of the survey was found to be inadequate based on measured airborne carbon dioxide (CO_2) concentrations, which act as a secondary indicator of that parameter. Concentrations in the northern portion of the building rose from about 725 ppm in the morning to over 1000 ppm in the afternoon (compared with the 1000-ppm NIOSH guideline for this parameter). Measurements of thermal comfort parameters there revealed that most air temperatures ranged from 77.0°F to 81.3°F, above recommended comfort ranges. Finally, air sampling for possible chemical contaminants revealed traces of several organic compounds, at concentrations below those expected to cause health complaints.

Although factors such as insufficient ventilation rates and slightly elevated temperatures may impact upon the IEQ in this building, the findings of this evaluation cannot substantiate these or other factors as causative in relation to the alleged complaints and symptoms. However, the presence of ETS in the cafeteria constitutes a potential chronic health hazard regardless of the extent (if any) to which it contributes to the complaints. Recommendations include increasing ventilation rates and establishing a separate smoking lounge.

Keywords: SIC 5063 (electrical products -- wholesale trade), air temperature, tobacco smoke, indoor environmental quality, ventilation, carbon dioxide.

BACKGROUND AND INTRODUCTION

On May 8, 1990, the National Institute for Occupational Safety and Health (NIOSH) received a confidential request for a Health Hazard Evaluation (HHE) from employees of the AMP Incorporated facility in Berwyn, Pennsylvania. These requestors alleged that some of the approximately 100 sales correspondents and others working in the Sales-Service office area of the facility's 400 Building had often complained of excessive headaches, runny noses, coughing, lost voices, and bronchial symptoms which, in many cases, resolved upon leaving work. They also complained of poor thermal comfort and a feeling of inadequate air circulation in the Sales-Service office area. These employees asked NIOSH to investigate the facility's indoor environmental quality (IEQ) to determine if airborne contaminants and/or other problems were present which could account for the alleged symptoms and complaints. An environmental survey was conducted at the facility by NIOSH investigators on February 6 and 7, 1991. At the time of the survey, AMP officials asked the NIOSH investigators to include the cafeteria, which was the only area in the building where cigarette smoking was permitted, in the evaluation. On January 27, 1992, an interim letter summarizing the results of this HHE was sent to the concerned parties, both management and employee.

FACILITY DESCRIPTION

GENERAL DESCRIPTION

The Sales-Service office area and the cafeteria, along with other offices, a computer room, and a few other ancillary rooms (e.g., restrooms, a coatroom, etc.) are located in the northern portion of the single-story 400 Building (see Figure 1). The remainder of the 400 Building is occupied by a large warehouse and some additional offices.

The northern portion of the building, with over 20,000 square feet of floor space, contains workspace for an estimated maximum of 162 employees, including 110 in the Sales-Service office area and 50 in the other office space at the west end of this portion of the building (based upon the number of workstations and small office areas shown in a recent building plan [see Figure 1]). At the time that the HHE request was made, over 100 employees reportedly worked in the northern portion including approximately 100 in the Sales-Service area alone. At the time of the NIOSH survey, workloads had reportedly declined and the space was occupied by about 98 employees (at least 80 worked in the Sales-Service office area, and about 18 worked in the other office space at the west end of this portion of the building).

Most of the northern portion of the building was built in 1979 as an addition to an existing structure, while the remainder of it is a part of the original structure and was remodelled at the time of the 1979 addition (see Figure 1).

DESCRIPTION OF FACILITY'S HEATING, VENTILATION, AND AIR-CONDITIONING SYSTEMS

Heating, ventilation, and air conditioning (HVAC) in the 400 Building is provided by several different systems. With the exception of the computer room, the entire northern portion of the building is served by a ventilation and air-conditioning system which includes air-handling-unit (AHU) AC-1 (see Figure 1). This system provides mechanical ventilation to the areas it serves by inducting outside air (o.a.) through o.a.-intake openings on AC-1 and supplying to these areas, at variable rates, "supply air" (s.a.) that consists of at least 10% o.a. (according to the system's design specifications). The system is described in more detail in Appendix A. Perimeter areas and the two restrooms in this portion of the building are additionally served by several separate heating systems, but none of these provide mechanical ventilation (o.a. exchange).

Mechanical o.a. exchange in the northern portion of the building is also facilitated by exhaust fans which discharge above the roof. The two restrooms are served by a single exhaust system which has one fan with a design-specified flowrate of 1000 ft^3/min (cubic feet per minute, or cfm). Air from adjacent areas enters the restrooms to make up for the exhausted air, since they are not supplied air directly from the ventilation and air-conditioning system. At the time of the NIOSH survey, the cafeteria (which had been designated as the "smoking area") also had an exhaust fan to help remove cigarette smoke. No design specifications were available for this fan, but, judging by the appearance of the system, its exhaust-air flowrate is probably a few hundred cubic feet per minute. Aside from normal infiltration and exfiltration through doors, small cracks and crevices, etc., these exhaust systems and the o.a.-intake openings on AHU AC-1 are the only provisions for o.a. exchange in the northern portion of the building. The windows do not open.

The air-handling systems (ventilation and air-conditioning, as well as heating) that serve the northern portion of the building do not serve the warehouse or the older section of offices along the western side of the building (see Figure 1); those areas are served, respectively, by individual oil-fired unit heaters and exhaust fans, and by completely separate air-handling systems. Therefore, the only air exchange between the areas is through doorways and similar openings.

EVALUATION CRITERIA

NIOSH investigators have completed over 1100 investigations of the occupational indoor environment in a wide variety of non-industrial settings. The majority of these investigations have been conducted since 1979.

The symptoms and health complaints reported to NIOSH by building occupants have been diverse and usually not suggestive of any particular medical diagnosis or readily associated with a causative agent. A typical spectrum of symptoms has included headaches, unusual fatigue, varying degrees of itching or burning eyes, irritations of the skin, nasal congestion, dry or irritated throats and other respiratory irritations. Typically, the workplace environment has been implicated because workers report that their symptoms lessen or resolve when they leave the building.

A number of published studies have reported high prevalences of symptoms among occupants of office buildings.[1,2,3,4,5] Scientists investigating indoor environmental problems believe that there are multiple factors contributing to building-related occupant complaints.[6,7] Among these factors are imprecisely defined characteristics of heating, ventilating, and air-conditioning (HVAC) systems, cumulative effects of exposure to low concentrations of multiple chemical pollutants, odors, elevated concentrations of particulate matter, microbiological contamination, and physical factors such as thermal comfort, lighting, and noise.[8,9,10,11,12,13] Indoor environmental pollutants can arise from either outdoor sources or indoor sources.[14]

There are also reports describing results which show that occupant perceptions of the indoor environment are more closely related than any measured indoor contaminant or condition to the occurrence of symptoms.[15,16,17] Some studies have shown relationships between psychological, social, and organizational factors in the workplace and the occurrence of symptoms and comfort complaints.[17,18,19,20]

Less often, an illness may be found to be specifically related to something in the building environment. Some examples of potentially building-related illnesses are allergic rhinitis, allergic asthma, hypersensitivity pneumonitis, Legionnaires' disease, Pontiac fever, carbon monoxide poisoning, and reaction to boiler corrosion inhibitors. The first three conditions can be caused by various microorganisms or other organic material. Legionnaires' disease and Pontiac fever are caused by *Legionella* bacteria. Sources of carbon monoxide include vehicle-engine exhaust emissions and inadequately ventilated kerosene heaters or other fuel-burning appliances. Exposure to boiler additives can occur if boiler steam is used for humidification or is released by accident.

Problems NIOSH investigators have found in the non-industrial indoor environment mirror those discussed in the preceding three paragraphs, and have included poor air quality due to ventilation system deficiencies, overcrowding, volatile organic chemicals (from building materials and office furnishings, machines, and other contents), tobacco smoke, microbiological contamination, and outside air pollutants; comfort problems due to improper temperature and relative humidity conditions, poor lighting, and unacceptable noise levels; adverse ergonomic conditions; and job-related psychosocial stressors. In most cases, however, these problems could not be directly linked to the reported health effects.

Standards for exposures to chemical substances and other agents specifically for the non-industrial indoor environment do not exist. NIOSH, the Occupational Safety and Health Administration (OSHA) and the American Conference of Governmental Industrial Hygienists (ACGIH) have published regulatory standards or recommended limits for occupational exposures.[21,22,23] With few exceptions, airborne pollutant concentrations observed in the office work environment fall well below these published occupational standards or recommended exposure limits. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) has published recommended building ventilation design criteria and thermal comfort guidelines.[24,25] The ACGIH has also developed a manual of guidelines for approaching investigations of building-related complaints that might be caused by airborne living organisms or their effluents.[26]

Measurement of indoor environmental contaminants has rarely proved to be helpful in determining the cause of symptoms and complaints except where there are strong or unusual sources, or a proved relationship between a contaminant and a building-related illness. The usual low-level concentrations of particles and variable mixtures of organic materials found are troublesome to interpret. However, measuring ventilation and thermal-comfort parameters is often useful in the early stages of an investigation in providing information relative to the proper functioning and control of HVAC systems. The bases for the specific measurements made in this investigation are described in the following subsections.

VENTILATION RATES

ASHRAE™ Standard 62–1989, "Ventilation for Acceptable Indoor Air Quality," generally specifies a minimum outside-air (o.a.) intake rate of 20 cfm per person for office spaces.[24] However, when more than one space is served by a common air-supply system, using this criterion to directly determine the entire system's o.a.-intake rate may not be correct; the ratio of o.a. to supply air (s.a.) required to satisfy the ventilation and thermal control requirements usually differs from space to space, and, if this is the case, the system's o.a.-intake rate must be determined from the procedure specified in the ASHRAE standard's Section 6.1.3.1, "Multiple Spaces." Additionally, Section 5.4 of this standard specifies that provisions must be made to maintain acceptable indoor air quality in each occupied space served when s.a. flowrates are reduced (during times the spaces are occupied) by the normal operation of certain types of systems, such as "variable-air-volume" (VAV) systems (these have variable s.a. flowrates, to individual spaces served and for the system overall). The most certain way to assure this is to employ the minimum s.a. flowrate to each space when determining o.a. requirements with the "Multiple Spaces" procedure. The ASHRAE standard also specifies o.a. requirements for other types of individual spaces, besides offices, found in this facility. For cafeterias, 20 cfm per person is recommended.

For spaces such as smoking lounges and restrooms, where more air contaminants may be generated than in spaces such as offices, the ASHRAE ventilation standard does specify ventilation rates, including 60 cfm/person for smoking lounges, but it also designates a different method for delivering the specified rates. This method calls for mechanically exhausting the comparatively contaminated air directly outside at the specified rate, and allowing comparatively uncontaminated air from nearby areas to flow into the space to make up for the exhausted air. Recirculation of contaminated air from smoking lounges, restrooms, and similar spaces back to common air-supply systems is not recommended. Since this method does not necessarily require the air entering such spaces to be composed partially of fresh o.a., the recommended ventilation rates for these spaces do not directly affect the determination (with the "Multiple Spaces" procedure) of o.a. requirements for common air-supply systems. However, the total o.a.-intake rate to an office building or a wing of offices should be somewhat greater than the total rate at which exhausted air is removed (by all exhaust systems combined) so that a slight "positive static pressure" is maintained in the office building, compared to the surroundings. This induces air to flow outward to, rather than inward from, the surroundings through available openings such as gaps around doors and in construction materials.

Carbon dioxide (CO_2) is a normal constituent of exhaled breath; measurement of CO_2 concentrations can be used as a screening technique to evaluate whether fresh air is being introduced into an occupied space at an adequate rate. Indoor-air CO_2 concentrations are normally higher than the generally constant ambient-air CO_2 concentration, which usually ranges from 300 to 350 parts per million (ppm). When indoor CO_2 concentrations exceed 1000 ppm in areas where the only known source is exhaled breath, inadequate ventilation is suspected.[24] Elevated CO_2 concentrations suggest that other indoor contaminants may also be increased.

TEMPERATURE AND RELATIVE HUMIDITY

The perception of comfort is related to one's metabolic heat production, the transfer of heat to the environment, physiological adjustments, and body temperatures. Heat transfer from the body to the environment is influenced by factors such as temperature, humidity, air movement, personal activities, and clothing. ANSI/ASHRAE Standard 55–1981 (see Figure 2) specifies conditions in which 80% or more of the occupants would be expected to find the environment thermally comfortable.[25] ASHRAE further recommends maintaining relative humidities between 30% and 60% "to minimize the growth of allergenic or pathogenic organisms."[24]

EVALUATION METHODS

The environmental survey included an inspection of the northern portion of the 400 Building and the HVAC systems serving this area, discussions with both AMP Incorporated and contract maintenance personnel about these items, and an evaluation of the HVAC systems' design features and specifications. The effectiveness of the ventilation in the northern portion of the building, as indicated by airborne CO_2 concentrations, was also evaluated. Air temperatures and relative humidities were measured to assess thermal comfort. The survey also included air sampling for possible chemical contaminants.

EVALUATION OF HVAC SYSTEMS

The design features and specifications of the HVAC systems serving the northern portion of the 400 Building were evaluated to determine if the design provides for adequate ventilation (o.a.-exchange) rates for the occupied spaces in this portion of the building, compared to the ASHRAE ventilation standard. This evaluation was performed by reviewing the HVAC plans for the building, and holding discussions with both AMP Incorporated and contract maintenance personnel about the operation of the systems and modifications that have been made to them.

As a secondary indicator of actual ventilation effectiveness at the time of the NIOSH survey, airborne CO_2 concentrations were measured, using an electronic, direct-reading GasTech RI411A CO_2 Meter with infrared detection. Simultaneous measurements were also made occasionally with the Dräger detector-tube system (specifically, a hand-held bellows pump and colorimetric, length-of-stain 0.01%/a CO_2 detector tubes were used).

Air temperatures and relative humidities were measured using an Environmental Tectonics Corporation Psychro-Dyne automatic psychrometer with two mercury-containing glass thermometers (one wet and one dry bulb).

The CO_2 concentrations, temperatures, and relative humidities were measured several times during the workday in four locations: (1) the Sales-Service office area, upon which the requestors' complaints were focussed; (2) the cafeteria, which served as the "smoking" area at the time of the survey; (3) the warehouse, considered an "indoor background" location since complaints were not focussed on this area; and, (4) an "outdoor background" location on the roof near the outside-air intake opening of AHU AC–1. Background measurements are needed when evaluating these parameters, because comparisons between the levels in the areas being investigated and the ambient background levels are important.

AIR SAMPLING FOR CHEMICAL CONTAMINANTS

A total of 12 general-area air samples were collected and analyzed for general volatile organic compounds (VOCs) and aldehydes using several methods, the details of which are provided in Appendix B. Each sample was collected by using a battery-powered "low-flow" air-sampling pump to draw air, at a measured rate and for a measured period of time, through a collection medium appropriate for the specific method. Sampling durations were approximately 8 hours (hr), with sample collection during the workday on February 7, 1991.

Each sample was collected in one of the four locations mentioned previously (where CO_2 concentrations, temperatures, and relative humidities were measured), including the "background" locations (background measurements are also important when evaluating potentially "trace" concentrations of contaminants).

OBSERVATIONS AND FINDINGS

The visual inspection of the condition of the HVAC systems revealed no apparent problems or hazards. The interiors of the AHUs that were inspected were found to be acceptably clean and dry.

VENTILATION RATES

The results of the evaluation of the design features and specifications of the HVAC systems (including modifications that reportedly have been made to them) serving the northern portion of the 400 Building suggest that the minimum ventilation rates provided by these systems is insufficient under most operating conditions, compared with the criteria recommended in the ASHRAE ventilation standard (ASHRAE™ Standard 62–1989). The design-specified minimum intake rate of o.a. by the ventilation and air-conditioning system which includes AHU AC-1 is insufficient, under most operating conditions, for the occupancy level of the northern portion of the building at the time of the NIOSH survey (about 98 employees). Further, for the estimated 162-employee maximum workforce of this area, the minimum intake rate of o.a. by this system is even more deficient (and is deficient under all operating conditions). Adequate ventilation rates are not assured by the estimated exhaust airflow rates of the exhaust systems in this portion of the building, either.

Requirements for o.a. intake were determined under a variety of conditions for the ventilation and air-conditioning system which includes AHU AC-1, and some examples are described in this and the next paragraph which illustrate the finding of insufficient ventilation rates. The examples in this paragraph are based on the occupancy levels that existed at the time of the NIOSH survey. In this case, an effective o.a. delivery rate of 1600 cfm is needed for the Sales-Service office area. However, if all VAV terminals were to modulate to their design-specified minimum s.a. flowrates, the total s.a. provided to the Sales-Service office area would be only 1195 cfm. Thus, at minimum s.a. flow, not even s.a. consisting of 100% o.a. is adequate. Certainly, the modulation of the VAV terminals to their minimum s.a. flowrates is not likely to occur much of the time, if at all. However, if all VAV terminals were to modulate to 50% of their design-specified maximum s.a. flowrates, the "Multiple Spaces" procedure specified in the ASHRAE standard indicates that the proportion of o.a. needed in the system s.a. is 22.0%, so under these more-likely conditions the design-specified minimum proportion of 10% would be inadequate. In fact, only if all VAV terminals modulate to their design-specified maximum s.a. flowrates would the design-specified minimum proportion of 10% be adequate, since the "Multiple Spaces" procedure indicates that the proportion of o.a. needed in the system s.a. is 10.5% under these conditions.

As one would expect, the design-specified minimum intake of o.a. by the system is even more deficient at the estimated maximum employment levels, as the remaining examples illustrate. At these occupancy levels, an effective o.a. delivery rate of 2200 cfm is needed for the Sales-Service office area. Therefore, as before, even supplying air consisting of 100% o.a. is inadequate if all VAV terminals were to modulate to their design-specified minimum s.a. flowrates, providing a total of only 1195 cfm to the Sales-Service office area. If all VAV terminals were to modulate to 50% of their design-specified maximum s.a. flowrates, the "Multiple Spaces" procedure indicates that the proportion of o.a. needed in the system s.a. is 35.5%, and even if all VAV terminals modulate to their design-specified maximum s.a. flowrates, the proportion of o.a. needed in the system s.a. is 17.2%. Therefore, under all conditions the design-specified minimum proportion of 10% would be inadequate.

The cafeteria was not considered (in the <u>any</u> of the preceding examples) when using the "Multiple Spaces" procedure to determine o.a.-intake requirements for the ventilation and air-conditioning system because of this space's use as a smoking lounge, for which the ventilation needs may be satisfied by "transfer air" drawn from adjacent spaces to make up for air mechanically exhausted directly outside. Also, the entire Sales-Service office area including the small partitioned areas were considered to be one space when using the "Multiple Spaces" procedure, due to the configuration of the s.a. and r.a. diffusers. This was also the case for the "other" offices at the west end of the system's service area. Spaces such as the coatroom and lobby were assumed to have an occupancy of 0 or 1 person each, and therefore had little effect on the "Multiple Spaces" determinations.

Possibly, the **combined estimated exhaust-air flowrates for the northern portion** of the building may exceed under some conditions the design-specified o.a.-intake rate of the ventilation and air-conditioning system serving the area, causing the infiltration of additional air to make up for that exhausted and putting the area under "negative pressure" compared to the outdoors. For example, if all VAV terminals were to modulate to 50% of their design-specified maximum s.a. flowrates, the design-specified minimum o.a.-intake rate for the system (10% of the calculated system s.a. flowrate) would be 978 cfm. This is less than the estimated combined exhaust rate of about 1500 cfm for the two exhaust systems in the area. However, this would not necessarily improve the overall ventilation rates so as to overcome the deficiencies described above. Even if air entering at this rate was properly distributed by the ventilation system, total o.a. needs (based on the "Multiple Spaces" procedure) under these conditions, at the occupancy levels that existed at the time of the NIOSH survey, would be 2150 cfm (22.0% of the calculated system s.a. flowrate) which exceeds the total exhaust flowrate. Furthermore, air entering by infiltration will not likely be distributed properly. Additionally, infiltration and "negative pressure" conditions are undesirable in office structures for other reasons as well.

Measured airborne concentrations of CO_2 during the NIOSH visit averaged around 400 ppm outdoors, whereas levels in the northern portion of the 400 Building, measured in both the Sales-Service office area and the cafeteria, rose from about 725 ppm in the morning to over 1000 ppm as the day progressed (see Table 1). The latter level is considered slightly elevated, and inadequate o.a. exchange may be indicated.

Considering the ambient environmental conditions during the NIOSH visit (see Table 1), the "economizer" control would be expected to open the variable-position o.a.-intake dampers to increase the proportion of o.a. in the s.a. well above the design-specified minimum of 10%. Example calculations (similar to those discussed previously) suggest that the proportion of o.a. needed at that time was only about 20%. Therefore, the slightly elevated and rising CO_2 levels measured were unexpected. These findings suggest a malfunction in the "economizer" control, or perhaps some other system performance problem. The variable-position o.a.-intake dampers were observed to be slightly open, but this observation does not necessarily mean that the proportion of o.a. in the s.a. reached 20% or that the economizer control was operating properly.

TEMPERATURE AND RELATIVE HUMIDITY

All measured indoor relative humidities were within recommended ranges except for one measured level (64%) in the Sales-Service office area (see Table 1). However, most of the air temperatures measured in the areas served by the ventilating and air-conditioning system which includes AHU AC–1 (the Sales-Service office area and the cafeteria) were above the recommended range (see Table 1). It is uncertain why this was the case, but a malfunctioning "economizer" control could be responsible. The system controls reportedly deactivate the refrigeration-system compressors whenever the o.a. temperature is below 55°F, as it was at the time of the survey, and the system then relies exclusively on the induction of sufficient o.a. for cooling. If the "economizer" control malfunctions, insufficient o.a. induction to provide needed cooling may occur. Other possible reasons for temperatures above the recommended range include the following: the thermostats on the VAV terminals near the measurement locations may have been improperly set; the VAV terminals near the measurement locations may have been malfunctioning or out of adjustment; AC–1 may not have sufficient cooling capacity or its refrigerant or control system may have been otherwise malfunctioning; and, this system may provide poor or inappropriate supply-air distribution. It is unclear whether chronically high temperatures are a factor in the IEQ complaints at this facility.

AIRBORNE CHEMICAL CONTAMINANTS

The results of the general-area air samples for volatile organic compounds and aldehydes do not indicate the presence of any unusual chemical compounds in the air of the facility. As is typical for indoor environments, traces of a number of compounds were detected qualitatively. Specifically, acetaldehyde, formaldehyde, ethanol, isopropanol, heptane isomers, 1,1,1–trichloroethane, trichloroethylene, tetrachloroethylene, toluene, xylene isomers, a siloxane compound, and a mixture of branched aliphatic hydrocarbons (primarily C_{10} to C_{12}) were identified in the air of the Sales-Service office area and the cafeteria. The specific composition of the branched aliphatic-hydrocarbon mixture detected was determined to be very similar to certain photocopier toner solutions.

Quantitative analyses were performed for acetaldehyde, formaldehyde, 1,1,1–trichloroethane, trichloroethylene, toluene, and the branched aliphatic-hydrocarbon mixture; the results are presented in Table 2. None of the concentrations of these compounds found in the air of the facility at the time of the NIOSH survey were unusual for an indoor environment and, as is typically the case, they were below all industrial evaluation criteria. There are no specific criteria for non-industrial settings.

The estimated airborne concentrations of aldehydes (acetaldehyde and formaldehyde) in the cafeteria, which served as the "smoking" area at the time of the survey, were higher than those estimated in the other sampling locations. Aldehydes are constituents of tobacco smoke. Even though employee exposures to these two aldehydes during the NIOSH visit were below all industrial evaluation criteria, environmental tobacco smoke (ETS), which can cause upper respiratory irritation and other complaints (depending upon exposure levels and individual sensitivities), was observed to be present in the cafeteria (and possibly could be recirculated to other areas; see Appendix A). NIOSH has determined that ETS may be related to an increased risk of serious chronic health effects -- lung cancer and possibly heart disease -- in occupationally exposed workers who do not smoke themselves,[27] and no safe levels have been established for cancer-causing substances.

CONCLUSIONS

Several factors which may impact upon the IEQ in this building have been identified in the previous section and are addressed with recommendations below, but the findings of this evaluation cannot confirm any of these factors as causative in relation to the employees' complaints and reported symptoms. Nevertheless, the presence of ETS in the cafeteria, and the possibility of its recirculation to other areas, constitutes a potential chronic health hazard regardless of the extent (if any) to which it contributes to the reported complaints.

RECOMMENDATIONS

1. A separate "smoking lounge" is preferred over the use of the cafeteria as a "smoking" area. In accordance with the ASHRAE ventilation standard, ventilation should be provided to the smoking lounge by mechanically exhausting the comparatively contaminated air directly outside (at a rate of 60 cfm/person, as mentioned previously), and allowing comparatively uncontaminated air from nearby areas to flow into the space to make up for the exhausted air. Recirculation of the contaminated air, from the smoking lounge back to the ventilation and air-conditioning system serving the northern portion of the 400 Building (or any other common air-supply system), is not recommended. If conditioned air is supplied to the smoking lounge by the system, the supply rate to the room must be less than the exhaust rate from it so that "negative static pressure" is maintained in the room compared to surrounding areas. As long as the cafeteria is a "smoking" area, its ventilation should also meet the above requirements.

2. An increase in the minimum proportion of o.a. in the s.a. of the ventilation and air-conditioning system which serves the northern portion of the 400 Building is needed to enable this system to consistently provide ventilation to all spaces served at the rates recommended in the ASHRAE ventilation standard. A mechanical firm with engineering capability should be retained to recommend appropriate design and equipment modifications for the HVAC system. This firm should give particular attention to the portion of the ASHRAE standard regarding VAV systems and the provision of acceptable indoor air quality when airflows are reduced by the normal operation of such systems. The mechanical firm also should utilize the "Multiple Spaces" determinations when formulating its recommended system modifications, and this procedure may need to be repeated with the cafeteria included to account for the establishment of a separate smoking room and the consequent discontinuation of the cafeteria's use for this purpose.

   The occupancy levels that existed at the time of the NIOSH survey were reportedly below the capacity of the building. Reasonable projections for future usage of each area, including occupancy levels, should be developed for use by the contractor in formulating its recommended system modifications. Also, the contractor should assure that the system's o.a.-intake rate, under all operating conditions, exceeds the combined total exhaust-air flowrate of all exhaust systems in the area served (i.e., the exhaust systems for the cafeteria and/or smoking room, and the restrooms) so that the building is maintained under slight "positive pressure" compared to the outdoor environment.

3. The mechanical contractor should check, in particular, the performance of the "economizer" control on AC-1 (the AHU of the ventilation and air-conditioning system which serves the northern portion of the 400 Building), since the elevation of air temperatures and CO_2 concentrations were both consistent with an "economizer" malfunction. Since the problems noted also could be symptoms of numerous other conditions, the contractor should also check system performance, after any recommended modifications to the design and/or equipment are complete, to assure compliance with both cooling and airflow design specifications.

4. The mechanical contractor should determine the current efficiency of the air filters in all AHUs, and recommend whether the filters should be upgraded to higher-efficiency types (which must be compatible with the existing hardware so that airflow rates are not adversely affected). ASHRAE recommends that filter efficiency (not "arrestance") be at least 35 to 60%, and 85% is often specified in modern buildings. The filter supplier's and/or manufacturer's recommendation for frequency of filter changes should be strictly followed. Improvements in filter efficiencies not only help provide cleaner air to occupied spaces, they help vital parts of AHUs, particularly cooling coils, stay cleaner.

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HETA 90-264
AMP Incorporated
Berwyn, Pennsylvania

6 and 7 February 1991

Figure 1. Floor plan, 400 Building.

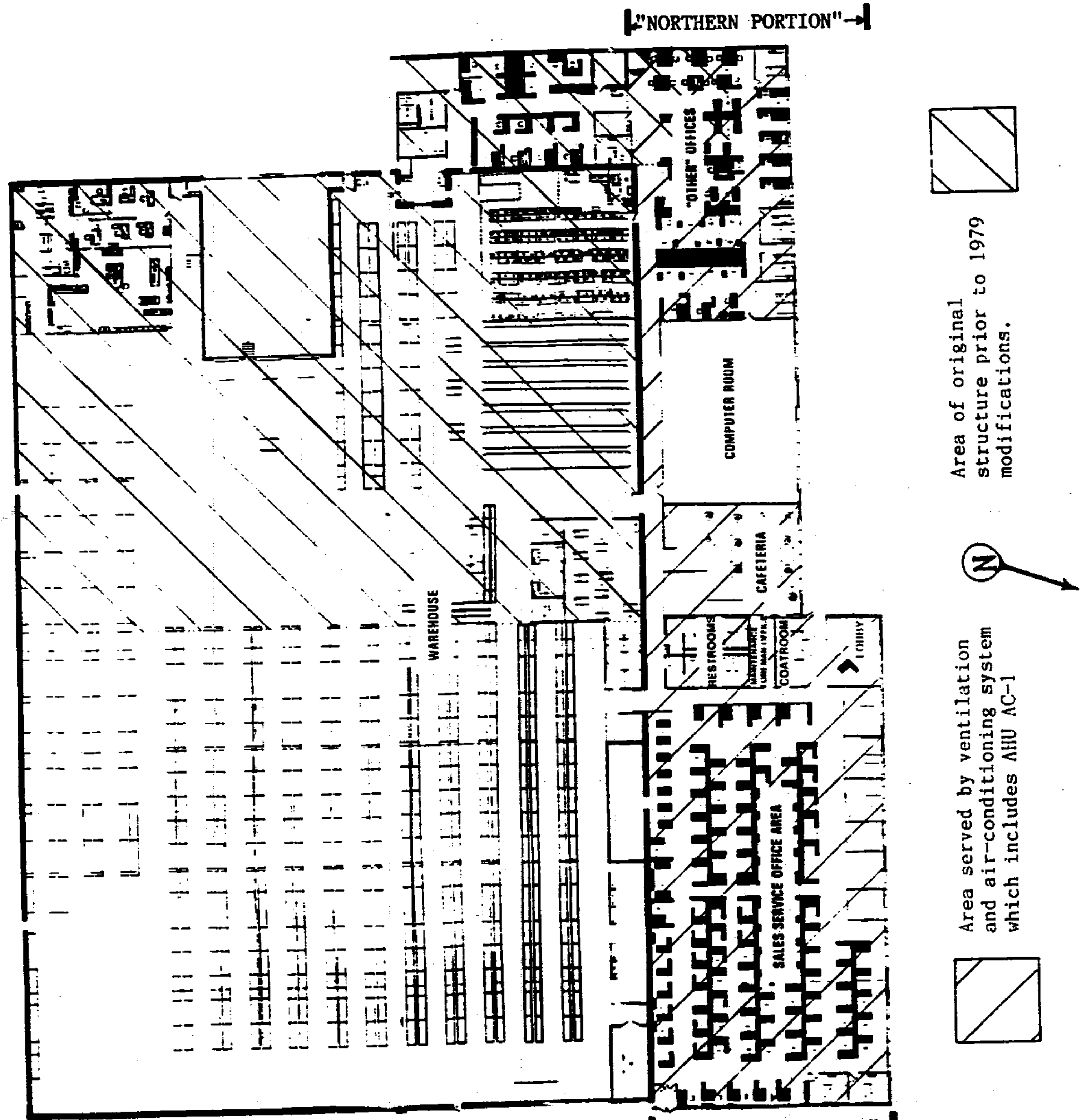
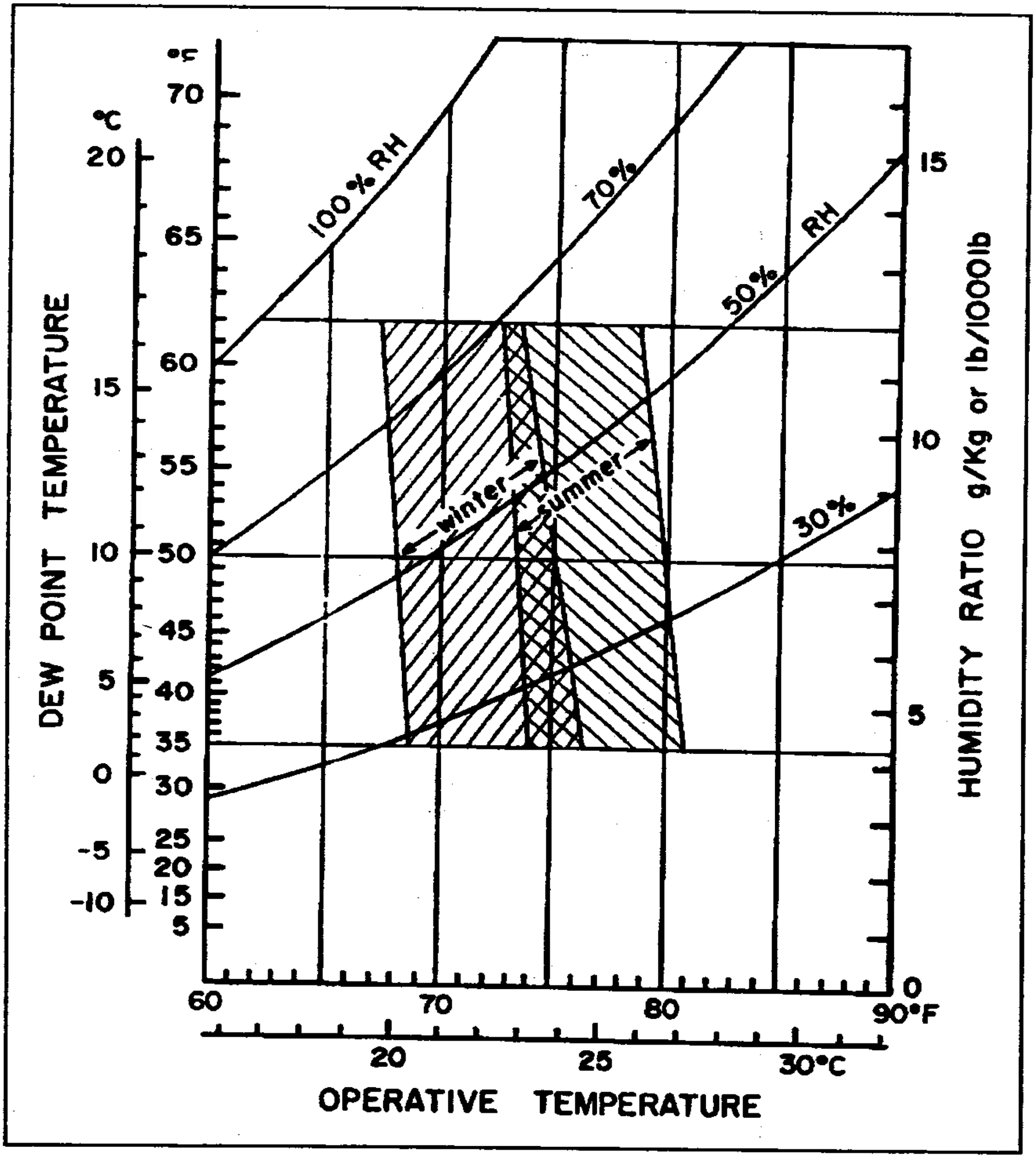


Figure 2. Thermal-comfort criteria, from ANSI/ASHRAE Standard 55-1981.



Acceptable ranges for persons, at light activity levels, wearing typical summer and winter clothing.

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7 February 1991

Table 1. Measured air temperatures, relative humidities, and carbon dioxide (CO_2) concentrations

Location	Time (military)	CO_2 Concentration (ppm) Meter*	CO_2 Concentration (ppm) d.t.**	Temperature (°F)	Relative Humidity (% Saturation)	Dew Point (°F)
Main area of Sales-Service office	0915	725	850	77.0‡	64%†#	64.5†#
	1206	950	--	73.2	44%	51.1
	1610	1000	975	79.6‡	34%	49.6
Cafeteria	0925	725	--	78.6‡	33%	47.7
	1225	1025	--	78.5‡	33%	47.5
	1625	950	1050	81.3‡	30%	47.8
Warehouse, center (indoor background location)	0900	425	--	72.0	34%	43.2
	1218	600	--	72.5	38%	46.6
	1650	550	--	71.7	39%	45.9
Outdoor ambient (on roof, near AHU)	0855	375	--	46.2	91%	43.9
	1215	450	--	50.7	82%	45.2
	1645	425	--	48.3	81%	42.7

* Reported CO_2 concentrations measured with GasTech meter.
** Reported CO_2 concentrations measured with Dräger detector tubes.
‡ Temperature above winter range specified in ASHRAE thermal-comfort criteria (see Figure).
† Humidity above range specified in ASHRAE thermal-comfort criteria (specified maximum absolute humidity corresponds to 62°F dew point; see Figure).
\# Relative humidity above ASHRAE-recommended range of 30% to 60% intended "to minimize the growth of allergenic or pathogenic organisms."

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Table 2. Measured full-day, time-weighted-average, airborne concentrations of organic compounds.

Location	Concentration (ppm)					Concentration (mg/m^3)
	1,1,1-Trichloroethane	Trichloroethylene	Toluene	Formaldehyde	Acetaldehyde	Branched Aliphatic Hydrocarbons
Main area of Sales-Service office	0.033	0.004**	0.014	0.01#**	0.003**	2.1
Cafeteria (designated "smoking" area)	0.033	0.004**	0.013	0.02#**	0.006**	1.2
Warehouse, center (indoor background location)	0.039	0.0093	0.017	0.008**	<0.003*	0.35
Outdoor ambient (on roof, near AHU)	<0.002*	0.002**	0.003**	0.008**	0.003**	<0.07*

* Concentration is less than the "minimum detectable concentration."
** Concentration is below the "minimum quantifiable concentration," indicating that the reported value lacks precision and is therefore only an estimate of the true concentration.
# The 8-hr time-weighted-average exposure to formaldehyde for an employee spending about 7 hr in the Sales-Service office area and about 1 hr in the cafeteria during this workday would have been an estimated 0.011 ppm, which is below all relevant industrial evaluation criteria.

APPENDIX A

DESCRIPTION OF VENTILATION AND AIR-CONDITIONING SYSTEM WHICH INCLUDES AHU AC-1

The ventilation and air-conditioning system which includes AHU AC-1, serving the northern portion of the 400 Building (except the computer room), is a variable-air-volume (VAV) type system designed to supply cool, constant-temperature (reportedly 55°F) air to the occupied spaces to remove excess heat; except along the building's perimeter, internally-generated heat from people, lights, equipment, etc. must be removed year-round. In such a system, the volumetric flowrate of the cool "supply air" (s.a.) provided to the occupied spaces is variable in response to thermostats in the spaces, in order to maintain a desirable temperature.

AHU AC-1 mixes inducted outside air (o.a.) with "return air" (r.a.), air returning to the AHU from the occupied spaces (including, notably, the cafeteria, despite its designation as the "smoking" area at the time of the survey). Air in the occupied spaces passes through grilles in the false ceilings to a common plenum area above, and from there it enters a return duct leading to the AHU. The mixture of o.a. and r.a. in AC-1 is filtered, then cooled if necessary by passing through the evaporator coils of the mechanical refrigeration system in the unit, then discharged by the s.a. fan to s.a. ductwork leading to numerous VAV terminals in the ceilings of the occupied spaces. Each VAV terminal has a slot-type diffuser through which the s.a. is discharged into occupied space, and each also has an internal damper to regulate the s.a. flowrate in response to a nearby (or built-in) thermostat. Most thermostats in this system control two terminals.

Each VAV terminal can be manually adjusted to allow the proper maximum s.a. flowrate for that terminal, which is specified in the system design. Each terminal also has a minimum s.a. flowrate of either 25 or 40 cfm, depending upon which of four different terminal models used in this system is specified in the design; the minimum flowrates are not adjustable on these terminals. The design-specified maximum s.a. flowrate for the system as a whole (as modified, with the terminals originally specified to serve the computer room removed from the system) is 19,560 cfm, based on the sum of the specified maximums for the terminals. Similarly, the design-specified minimum s.a. flowrate for the entire system is 2190 cfm.

AHU AC-1 has two types of o.a.-intake dampers, the fixed-position (or "minimum") type and the automatically-variable "economizer" type. The fixed-position damper is designed to assure that a minimum proportion of the s.a. consists of o.a., even if the variable-position damper is completely closed. A 2000-cfm o.a.-intake rate through the fixed-position o.a.-intake damper is specified in the system design to occur at the 20,000-cfm design-specified (maximum) flowrate for the s.a. fan in AC-1. Therefore, the design provides for a minimum proportion of o.a. in the s.a. of 10%. Although the s.a. fan is specified to provide up to 20,000 cfm, the system s.a. flowrate actually will vary between the minimum and maximum levels of 2190 and 19,560 cfm mentioned in the previous paragraph, depending upon the heat loads in the areas served, if the system is operating to specifications. If that is the case, then the minimum o.a.-intake rate will vary between 219 and 1956 cfm.

Whenever the temperature of the o.a. is such that increasing its proportion in the s.a. would help cool the s.a. to the desired temperature (about 55°F) and thereby decrease the need for the mechanical refrigeration system to operate, the "economizer" control automatically modulates the variable-position damper to achieve this increased proportion, up to a reported maximum of about 60%. However, during warmer weather, an increased proportion of o.a. will not help the system handle its heat load but rather may add to it, and during very cold weather an increased proportion of o.a. may excessively cool the s.a. Under these conditions, the "economizer" control will close the variable-position damper, returning the proportion of o.a. in the s.a. to its minimum.

APPENDIX B

DETAILS OF AIR SAMPLING AND ANALYTICAL METHODS FOR POSSIBLE CHEMICAL CONTAMINANTS

Each air sample was collected for use with one of two complementary analytical purposes: (1) qualitative analysis to identify any organic compounds which may have been present in the air sampled; or, (2) subsequent quantitative determination of the airborne concentrations of any compounds qualitatively identified. To achieve these analytical purposes for a wide variety of organic compounds, including aldehydes, two types of collection media were used: (1) tubes packed with activated-charcoal adsorbent ("charcoal tubes") were used to collect samples for the qualitative and quantitative analyses of general volatile organic compounds (VOCs); and, (2) special reagent-containing tubes were used to collect samples for qualitative and quantitative analyses of aldehydes.

CHARCOAL-TUBE samples for VOCs, whether for qualitative or quantitative analyses, were collected using an air-flow rate of 200 milliliters per minute (mL/min). The analyses of both types of these samples included desorption with carbon disulfide followed by some type of gas chromatography (GC). The qualitative analyses utilized GC with mass-spectrometry detection (MSD), while the quantitative determinations were accomplished by GC with flame-ionization detection (FID), similar to NIOSH Methods 1003, 1500, and 1501.[28]

THE SPECIAL REAGENT TUBES used to collect samples for aldehydes, whether for qualitative or quantitative analyses, contain XAD-2 resin coated with (2-hydroxymethyl)piperidine (2-HMP). For both types of sample, an air-flow rate of 80 mL/min was used. Each variety of aldehyde present reacts with the 2-HMP to form the oxazolidine derivative of that aldehyde. The qualitative aldehyde samples were collected and analyzed in accordance with NIOSH Method 2539.[28] A variety of sampling and analytical methods are available for the quantitative determination of aldehydes, depending upon which of these compounds are detected with the qualitative sampling. Two of these, NIOSH Methods 2538 and 2541,[28] for acetaldehyde and formaldehyde, respectively, were used for this HHE. For all three methods mentioned here, analysis includes desorption of the oxazolidine derivatives with toluene followed by GC with FID. For the qualitative analyses only, initial identification of any oxazolidine derivatives present is made by GC-FID, and this is followed by GC-MSD to confirm these initial identifications.

SAMPLING LOCATIONS BY SAMPLE TYPE were as follows:

- Sales-Service office area, and cafeteria: In each area, two charcoal-tube samples (one for qualitative and one for quantitative analysis) and two aldehyde reagent-tube samples (for similar purposes).
- "Background" sampling locations, both indoor (warehouse) and outdoor: In each area, one charcoal-tube sample and one aldehyde reagent-tube

sample, for the quantitative analysis of any compounds qualitatively identified in the above two locations.

MINIMUM DETECTABLE AND MINIMUM QUANTIFIABLE CONCENTRATIONS. Some of the results of air sampling conducted with the quantitative methods are reported (see Table 2) as "less than the minimum detectable concentration (MDC)" or "below the minimum quantifiable concentration (MQC)." The MDC is based on the volume of air sampled and the analytical limit of detection (LOD), in mass of substance per sample, for the analytical method and the particular substance. For the samples collected during this survey, the analytical LODs were: 0.2 micrograms per sample (μg/sample) for acetaldehyde and formaldehyde; 1 μg/sample for 1,1,1-trichloroethane and trichloroethylene; 0.8 μg/sample for toluene; and, 7 μg/sample for the branched aliphatic hydrocarbon mixture.

The MQC is based on the volume of air sampled and the analytical limit of quantification (LOQ), in mass of substance per sample, for the method and substance. A value below the LOQ lacks precision and is therefore only an estimate of the true mass collected. For the samples collected during this survey, the analytical LOQs were: 0.9 μg/sample for acetaldehyde and formaldehyde; 3.2 μg/sample for 1,1,1-trichloroethane and trichloroethylene; 2.7 μg/sample for toluene; and, 24 μg/sample for the branched aliphatic hydrocarbon mixture.

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