GEORGIA INSTITUTE OF TECHNOLOGY
Engineering Experiment Station

PROJECT INITIATION

Date: March 7, 1969

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Project No.: E-359
Project Director: T. W. Kethley
Sponsor: Public Health Service
Effective: February 1, 1969; Estimated to run until: January 31, 1970
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Reports: Short Summary Progress Report to accompany continuation application

Contact Person: Dr. Paul J. Sanazaro, Director
National Center for Health Services
Research and Development
Health Services and Mental Health Administration

*Cost sharing requirement $2,812; Companion Account E-600-604

Assigned to Nuclear Sciences Division

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PROJECT INITIATION

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Project No.: B-377
Project Director: T. W. Kethley
Sponsor: Public Health Service

Effective: February 1, 1970
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Contact Person: Dr. Robert R. Huntley
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National Center for Health Services
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*Plus $3,527 to be transferred from B-359 for a total of $53,921 under the grant and $2,838 to meet 5% cost sharing requirements; Companion Account E-600-604.
FINAL TECHNICAL REPORT

Project B–377

AIR TREATMENT FOR ODOR CONTROL IN THE HOSPITAL

by T. W. Kethley

Grant No. HS 00068

January 1974

Prepared for
National Center for Health Services Research and Development
Health Services and Mental Health Administration
Public Health Service
Department of Health, Education, and Welfare

Engineering Experiment Station
GEORGIA INSTITUTE OF TECHNOLOGY
Atlanta, Georgia
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by T. W. Kethley

Grant No. HS 00068
EES Project B-377

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PREFACE AND SUMMARY

This report covers the laboratory work for the period since the last progress report (11-1-69) as well as data interpretation and report preparation through December 1973. Data from all phases of the project are collated in this report, as needed to support the interpretation finally achieved. This interpretation is that dilution ventilation is not an effective procedure for odor control in the hospital.

The specific aims of this project were set forth originally (and adhered to, during the study):

1. To estimate the makeup air requirements for odor control in hospital operating rooms, especially when operating rooms are ventilated as part of larger central ventilation zones; makeup air requirements assumed to be met either as outside "fresh" air or as treated recirculated air.

2. To evaluate the capacity and effectiveness of common air treatment systems in "freshening" recirculated air in the hospital situation.

3. To determine the effectiveness of air treatment systems found suitable for the hospital situation in "freshening" outside air, which is polluted as in a large city in the United States.

These aims have been met in the following manner:

1. The makeup air requirement for odor control in the hospital operating room probably is not much greater than two changes per hour equivalent fresh air, which, for the average room (3600 ft$^3$ volume) is 120 cfm, or approximately 10 percent for a room ventilated at 20 ch/hr. This is within the range of accepted practices. To increase the amount of makeup fresh air beyond this would accomplish very little in the way of odor control because of the holdup of odors within the operating room. It is possible that odor-removing devices located within the operating room adjacent to the sources of odorants would be more effective in controlling odors than would an increase in the amount of makeup air.
These same conclusions apply to patient care areas. In short, increased amounts of fresh air offer little or no help in controlling odors arising within the hospital.

2. The common air treatment systems available for possible odor control within the hospital are: refrigeration coils; water washers; odor-removal equipment such as carbon filters. Refrigeration coils do condense out vaporous odorants, but effectively concentrate them for subsequent return into the air stream. Although we found no practical value in low temperature surfaces as now employed, it is probable that non-aqueous systems would be effective. However, for internal recirculation, we found that air is a poor medium for conducting many odorants, and central refrigeration units, as well as centrally located water-washers would have little practical value in handling vaporous odorants. On the other hand, water-soluble gases, such as sulfur dioxide can be removed by water washers.

For the removal of vaporous odorants from the air, carbon filters offered the greatest promise, showing single-pass efficiencies not greatly less than those claimed by the manufacturers (85-95 percent). However, because many odorants are condensed or sorbed upon surfaces, the air is not an efficient transport medium. As a result, carbon filters used internally as part of zone or central recirculating systems will not aid greatly in removing odors, because the odorant must be carried by dilution ventilation to centrally located carbon filters. On the other hand, carbon units located within individual rooms could be much more effective; this latter case could apply also to permanganate systems (Purafil units).

3. The air treatment systems commonly found in patient care institutions are limited to refrigeration coils, water washers, carbon filters, particle arresters (filters and electrostatic precipitation). We made no evaluation of particle arresters, although it has been reported that high efficiency particle arresters (HEPA filters) have been effective in protecting patients against particulates resulting from photochemical smog. We found no value in refrigeration coils; any
contaminant removed usually appeared at higher concentrations during cycling.

Water washers were found to be of potential value in removing water soluble air contaminants such as sulfur dioxide, which is the most likely extramural air pollutant to be a problem of importance to hospital patients. At this point, it should be noted that carbon monoxide might become a problem; we were unable to find anything of practical value in removing this pollutant from the air.

Carbon filters were found to be effective in removing vaporous odorants from the air, with an efficiency not greatly less than that claimed by the manufacturers. However, for the removal of extramural air pollutants, carbon filters have very little to offer, unless specially treated, because most of these are true gases. The single-pass efficiency of the solid alumina-permanganate systems (Purafil) we tested was too low for such an application.

In general, it was concluded that problems of odor control are not a deterrent to the use of recirculation within the hospital; the amounts of makeup air now employed (10 percent or more) are sufficient to prevent odor buildup. On the other hand, if extramural air pollutants become such a problem as to encourage greater use of internal recirculation, any make up air should be treated. In this case, water washers are the only pieces of equipment ordinarily available to aid in such treatment, and these would remove only water soluble compounds. There appears to be a need for the development of air-treatment systems capable of protecting special risk populations such as certain types of hospital patients, even though internal recirculation of air is employed.
I. EQUIPMENT FOR CHAMBER EXPERIMENTS

A primary objective of all of these studies was to determine the effectiveness of dilution ventilation in removing odorants from intramural spaces when those odorants originate within such spaces. Such findings were intended to be applied to patient care facilities, and, unless otherwise specified, all work was conducted at temperatures and humidities normally encountered in such facilities (70-75°F, 40-60 percent relative humidity).

In order to simulate as many segments of the intramural environment as possible, the chamber which had been employed previously as a simulated operating room was set up as follows: internal recirculation through fiberglass lined ducts and prefilters and 95% DOP filters with a fixed amount of makeup of fresh air. The system thus included (1) a 12 x 16 x 8½ room with vinyl tile floor, enameled surface metal walls, ceiling composed of acoustical tile interspersed with metal air-supply preforated ceiling panels; (2) recirculating section consisting of two 20 x 24 inch fiberglass lined return ducts, each with a roughing filter and 95% DOP filter, blower, and sheet metal duct leading into the preforated ceiling panels; (3) makeup fresh air system, consisting of two end wall grilles in the front of the chamber, and an outlet located in the center of the rear of the chamber. When the complete system was operating internal recirculation was at the rate of 1,000 cfm. Fresh air was taken from the conditioned air of the work room and mechanically exhausted from the chamber through a stack to the roof of the building.

The rationale behind this design was to employ a confined intramural space including as great as possible amount of surface; to be able to introduce odorants into this space; to purge the intramural space in such a manner that none of the removed odorant could leak back into the intramural space. In order to assure intimate contact of the odorant with the intramural spaces, the recirculation system constantly operated at 1,000 cfm (500 cfm for each blower-filter unit). For the majority of the work air
was extracted from the chamber at exactly 700 cfm, constituting a fresh air ventilation rate of 0.388 changes per hour for the volume of 1,800 cubic feet when the ceiling panels were sealed at 8.5 feet ceiling height or 0.350 changes per hour for the 2,000 cubic feet volume when the ceiling panels of acoustical tile were removed to yield a 10 foot ceiling height. These volumes included the duct work as well as the chamber itself. Additionally when the ceiling tiles were removed it was possible to employ the chamber only, so that there was no internal recirculation and the odorant was exposed to enamel surfaces only, and not to the fiberglass insulation in the duct; in which case the volume was 1,800 cubic feet.

In the early stages of this study, it was assumed that exposing odors or air pollutants to extensive surface areas such as fiberglass insulation would result in greater sorption-desorption than when only painted surfaces were involved. No attempt was made to evaluate the total exposed surfaces represented by fiberglass duct liners, but the gross surface areas were as follows: (1) the bare chamber, enamel coated walls and vinyl floor covering, approximately 1,000 square feet total exposed surface, (2) the complete chamber with recirculation through lined ducts, prefilters, filters, blowers and sheet metal ducts, had exposed surfaces in square feet: in the chamber, 1,000; fiberglass duct liners, total of 320; prefilters, total of 20; micretain filters, total of 200; two sets of blower blades and sheet metal return ducts, 200; acoustical tile in ceiling, 100.

A. CALIBRATION OF THE CHAMBER SYSTEMS VENTILATED AT 700 CFM (21-23 CHANGES PER HOUR)

The bulk of the studies made upon odorant removal by dilution ventilation was made in the system described in the preceding section, at 700 cfm fresh air makeup. Because the exact value of fresh air was found to be of critical importance in subsequent experiments, the volume flow of fresh air was determined in a number of different ways, employing either physical measurements, or determinations with gases (in contrast to vapors).
1. Helium decay measurements

A Gow-Mac thermoconductivity cell and photo-volt recorder were employed; dew point was maintained constant within the workroom, and changes in the response of the thermal-conductivity cell were than due to changes in helium concentration. A quantity of helium sufficient to yield full-scale deflection on the recorder was introduced into the chamber by opening the valve of a helium cylinder connected to the chamber. The gas decay was graphically analyzed as equivalent changes per minute or changes per hour and expressed as cubic feet per minute equivalent fresh air (EFA). For the average of 6 determinations the EFA and its standard deviation (S.D.) was 734 ± 15 cfm. In addition, the leakage from the system was estimated with helium from the sealed chamber, and found to be 30 cfm EFA. Helium decays were employed as the most valid of all measurements for the true ventilation rate and EFA for the chamber.

2. Air velocity measurements

An Alnor Velometer and an Anemotherm Thermo-anemometer were employed originally. The middle range calibrations of both were verified in the Georgia Tech wind tunnel. When estimating air flow from air velocity measurements at supply and exhaust and in the 12 inch diameter duct, Alnor values averaged 749 cfm and Anemotherm 840 cfm. However, measurements made in the 8 inch diameter stack where velocities were in the middle range of the instruments, yielded values for the Alnor averaging 711 cfm and from the Anemotherm 730 cfm.

The high values from the Anemotherm at lower velocities prompted the exclusion of this particular instrument from subsequent measurement of air velocities; at high velocities all values obtained were consistent with those from the helium decays.

3. Freon-12 decay measurements

These were carried out by CDC personnel in the same manner as the helium decays; a LIRA (infrared sensing device) was employed to sense and record the decays. The average and its standard deviation for 9 determinations was 703 ± 32 cfm EFA.
4. Methane and building gas supply decays

Because a Beckman hydrocarbon analyzer (HC) was to be employed to determine the concentration of odorants in these studies, building supply gas was utilized for decay measurements with this analyzer. The results obtained indicated an EFA of not more than 600 cfm, in contrast to the 700 cfm or greater obtained with helium, freon, and air velocity measurements. A number of studies were made to determine the cause of this discrepancy: decay determinations were made for various concentrations, employing the analyzer at attenuations ranging from X3 to X300; the complete chamber system was employed including all linings, and also only the bare chamber; studies were made with building gas supply or with purified methane. None of these factors had a statistically significant effect upon the results. In addition an evaluation was made of the possible hold-up in the sampling system of the HC, which proved that this was not the cause of the problem (details shown in the appendix).

The average and standard deviation for 22 such gas decays were 580 ± 24 cfm EFA with 25 cfm EFA leakage (leakage is from the sealed, unventilated chamber system). In addition, it was found that when a concentration fell below a second decade, a new decay line was formed, having a lesser slope than the original. This tailing effect was labeled "The second decay," and for building supply gas or pure methane, the average and standard deviation of 6 determinations was 439 ± 66 cfm EFA.

Initially, it was concluded that the discrepancy between the decay values for helium and for methane was due to some nonlinearity association with the HC. As stated above, this factor was doubtful. The next approach was to introduce continuously metered quantities of pure methane and compare the established calibration of the analyzer to that obtained under these circumstances.

5. Continuous input of metered, purified methane (Matheson Gold label ultrahigh purity, 99.37% pure). This was metered at low flows with flow meter Matheson L-140 and at flows much greater than 100 cc per minute with flow meter Fisher-Porter T5-1504/1.

The L-140 flow meter was recalibrated with a bubble meter, and the T5-1504/1 against a dry test meter and ultimately against wet test metering
of measured volumes of water. To insure uniformity of flow, a micro-metering valve was introduced between the gas supply and the flow meter; from the flow meter a copper tubing line carried the gas into the center of the chamber. Operation of all components was continuous and information was collected after not less than 30 minutes preliminary operation.

For a total of 10 separate and complete experiments, input of methane was varied from 52 to a little more than 1,000 cc per minute. As read from the HC signals, based on 18.0 divisions per ppm carbon (from prior calibration of the instrument with ultrahigh purity propane-nitrogen mixture, Matheson analyzed) this yielded concentrations ranging from 2.6 to somewhat greater than 50 ppm as methane, covering instrument attenuations from X1 to X30. These data then yielded independent values for methane concentration and independent values for methane input, which were employed in the general expression for nominal concentrations at equilibrium:

\[ C = \frac{S_m}{Q} \]

where:  
\( C \) = concentration, here in ppm  
\( S_m \) = input of compound, here in cc/min.  
\( Q \) = quantity of diluting air, here in \((\text{cc/min}) \times 10^6\); dividing by \(28.3 \times 10^3\) converts to cfm.

Because both \( C \) and \( S_m \) were known, the expression was employed to solve for values of \( Q \) in cfm, which would be the quantity of dilution ventilation required to satisfy the observed information.

For the ten separate experiments, the average and standard deviation was 755 ± 31 cfm EFA. This value compared favorably and was not statistically different from that of 734 ± 15 from the helium decay determination; both of these averages being radically different from the value of 580 ± 24 for the methane gas decay.

6. Continuous input of metered building supply gas

This gas is primarily methane; to calibrate the HC against purified methane 3 experiments were conducted comparing the regulated metered building supply gas with metered purified methane gas. These yielded a
value of 1.11 for the building supply gas (due to the presence of a small amount of ethane). This conversion factor was employed to adjust values of metered input and 9 complete and separate experiments were performed in exactly the same manner as for the purified methane. The average and standard deviation for these 9 runs was 775 ± 59 cfm EFA. Although higher, this average is not statistically different from a 755 ± 31 obtained for the 10 runs with pure methane. Combining all the gas and methane runs yielded for the 19 experiments, 764 ± 47 cfm EFA; this value is significantly larger than the 734 ± 15 from the helium decay. Unfortunately, even though all meters were carefully calibrated a difference of only 30 cfm could be due to very slight errors in calibration; although the difference between 734 and 764 is here statistically significant, it may not be meaningful.

7. Summation

The objective was to set up the chamber system with approximately 700 cfm EFA, so that for a chamber with ceiling tiles removed and a volume of 2,000 cubic feet, we could expect 0.35 changes per minute (21 changes per hour), and for the chamber with false ceiling of acoustical tile, fiberglass ducts, filters, internal recirculation of 1000 cfm, volume of 1,800 cubic feet, we would expect 0.388 changes per minute (3.33 changes per hour). Initial estimates from fresh air velocity measurements in the exhaust stack showed the quantity of air to be 711-749 cfm. Employing various gases and detectors the following tabulation summarizes the determined values.

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Number of runs</th>
<th>( \bar{X} \pm \text{S.D.} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freon: LIRA. Decay</td>
<td>9</td>
<td>703 ± 32</td>
</tr>
<tr>
<td>Helium: TC. Decay</td>
<td>6</td>
<td>734 ± 15</td>
</tr>
<tr>
<td>Methane: HC. Continuous</td>
<td>19</td>
<td>764 ± 47</td>
</tr>
<tr>
<td>Methane: HC. Decay</td>
<td>22</td>
<td>580 ± 24</td>
</tr>
<tr>
<td>(Methane: HC. 2nd Decay)</td>
<td>6</td>
<td>439 ± 66</td>
</tr>
</tbody>
</table>

Table. Determined EFA, cfm, for the chamber, at expected 700 cfm mechanical ventilation (21-23 changes per hour).
Examination of the information in the above table led us to conclude that during the non-equilibrium stages of removing methane gas by dilution ventilation there is a significant and meaningful difference between the observed and expected rate of removal. This difference cannot be attributed to the methods employed for analyzing the gaseous concentration, but must be due to some process characteristic of the compound itself. In short, we were faced with incontrovertible evidence that even a compound as simple as methane, which is a gas at room temperature, is not necessarily removed from an enclosed space with the effectiveness predicted. Employing the nominal values of 700 cfm as the minimum expected ventilation, methane is removed during the non-equilibrium stage with only some 83% of predicted effectiveness. The hypothesis was advanced that these methen decays involved a process of surface sorption of the gas during build up to concentration, which might account for the fact that EFA values obtained from continued input of methane were higher than expected. There must then be a gradual desorption during the period when the decay was determined. The desorption would be caused by the concentration differential; during the ventilation process, the aerial concentration of gas would be decreased, thus increasing the concentration gradient between the surface and the air. Although direct supporting evidence was not obtained, this hypothesis remained the only explanation available for the differences. An analogous situation was found with water vapor; if small amounts were introduced into the system, ventilation was in accordance with expectancy, but, if steam was introduced in sufficient quantity to leave visible condensation, the decay was equivalent to 605 cfm EFA from the complete chamber system, with recirculation (see Appendix for details).
B. CALIBRATION OF THE CHAMBER SYSTEMS VENTILATED AT LESS THAN 21 CHANGES PER HOUR

Subsequent experiences in buildings at lower ventilation rates indicated that there were no such differences as obtained in ventilating methane at 21 changes per hour in the chamber. For this reason, detailed studies with methane were first conducted in the chamber employing either the bare chamber or the chamber with recirculation through the lined ducts. No significant difference resulted and results were combined.

For each run the chamber exhaust blower was throttled down to yield flows equivalent to 4, 8, or 10 changes per hour as estimated from air velocity measurements in the exhaust duct. Carefully regulated methane gas or building supply gas was introduced into the chamber continuously for approximately one hour, the equilibrium concentration recorded from the HC. The gas input was shut off and ventilation and HC recording continued through two decades of concentration. From graphical analysis both decay values were determined in terms of changes per hour and converted into cfm EFA. The HC value for the continued input was converted into ppm and the air flow through the chamber calculated from the base equation:

\[ Q = \frac{S_m}{C} \]

The previous studies at 700 cfm (21 changes per hour) had yielded a significant difference between EFA determined from the continuous input of gas and that determined from gas decays in the full chamber with recirculation through lined ducts and filters. In order to make meaningful comparisons all data were converted into ratios, dividing the cfm EFA determined from methane gas decays by the corresponding cfm EFA determined from the continuous input of metered gas and ppm as shown from the HC. The values for the 700 cfm studies and those for lower flow rate are summarized.
Table. Ratios: EFA from gas decay
EFA from continuous input

<table>
<thead>
<tr>
<th>Nominal ch/hr</th>
<th>EFA from continuous input of gas</th>
<th>Number of runs</th>
<th>First decay</th>
<th>Second decay</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>764</td>
<td>19</td>
<td>0.76</td>
<td>0.57</td>
</tr>
<tr>
<td>10</td>
<td>311</td>
<td>5</td>
<td>0.95</td>
<td>0.98</td>
</tr>
<tr>
<td>8</td>
<td>206</td>
<td>1</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>4</td>
<td>116</td>
<td>6</td>
<td>1.00</td>
<td>0.98</td>
</tr>
</tbody>
</table>

There is no question but what the data shown in the above table proved that a different effect exists when the air flow through the chamber is reduced to 10 or less changes per hour. At ventilation rates of 10 ch/hr or greater, the gas decay information shows definite desorption during the purge, with a resultant lowered efficiency of removal of the compound from the chamber system by dilution ventilation. At lower ventilation rates, this phenomenon is no longer apparent in the case of methane gas - perhaps because the rate of desorption is equal to or greater than the rate of removal by dilution ventilation. Such a phenomenon would be expected to be affected by the ventilation rate rather than the quantity of ventilating air.

For subsequent studies of fresh air make up of less than 700 cfm, either continuous input of building supply gas, or gas decays were employed to determine the EFA ventilation.
II. REMOVAL OF VAPORS OF VARIOUS ORGANIC COMPOUNDS FROM THE CHAMBER SYSTEMS BY DILUTION VENTILATION.

A. ETHYL ALCOHOL

1. At nominal 700 cfm (21 changes per hour). For these studies the value of 700 cfm was employed, being the most probable net value (corrected for leakage of 25-30 cfm).

   a. Continuous input of ethanol into the complete chamber system with recirculation through lined ducts and filters.

   Extensive studies were carried out with ethyl alcohol at concentrations ranging from 3-30 ppm in the air. Employing the HC, the concentration of ethanol was recorded continuously. The HC was calibrated against reference 8.5 ppm propane, and, for the series reported here, showed 18.0 divisions per ppm carbon; for ethanol this was 25.2 divisions per ppm (1.6 carbon equivalents). Laboratory grade, undenatured 95% alcohol was evaporated inside the chamber from an aluminum cup thermostatically controlled to a temperature of 90°C. The ethanol was fed dropwise into the heated cup from a #26 gage needle fixed to the tip of a half gallon reservoir filled with ethanol. A run was made over a period of 2-3 hours so that the amount of alcohol evaporated could be determined by weight loss with some degree of accuracy. Following completion of the continuous input ethanol evaporation was stopped and a decay ventilation determination was made.

   When operating in the manner described above, with complete recirculation through lined ducts and filters, the results obtained were highly variable; recoveries during continuous input ranged from 60 to 80 percent of expected, and ventilation decays showed only some 225 cfm EPA. In order to evaluate these findings, more detailed studies were made in the bare chamber.

   b. Continuous input of ethanol into the bare chamber, in the same manner as described above, except the bare chamber only was employed.

   For a series of 11 separate runs made for a continuous input of ethanol, 8 of which were followed by ventilation decays, the following information was obtained:

   (1) Taking the fresh air flow through the chamber at 700 cfm, the HC showed aerial concentrations of ethanol 74.9 ± 6.9% of that predicted from weight loss information; this would be equivalent to some 933 cfm EPA.
The 8 decay ventilation determinations showed $430 \pm 46$ cfm EFA, which is only some 60% of that expected. These two findings could be interpreted as showing that approximately 25% of the evaporated ethanol was absorbed on the surfaces of the bare chamber, during the period of continuous input and that this gradually desorbed when the input of ethanol was stopped, with continued mechanical ventilation. This could involve, for the longer runs at higher concentrations, as much as 15 grams of ethanol sorbed and then desorbed.

A number of attempts were made to obtain external evidence to verify or deny the loss of such quantities of ethanol by sorption. Foremost among these were efforts to determine the aerial concentration by wet chemical methods; all these involved observation of collected samples by permanganate or dichromate (as alkaline permanganate methods, or the COD methodology). Although none were unqualifiably successful, some confidence was established in the alkaline permanganate method (collect in alkaline 0.005 N permanganate; acidulate with sulfuric acid; add standardized ferrous ammonium sulfate in measured excess; back titrate with standardized ceric sulfate and orthophenanthroline indicator; compare results to a previous calibration against diluted alcohol standards). Results obtained with this procedure tended to agree with the concentration predicted by the weight loss information, suggesting that the absolute calibration of the HC was in error for ethanol, being some 19.1 divisions per ppm ethanol rather than the expected 25.2. However, results were not sufficiently reproducible to warrant any firm conclusion, especially since the extrapolated initial concentration from the plot of single quantities of evaporated alcohol verified the response of the HC (that is extrapolating a decay graph back to zero time yielded a reading for the HC which indicated an initial concentration equal to that predicted on a weight/volume basis when accomplished in a sealed chamber and evaporating 7 milliliters of ethanol; the leakage EFA was $29.6 \pm 2.7$ cfm for 6 such observations and the extrapolated concentration showed 106% recovery. Extrapolation from another series of 11 single inputs of quantities of ethanol ranging from 2-50 ml yielded $105 \pm 19$ percent of calculated concentration. There is no question about the validity of the reduced
effectiveness of dilution ventilation in removing ethanol from the ventilated space; the exact quantitation of sorption and desorption never was satisfactorily resolved.

c. Single inputs of ethanol into the complete chamber system with recirculation.

Quantities of ethyl alcohol ranging from 2-50 ml were evaporated dropwise in the heated aluminum cup (90°C). After allowing for mixing, decay determination was made from HC records. For 7 such determinations, the mean and standard deviation were equivalent to 284 ± 57 cfm EFA, or only some 36 percent of the expected 700 cfm. Comparing this to the 430 cfm EFA (60 percent effectiveness) for ethanol decays in the bare chamber, and the 225 cfm EFA obtained in the complete system, implicates the lined ducts and filters in the holdup of ethanol, in addition to sorption on the surfaces of the bare chamber.

2. Chamber flows of 10, 8 or 4 changes per hour.

a. Single inputs into the complete chamber system with internal recirculation through the lined ducts and filters. The air flow through the chamber was determined from hydrocarbon analysis of methane gas. For the ethyl alcohol studies a known quantity of unde-natured 95% alcohol (usually 7 milliliters) was dropped into a heated aluminum cup in such a fashion that evaporation took only a minute or so. HC recording was continuous and two decay periods were calculated after completion of the initial mixing. For the approximately 10 changes per hour mechanical ventilation 3 runs were made; a single run was made at 8 changes per hour and 2 runs at 4 changes per hour. The results of these experiments are given below:

<table>
<thead>
<tr>
<th>Nominal mechanical ventilation ch/hr.</th>
<th>EFA, from gas</th>
<th>Results with ethanol EFA</th>
<th>Ratios</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EFA</td>
<td>First decay</td>
<td>Second decay</td>
</tr>
<tr>
<td>10</td>
<td>311</td>
<td>279±15</td>
<td>274±5</td>
</tr>
<tr>
<td>8</td>
<td>206</td>
<td>198</td>
<td>186</td>
</tr>
<tr>
<td>4</td>
<td>116</td>
<td>112</td>
<td>102</td>
</tr>
</tbody>
</table>
These data are insufficient to warrant full statistical analysis, but the interpretation seems to be justified that ethyl alcohol is not ventilated as well as is methane gas, that is, there is a marked effect of desorption from the first decay at 10 changes per hour, which becomes negligible at 8 changes per hour or less; the second decay is noticeably affected by this desorption at all levels of mechanical ventilation shown here.

b. Single inputs into the bare chamber.

Because of the questions raised by the results shown above, a more extensive series of runs was made, determining the EFA by continuous input of laboratory gas, and obtaining two decade decays following the evaporation of a single measured amount of ethanol, in a manner similar to that above, except that there was no internal recirculation and only the bare chamber. Runs were made at 10 and 4 changes per hour. The following results were obtained for 3 each complete runs.

<table>
<thead>
<tr>
<th>Nominal mechanical ventilation ch/hr</th>
<th>EFA gas</th>
<th>EFA ethanol decay, for the bare chamber.</th>
<th>EFA gas input</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Results with ethanol</td>
<td>Ratios</td>
<td></td>
</tr>
<tr>
<td></td>
<td>EFA</td>
<td>First decay</td>
<td>Second decay</td>
</tr>
<tr>
<td>10</td>
<td>326±8</td>
<td>279±5</td>
<td>289±20</td>
</tr>
<tr>
<td>4</td>
<td>96±7</td>
<td>96±5</td>
<td>96±8</td>
</tr>
</tbody>
</table>

Comparing the results immediately above with those for ethanol decays in the chamber with complete recirculation through lined ducts and filters it is only at 4 changes per hour that there possibly is a difference, presumably due to desorption from duct liners and filters. This might be due to the fact that at 10 changes per hour the ventilating volume is great enough to mask any effect, or that the rate of desorption of ethanol is slower than this rate of removal of compound by dilution ventilation.

For purposes of comparison, leakage determinations from the sealed chamber were made with ethanol. The average and standard deviation of 6 runs was 29.6 ± 2.7 cfm EFA, which compares favorably with all other such determinations.
3. **In the combined workroom and chamber system.**

   In addition, ethanol was employed in the combined chamber and workroom space, which is some 8,000 cubic feet in volume; this was ventilated by the exhaust blower operating at the nominal 700 cfm or approximately 5 changes per hour. The results of 4 experiments showed no difference between the first and second decays, and an average for the 8 determinations of 799 ± 190 cfm EFA. As should be noted, the replication was of very poor quality, probably due to some two-compartment effect resulting from the chamber location within the workroom. However, the quantity indicated from these experiments is not too dissimilar from the expected (700 cfm nominal, 734 cfm from helium decay at 21 and 23 changes per hour). The most significant finding was that there was no difference between the first and second decay at 5 changes per hour, indicating a significant difference in the effectiveness of dilution ventilation in removing ethanol at greater than 10 changes per hour and that at 5 changes or less per hour. Certainly ventilation rate appears to be the most important variable thus far; total surface area is important, but even the bare chamber furnished sufficient area for some sorption-desorption effects at ventilation rates in excess of 10 changes per hour, but at 5 changes per hour total surface area seems unimportant.

4. **In the sealed chamber (with internal recirculation) Helium leakage was 30 cfm, methane gas 25 cfm. For ethyl alcohol the leakage was 23 cfm.**

5. **Summation**

   The essential information obtained with ethyl alcohol is shown in the two following tables. The first table summarizes the relative effectiveness of dilution ventilation in removing ethyl alcohol vapors from an enclosed space. The effect of ventilation rate, and also of amounts of available surface are self-evident.
Table  
Summary data for ethyl alcohol, relative rates of removal by dilution ventilation.

<table>
<thead>
<tr>
<th>Mechanical ventilation, ch/hr</th>
<th>RATIOS: EFA ethanol decay</th>
<th>EFA gas input</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>First</td>
<td>Second</td>
</tr>
<tr>
<td>Complete chamber:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>0.40</td>
<td>-</td>
</tr>
<tr>
<td>10</td>
<td>0.90</td>
<td>0.88</td>
</tr>
<tr>
<td>8</td>
<td>0.96</td>
<td>0.90</td>
</tr>
<tr>
<td>4</td>
<td>0.97</td>
<td>0.88</td>
</tr>
<tr>
<td>Bare chamber:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>0.60</td>
<td>-</td>
</tr>
<tr>
<td>10</td>
<td>0.86</td>
<td>0.89</td>
</tr>
<tr>
<td>4</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Workroom and chamber</td>
<td>1.14</td>
<td>1.05</td>
</tr>
</tbody>
</table>

There is no question but what significant quantities of ethyl alcohol are sorbed upon various surfaces, and that these are desorbed relatively slowly. The information in the table above indicates that the rate of desorption is such as to be matched by a ventilation rate of something less than 10 changes per hour. This fact suggests that ineffectiveness of attempts to increase the removal of vapor of ethyl alcohol by increasing amounts of dilution ventilation above 10 changes per hour. This finding is clarified by the data presentation in the next table, where are shown both cfm EFA for decays of ethanol vapors at 21 and 10 changes per hour and also the recovery from continuous inputs.
In the above table the most striking information is that the cfm EFA in removing ethyl alcohol by dilution ventilation is essentially the same whether the mechanical ventilation was 21 changes per hour (700 cfm) or 10 changes per hour (311 cfm). The source of the amounts of ethyl alcohol described to account for this phenomenon is shown in this table in the column for recoveries; approximately 25 percent of a continuous input of ethyl alcohol was sorbed upon the surfaces of the chamber system. This sorbed alcohol was then desorbed at such a rate that for a significant time following sorption, removal by dilution ventilation was inefficient at rates in excess of 10 changes per hour.
B. DIETHYL ETHER

1. At nominal 700 cfm in the chamber.

    Procedures were similar to those described above for ethyl alcohol, with the following exceptions; ether was dropped through a #27 gauge needle into the aluminum cup thermostatically controlled to a temperature of 46-48 C.; the HC analyzer calibration for diethyl ether was taken as 54 divisions per ppm from the base calibration of 18 divisions per ppm carbon. Findings were obtained with full chamber recirculation through lined ducts and filters with low concentrations of ether (about 7 ppm). The following results were obtained:

    1. for three continuous input runs, taking the fresh air at 700 cfm the HC analyzer showed the aerial concentration of diethyl ether to be 65 ± 10% of that predicted.
    2. for the decays determined following the continuous input, the first decay averaged 635 ± 33 cfm EFA, the second 497 ± cfm EFA equivalent to 90% and 71% of expected EFA.

    As with ethanol these findings could be interpreted as showing that a significant quantity of ether (some 35% of that evaporated which is as much as 10 grams) condensed or was sorbed upon the interior surfaces, and when the input of ether was discontinued, with fresh air ventilation continued, there was significant desorption. The fact that ether shows 90% of expected initial decay, in contrast to the 60% for ethanol could be due to the slower desorption of the ether from the surfaces of the interior of the chamber.

    However, three runs with single inputs of ether, followed by fresh air ventilation at initial concentrations almost 10 times that above (approximately 70 ppm), showed initial decay equivalent to 473 ± 4 cfm EFA and secondary decays of 310 ± 35 cfm EFA, corresponding to 68 and 44% of expected, respectively.

2. In the combined workroom and chamber system.

    For four runs in which 10 milliliters of ether was evaporated in the combined chamber and work room which has a volume of 8,000 cubic feet, with a nominal 700 cfm yields approximately 5 changes per hour mechanical
ventilation, the first decay showed $942 \pm 124$ cfm EFA, and the second decay $910 \pm$ cfm EFA, equivalent to 128 and 124% respectively. This is consistent with the more detailed findings with ethyl alcohol; at low rates of mechanical ventilation, diethyl ether is removed efficiently by dilution ventilation, but not at higher rates.

3. **In the sealed chamber (with internal recirculation).**

Helium leakage was 30 cfm, methane gas 25 cfm. For diethyl ether leakage was 25 cfm.
C. 2-OCTANOL

This compound has much to offer as an odorant for ventilation studies: a definite, but low vapor pressure (<0.1mm at 25°C); slight water solubility (<0.05 gm per 100 gm of water); being a liquid, does not sublime as does naphthalene; exhibiting only a mildly offensive odor does not have the drawbacks of isovaleric acid. As a result, 2-octanol was employed in a series of tests to validate the HC analyzer effectiveness. These tests showed:

1. Single inputs of 2-octanol in the sealed workroom (total volume, 6,000 ft³), concentration extrapolated back to zero time from decays, recovery; 90.7 ± 8.2 percent (n=3).

2. Single inputs of 2-octanol in the bare sealed chamber, (volume of 1800 ft³), concentration extrapolated back to zero time from decays, recovery; 79.7 ± 8.2 percent (n=8). The leakage from the sealed chamber was determined as 19.5 ± 3.3 cfm EFA (n=8).

3. 2-Octanol evaporated continuously from a heated bubbler into the chamber ventilated at 700 cfm mechanical ventilation, HC analyzer determination compared to weight loss determinations, recoveries; 118 and 117 percent for the two runs. Because apparent recoveries were greater during the dynamic runs than for the single-input runs, it was considered possible that the vaporized 2-octanol formed an aerosol, which did not evaporate in the case of the single-inputs. In order to examine this possibility a Royco particle counter, with recorder, was placed in the chamber, set to record all particles 0.3µm and greater, sampling 300 cc/min. A study was made during a dynamic run, with 2-octanol volatilized from the heated bubbler, and also from a single input when 2-octanol was evaporated from a hot plate.

Proof that 2-octanol did not form an aerosol in ventilated chamber

<table>
<thead>
<tr>
<th>Sequence of Events</th>
<th>Royco count, total particles</th>
<th>HC Signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>8-12 AM - No 2-octanol</td>
<td>2,200-4,000</td>
<td>Set to zero</td>
</tr>
<tr>
<td>1-2 PM - 0.25 cfm N₂ through heated bubbler of 2-octanol</td>
<td>2,500-4,000</td>
<td>300</td>
</tr>
<tr>
<td>4 PM - No 2-octanol</td>
<td>2,600-4,000</td>
<td>5</td>
</tr>
</tbody>
</table>
Proof that 2-octanol did not form aerosol in the sealed chamber

<table>
<thead>
<tr>
<th>Sequence of Events</th>
<th>Royco count, total particles</th>
<th>HC Signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>8-12 AM - Sealed chamber, no octanol</td>
<td>1,600-1,800</td>
<td>Set to zero</td>
</tr>
<tr>
<td>1:00 PM - 5.0 ml 2-octanol volatilized from hot plate in chamber</td>
<td>1,800-2,200</td>
<td>1050 maximum</td>
</tr>
</tbody>
</table>

The above findings were considered as definitive evidence that the techniques employed in volatilizing the test compounds did not form any lasting aerosols.

It was concluded that the HC analyzer system was at least 80 percent effective in demonstrating 2-octanol, and similar compounds dispersed into the air. Such validation was not absolutely essential because almost all of the ventilation studies of consequence were accomplished by determining decay rates.

For 2-octanol in the chamber (1800 ft$^3$ volume) and in the workroom (6,000 ft$^3$ volume) the ventilation equivalents were determined from decay rates as follows:

1. from the bare chamber, mechanical ventilation 700 cfm nominal, expected, 23 ch/hr;

<table>
<thead>
<tr>
<th>EFA, cfm</th>
<th>Equivalent ch/hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>First decay</td>
<td>Second decay</td>
</tr>
<tr>
<td>335 ± 33 (n=3)</td>
<td>173 ± 16 (n=2)</td>
</tr>
</tbody>
</table>

2. from the workroom, mechanical ventilation 700 cfm nominal, expected 7.0 ch/hr;

<table>
<thead>
<tr>
<th>EFA, cfm</th>
<th>Equivalent ch/hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>First decay</td>
<td>Second decay</td>
</tr>
<tr>
<td>516 ± 105 (n=4)</td>
<td>260 ± 70 (n=2)</td>
</tr>
</tbody>
</table>

There is no question but what a significant quantity of 2-octanol deposited upon the surfaces of the chamber and workroom, subsequently revolatilizing. The differences between first and second decays indicate that both condensation and sorption are involved in this revolatization. The bare chamber has mostly enamelled surfaces and the condensed 2-octanol evaporated quickly; the workroom contains a wide variety of surfaces, including vinyl coatings on the walls, into which 2-octanol could have sorbed or even dissolved.
D. 1-BUTANOL

Studies were made with vapors of 1-butanol in the bare chamber only (that is, the lined ducts and filters were sealed off). Quantities of compound ranging from 10-15 ml were evaporated within the chamber in the heated, thermostatically controlled aluminum cup. The concentration, as determined from HC analyzer data, never exceeded 60 percent of the expected, indicating that approximately 40 percent of the compound condensed or was immediately sorbed upon the walls of the bare chamber.

Based upon decay determinations, the following information was obtained for the ventilation of 1-butanol from the bare chamber:

<table>
<thead>
<tr>
<th>Chamber ventilation, determined with gas</th>
<th>EFA from decay of 1-butanol concentrations</th>
</tr>
</thead>
<tbody>
<tr>
<td>700 cfm (23 ch/hr)</td>
<td>139.5 ± 0.5 (n=2)</td>
</tr>
<tr>
<td>100 cfm (3.3 ch/hr)</td>
<td>73.5 ± 3.45 (n=6)</td>
</tr>
</tbody>
</table>

These findings are consistent with those obtained for other compounds; at a mechanical ventilation rate as great as 23 ch/hr, 1-butanol is desorbed from even enamel surfaces so slowly as to be removed with only 20 percent efficiency; at the lower rate of mechanical ventilation, removal is nearly 75 percent effective.
E. 2-HEXANOL

The HC analyzer responded to the presence of vapors of this compound in the air in a manner which was expected, that is, air from a mylar bag containing liquid 2-hexanol (gave a HC signal nearly equivalent to expected saturation concentration of 2-hexanol). However, extremely variable results were obtained in attempts to remove 2-hexanol by dilution ventilation from the chamber. Up to 10 grams of the compound were evaporated into the chamber system, and at no time were the resultant signals as great as expected. When the chamber system was ventilated at nominal 700 cfm (23 ch/hr) 2-hexanol was removed at rates equivalent to 50-150 cfm EFA. Ventilating the chamber at nominal 100 cfm (3.3 ch/hr), 2-hexanol was removed at rates equal to EFA ranging from 20-40 cfm.

At the end of ventilation experiments with 2-hexanol no odor was detectable subjectively; the original liquid had a slight mint-like odor. No explanation was ever obtained as to the cause of these phenomena.
This compound is of the greatest interest as an odorant being responsible for "body-odor" associated with perspiration, and is the most significant component of "locker-room" odors. Isovaleric acid was the one compound for which it was possible for untrained observers to identify all concentration levels well below those which the HC analyzer could detect. The odor of iso-valeric is so offensive and lingered so long that several days were required to purge the chamber and workroom of it. This added greatly to the length of time required to conduct studies on this compound. In one instance, 15 ml of isovaleric acid was volatilized in the chamber, opened into the workroom, and it was two weeks before the residual odor was removed. During that time, elevated temperature and humidity (90°F, 90 percent relative humidity) was intermittently employed, alternating with high ventilation rates. Even after three days of ventilation, when the chamber was closed overnite, the concentration of isovaleric within the chamber built up to 50 percent of initial, as indicated by the HC analyzer.

1. At nominal 700 cfm mechanical ventilation in the bare chamber (23 ch/hr) (ducts and filters sealed off): 35 ± 32 cfm EFA (n=9), determined from the rate of disappearance of 15 ml of isovaleric acid volatilized into the air of the chamber, as determined by the HC analyzer. The observed concentration ranged from 20 to 40 percent of expected, indicating that 60-80 percent of the volatilized compound had immediately condensed or sorbed on the chamber surfaces. For the sealed chamber the leakage was found to be 15.8 ± 3.4 cfm EFA (n=5). In short, the quantitative evidence simply verifies that of the personal olfactory response - isovaleric acid is a long-lasting odorant, and is not efficiently removed by dilution ventilation.

2. At nominal 700 cfm mechanical ventilation in the workroom, with the chamber sealed off (7 ch/hr): 206 ± 35 cfm EFA (n=2), determined from the rate of disappearance of 15 ml of isovaleric acid volatilized into the workroom, as determined from the HC analyzer record. The maximum concentration observed was approximately 12 percent of that expected.
As with other compounds, the rate of removal by dilution ventilation is markedly affected by the rate of mechanical ventilation decreasing markedly as the rate of mechanical ventilation is increased. The bulk of the volatilized isovaleric acid condensed or was sorbed on the surfaces of the chamber or workroom and slowly revolatilized. The rate of revolatilization becomes the controlling factor in the removal of such an odorant - increasing the quantity of ventilating air above that required to supply this rate of ventilation accomplishes little or nothing towards the removal of the compound.
G. NAPHTHALENE

A considerable amount of effort was expended upon studies with this compound. Because of its low vapor pressure and ability to sublime, it seemed similar to odorants of the "lingering" type associated with human body odors. These characteristics meant that ventilation studies in the chamber were conducted over a number of hours, and often, for several days.

In general, employing the full chamber system, complete with ducts and filters, the concentration of naphthalene found in the air of the chamber was never more than 25 percent of that expected, indicating that some 75 percent of the compound condensed or sorbed. Under these conditions, with mechanical ventilation of 700 cfm (21 ch/hr) the removal of naphthalene by ventilation showed no more than 43 cfm EFA, as determined from the rate of disappearance. Leakage was usually of the order of 18 cfm EFA. A very large number of studies were made, and the low value well-established. It was not until later that it was realized that these studies were all made at 21 ch/hr mechanical ventilation and with the full chamber system in use - conditions which would emphasize the reduced rate of removal by ventilation of a compound exhibiting a low vapor pressure. Subsequently, a series of studies were conducted employing the entire workroom, where 700 cfm mechanical ventilation is equivalent to only 5 ch/hr.

In contrast to the runs at 21 ch/hr, those in the workroom at 5 ch/hr yielded more reasonable rates of disappearance of naphthalene. However, the results were highly variable, and the cause was not evident until it was realized that the rate of removal of naphthalene by ventilation correlated with the quantity of compound volatilized, ranging from as great as 472 cfm EFA for 1.0 gram of naphthalene to as little as 130 cfm EFA for 10.0 grams of naphthalene. Although the reproducibility was not of the best, this correlation is evident among the data obtained for 10 runs made with varying quantities of naphthalene, under otherwise identical conditions, that is, dispersed into the workroom 700 cfm mechanical ventilation, to yield 5 ch/hr:
<table>
<thead>
<tr>
<th>Naphthalene volatilized, gms</th>
<th>EFA in cfm</th>
<th>First decay</th>
<th>Second decay</th>
<th>Third decay</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 (n=2)</td>
<td>457 ± 25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.0 (n=2)</td>
<td>301 ± 5</td>
<td>290 ± 47</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.0 (n=5)</td>
<td>228 ± 65</td>
<td>250 ± 75</td>
<td>150 ± 40</td>
<td></td>
</tr>
<tr>
<td>8.0 (n=2)</td>
<td>230 ± 66</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.0 (n=2)</td>
<td>149 ± 20</td>
<td>370 ± 65</td>
<td>170 ± 16</td>
<td></td>
</tr>
</tbody>
</table>

It should be noted that this relationship was observed in the early stages of the study, and the details of volatilizing naphthalene were carefully considered. This was conducted on an aluminum pie-plate on the thermostatically controlled hot plate, and no evidence was ever obtained that there was incomplete volatilization of the naphthalene. Attempts to account for all of the compound through summation of the aerial concentrations in the exhaust air were never completely successful, but they did show that large amounts of naphthalene must have deposited on the surfaces of the workroom and later volatilized again when the aerial concentration decreased. This conjecture also serves to explain the inverse correlation of input quantity and rate of removal: the greater the input quantity, the greater the amount deposited on the workroom surfaces and subsequently revolatilized.
H. OTHER ORGANIC COMPOUNDS

Among the number of compounds considered as odorants, two of those which were examined as candidates proved to be entirely useless. These were benzyl alcohol and camphor. In both instances, the HC analyzer responded to the compound when "sniffing" from a mylar bag containing the compound. However, when volatilized into the air of the chamber, almost no signal was obtained on the HC analyzer, and very erratic revolatilization signals were obtained over periods of many hours.

Additionally, methanol had been considered for these studies, but the effective HC analyzer signal was too poor to warrant any formal investigations.

Formaldehyde had been selected for these studies as a gaseous odorant (in contrast to vaporous odorants), but the HC analyzer was not suitable for this compound. However, a wet-chemical method for aldehydes was available, and a considerable amount of work was accomplished with this compound, however, because no recording equipment was available at the time, only a few decays were determined. The bulk of the work was accomplished in evaluating methods of removal, such as activated carbon and permanganate, where a wet chemical method employing spot samples could be useful. These studies are summarized separately. For the few decay determinations made in the ventilated chamber with formaldehyde the results indicated that this compound does not act entirely as a gas, a not unexpected finding, in view of the polymers which readily form. For the mechanical ventilation of 700 cfm nominal, formaldehyde was ventilated at some 640 cfm EFA from the bare chamber for the first decay, but with a long second decay indicating a 103 cfm EFA, apparently due to the slow volatilization of polymeric products. These are equivalent to 21.3 and 3.4 ch/hr, respectively, for the gaseous phase of formaldehyde and the polymeric forms.
III. REMOVAL OF VAPORS OF ORGANIC COMPOUNDS FROM THE CHAMBER BY
METHODS OTHER THAN VENTILATION.

A. CARBON FILTERS

Although we did not find the practical efficiency of carbon filters
to be as high as generally claimed, nevertheless, for removal of most
odorant vapors, single pass carbon filters are at least 85 percent
effective, until saturated. Thus, for odorants arising within a general
ventilating zone, carbon filters are very effective, and can be compared
to outside fresh air on a direct economic basis. The economic basis
is very difficult to determine because of wide variation in local factors
such as installation, maintenance and labor costs. If there is any
question as to the pollutant load of outside air, the use of internal
recirculation, aided, if necessary, by carbon filters would be the
method of choice. However, for most odorants, we find that only a
fraction of the total amount is carried by ventilating air, and thus
much of the odorant will not be carried back to central zone carbon
filters. This phenomenon is the basis for the rather surprising
effectiveness of small units located within a room wherein a source
of odorant is located.

As a result of the experiences described above, carbon filters were
evaluated within the chamber where two filters were located, air
circulating through them at a total of 2,000 cfm. Compound was vola-
tilized within the sealed bare chamber; the rate of removal determined
from the HC analyzer records, translated into EFA in cfm, and finally
expressed as percent effectiveness, employing 2,000 cfm as the reference
quantity.

As a check on the carbon filters, they were installed in the exit
of the chamber and 2-octanol laden air passed through them; the average
efficiency removal of 2-octanol was 85 percent. On the other hand, as
expected, the removal of methane gas averaged 5 percent.
Effectiveness of Carbon Filters Located within the Chamber

<table>
<thead>
<tr>
<th>Compound</th>
<th>EFA, cfm</th>
<th>Equivalent Fresh Air, ch/hr</th>
<th>Average percent effectiveness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethanol</td>
<td>343 ± 11 (n=3)</td>
<td>11.4</td>
<td>17.1</td>
</tr>
<tr>
<td>Diethyl ether</td>
<td>904 ± 120 (n=3)</td>
<td>30.1</td>
<td>45.2</td>
</tr>
<tr>
<td>Isovaleric acid</td>
<td>126 ± 30 (n=2)</td>
<td>4.2</td>
<td>6.3</td>
</tr>
<tr>
<td>2-Octanol</td>
<td>510 ± 75 (n=3)</td>
<td>17.0</td>
<td>25.5</td>
</tr>
</tbody>
</table>

The data obtained show that a sorptive system located within a room can remove considerable amounts of the vapors of odorants which arise within the room, but that once the odorant has sorbed or condensed upon the room surfaces, the rate of revolatilization becomes the controlling factor. In short, it is more effective to locate odor-removing devices within the spaces where the odor arises, but even in this instance, odor removal is not a very efficient process because of the sorption and condensation of odorants on room surfaces.

Losses to surfaces and revolatilization vary with the compound; the equivalent ch/hr of fresh air varies from 4.2 for isovaleric acid (which is very long-lasting) to 30.1 for diethyl ether (which ventilates relatively easily). Comparison of these to the EFA with 700 cfm mechanical ventilation emphasizes the importance of these factors.

Comparison of EFA, ch/hr, in bare chamber (1800 ft³):

<table>
<thead>
<tr>
<th>Compound</th>
<th>Equivalent Fresh Air, ch/hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal carbon filters, recirculating 2,000 cfm</td>
<td>Mechanical ventilation, 700 cfm fresh air</td>
</tr>
<tr>
<td>Diethyl ether</td>
<td>30.1</td>
</tr>
<tr>
<td>Ethanol</td>
<td>11.4</td>
</tr>
<tr>
<td>2-Octanol</td>
<td>17.0</td>
</tr>
<tr>
<td>Isovaleric acid</td>
<td>4.2</td>
</tr>
</tbody>
</table>

With the exception of ethanol, the data show an advantage to locating an odor-removing device within the room where the odor arises, and thus preventing its buildup in other portions of the institution.
B. WATER WASHER IN THE AIR CONDITIONING SYSTEM

In order to evaluate the actual effectiveness of water washers, which in practice would be installed as a portion of an air handling system, studies were made in the workroom, utilizing the air conditioning system water washer. The workroom has a gross volume of 8,000 ft\(^3\), and the air conditioning system draws in 2,000 cfm from the room, first through a wetted coil water washer, then into a tempering section where the air is reheated to the desired temperature and returned to the workroom. The temperature of the water washer determines the dewpoint of the treated air. For the studies reported here, the temperature of the water washer was 35 ± 2°F, yielding a dewpoint of 45°F in the conditioned air.

Single amounts of compounds were liberated or volatilized into the workroom with all fresh air supply and exhaust sealed off, and the air conditioning system operating. Concentrations of compound were determined with the HC analyzer, and this record converted into decay values which yielded cfm EFA. This quantity was converted into percent efficiency of the water washer employing 2,000 cfm as the basis. Such efficiency values include losses to surfaces and revolatilization effects, as can be seen from the differences between first and second decay values for some of the compounds.

<table>
<thead>
<tr>
<th>Compound</th>
<th>EFA, cfm</th>
<th>Apparent percent efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>First decay</td>
<td>Second decay</td>
</tr>
<tr>
<td>Ethanol</td>
<td>496 ± 37 (n=4)</td>
<td>368 ± 65 (n=4)</td>
</tr>
<tr>
<td>Diethyl ether</td>
<td>204 ± 1 (n=2)</td>
<td>132 ± 7 (n=2)</td>
</tr>
<tr>
<td>2-Octanol</td>
<td>120 (n=1)</td>
<td>-</td>
</tr>
<tr>
<td>Naphthalene</td>
<td>100 ± 3 (n=2)</td>
<td>-</td>
</tr>
<tr>
<td>Lab gas</td>
<td>150 ± 22 (n-6)</td>
<td>120 ± 17 (n=8)</td>
</tr>
</tbody>
</table>

The information shown above for apparent efficiency of a water washer for removing odorants from air includes both losses to surfaces and revolatilizations. There is some removal of almost any compound, including
laboratory gas, which is primarily methane. However, the only compound removed with significant efficiency was ethanol, which is infinitely soluble in water. For the vapors of 2-octanol and naphthalene the removal probably was effected by the lowered temperature of the water, being a condensation phenomenon rather than solution. However, high water solubility is characteristic of some compounds of interest, such as sulfur dioxide, and the potential of water washers should not be overlooked.

Considering the potential of lowered temperatures - for condensing the vapors of odorants out of the air, a number of attempts were made to capitalize upon this. For these studies the workroom was employed, employing the refrigeration coils without the water washers. Otherwise, the procedure was identical to that above. Coil temperatures were maintained at 20-30°F. The results were uniformly disappointing; although indicating theoretical response, in practice, recycling of coil temperatures and build up of compound all resulted in short term removals followed by revolatilization of the compound. Often the concentrations observed during the revolatilization phase were greatly in excess of those observed originally.
IV. STUDIES WITH SULFUR DIOXIDE

Sulfur dioxide was selected for these studies as a representative extramural air pollutant, and also as a highly water-soluble true gas (in contrast to a vapor). Unfortunately, analytical recording devices were not available to us, primarily because of excessive costs, and sulfur dioxide studies were carried out with wet-chemical methods on individual samples. Although time-consuming, such techniques were found suitable for all the required studies, except a few in which short-term decay values were desired; these could not be obtained because of the requirement for a minimum of 10 minutes for sampling.

In order to conduct essentially continuous monitoring of sulfur dioxide concentrations, three Gelman 24-place Sequential Samplers (model 24008) were employed, providing up to 72 hours of samples, one per hour. A modified West-Gaeke method was employed for analysis (details in Appendix). Chemically pure anhydrous sulfur dioxide was obtained in cylinders, and with the aid of regulators and micro-flow valves, small flow meters were employed to introduce constant inputs of known amounts of sulfur dioxide into the chamber for long periods of time. The flow meters were calibrated against wet-test meters and bubble meters and then calibrated for sulfur dioxide by collecting in standardized iodine solutions and back titrating with thiosulfate. Such standardizations were later validated by comparing chamber air concentrations to concentrations predicted from the sulfur dioxide flow meter readings.

A. REMOVAL BY DILUTION VENTILATION

Although a great deal of effort was expended upon a large number of ventilation studies with sulfur dioxide, the essential information is easily summarized:

1. When sulfur dioxide was introduced continuously into the bare chamber at 300 mg/minute, with 23 ch/hr mechanical ventilation, the calculated rate of ventilation of sulfur dioxide was 25 ch/hr. This value was repeatedly verified for numerous runs over several days; the only exception was that a value slightly greater than this was sometimes
observed during the first 24 hours of a run. It was concluded that, at relatively high concentrations, sulfur dioxide is sorbed on wall surfaces, but that this effect is almost negligible insofar as calculating rates of removal of this compound by ventilating air.

2. When single inputs of sulfur dioxide were introduced into the workroom (8,000 ft³ volume), ventilated at 5 ch/hr, repeated decay evaluations showed rates of removal of sulfur dioxide of: 5.5 ch/hr for the first decay, followed by a second decay of 3.6 ch/hr. The only possible explanation of the second decay is that the vinyl coating of the workroom is responsible; otherwise, sulfur dioxide acted as a simple gas.

B. REMOVAL BY WATER WASHER

In addition to the ventilation studies, other methods of removing sulfur dioxide from the air were investigated, primarily to evaluate devices for removing an extra mural air pollutant from outside air. As a result, most of these studies were concerned with single-pass evaluations.

The water washer in the air conditioning system showed slightly over 30 percent efficiency in removing sulfur dioxide from the air, at a concentration of 0.57 ppm (1.5 μg/L). Although this is a small amount of sulfur dioxide, it is still somewhat greater than would be expected from extra mural sources, even in urban areas. However, this efficiency would be expected at even lower concentrations because the contact efficiency of the water washer employed is only about 40 percent. It is reasonable to predict that more effective water washers could be a simple method for protecting the interior of institutions from water-soluble air pollutants such as sulfur dioxide.

C. REMOVAL BY ACTIVATED CHARCOAL

For treatment of makeup air, commercial charcoal filters could be employed, but the life-expectancy is not very great, and there is always the danger of desorption when removing a true gas with activated charcoal. Specially treated reactive carbons are available, but there is an added cost. A typical run on a pair of commercial activated charcoal filters consisted of introducing sulfur dioxide into the chamber at such a rate as to yield a challenge concentration of 2.7 ppm sulfur
dioxide, running air through the filters within the chamber, and sampling both upstream and downstream from the filters. Downstream samplings were taken from a tunnel arrangement, which prevented back intrusion of chamber air. Samplings were made for periods during a test. The results of such a test are tabulated below:

Performance of commercial activated charcoal filters* continuously exposed to 2.7 ppm sulfur dioxide for 42 days.

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Downstream of filters averages for 24 hour observations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SO₂ ppm</td>
</tr>
<tr>
<td>1st 24 hours</td>
<td>0.3</td>
</tr>
<tr>
<td>2nd &quot; &quot;</td>
<td>0.4</td>
</tr>
<tr>
<td>6th &quot; &quot;</td>
<td>0.5</td>
</tr>
<tr>
<td>14th &quot; &quot;</td>
<td>0.8</td>
</tr>
<tr>
<td>30th &quot; &quot;</td>
<td>1.1</td>
</tr>
<tr>
<td>42nd &quot; &quot;</td>
<td>1.5</td>
</tr>
</tbody>
</table>

*Two Barneby-Cheney FMD, SP-1713, U-5242, each rated and operated 1000 cfm, containing 45 pounds activated charcoal.

The results obtained for these commercial carbon filters shows good original efficiency for sulfur dioxide, but this has dropped markedly by the end of the forty-second day.

Almost all manufacturers of activated charcoal filters make small units for individual room use. Although these are designed for removal of odors, the general understanding is that this means vaporous odorants. However, some tests were made against sulfur dioxide with a small unit, the Deodor-All. This unit has a small fan and moves 180 cfm through a bed of activated charcoal. It is advertised to deodorize rooms up to 3,040 ft³, maximum volume. Single inputs of sulfur dioxide of 10 µg/L were introduced into the sealed recirculating chamber (volume, 2,000 ft³), and the effectiveness of the unit evaluated from the decay of sulfur dioxide concentrations. These single inputs were repeated for six days;
concentrations were monitored on the first day and then monitoring started again on the fourth day. The results obtained are tabulated below:

Effectiveness of Deodor-All unit in removing sulfur dioxide; single inputs of 10 μg/L in recirculating chamber of 2,000 ft³ volume.

<table>
<thead>
<tr>
<th>Period</th>
<th>EFA, cfm</th>
<th>Efficiency of removal, percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>First 24 hours</td>
<td>75.5</td>
<td>42</td>
</tr>
<tr>
<td>Fourth</td>
<td>62</td>
<td>34</td>
</tr>
<tr>
<td>Fifth</td>
<td>50</td>
<td>28</td>
</tr>
<tr>
<td>Sixth</td>
<td>45</td>
<td>25</td>
</tr>
</tbody>
</table>

These results indicate, just as did these for the larger commercial filters, that activated charcoal can remove sulfur dioxide from the air, but it is rather quickly saturated.

D. REMOVAL BY PURAFIL UNIT

The Purafil unit is designed for deodorizing in rooms; it consists of blowers (2-speed, 250 cfm on Low; 450 cfm on High), housing and a perforated filter unit containing some 25 pounds of small pellets of aluminum oxide, which are impregnated with potassium permanganate (approximately 5 percent by weight). This unit was developed with the idea in mind that odorants are almost invariably organic compounds which can be oxidized to non-odorous materials; the alumina is intended to sorb the odorant, followed by oxidation by the permanganate. We had become interested in this unit for possible removal of cigaret-smoke odors, and found it of value in removing formaldehyde from the air.

Trials with sulfur dioxide were made, originally from idle curiosity, but later from a real interest, not so much in the commercial unit itself, but in some of the reaction mechanics involved. Following tests with formaldehyde in the chamber, a Purafil unit was exposed to sulfur dioxide, and the concentration decay determined. For this run 135 cfm EFA was obtained, a value which indicated the unit might have some value in uptake of sulfur dioxide, although having little single-pass value (the equivalent single-pass effectiveness at 450 cfm would be
30 percent). However, that same night, the unit was exposed continuously to 1.5 ppm sulfur dioxide, and showed only 35 cfm EFA. After another day the single input decay was repeated, and showed 64 cfm EFA. A few days later the continuous input study was repeated and showed 64 cfm EFA. It was suggested by the manufacturer that there is a lag in the uptake and reaction involved in sorption of sulfur dioxide on the surface of the alumina pellets and subsequent oxidation by the permanganate. Allowing a few days "rest" refurbished the surfaces and renewed the activity.

It seemed possible that some such system as described above would have advantages over carbon. Carbon, when approaching saturation, tends to desorb compound when the aerial concentration of the compound is lowered; the alumina-permanganate system is renewed under such conditions. As a result, some very lengthy studies were conducted, hoping to obtain information which might lead to development of a better method of removing low concentrations of sulfur dioxide from the air, if such were ever needed.

Continuing in the chamber, a new charge of Purafil pellets was introduced into the unit. Allowing a week between runs, the following results were obtained:

a. from continuous exposure to 0.6 ppm sulfur dioxide; two runs, 387 and 260 cfm EFA.

b. from single inputs and decay determinations, 172 and 260 cfm EFA.

This unit, with the same pellets, now having been used some 100 hours, was placed in a chamber formed by polyethylene film and exposed continuously to a concentration of 1.5 ppm sulfur dioxide. For the first 24 hours the EFA was 165 cfm, but the second day it fell to 54 cfm. The system was allowed to operate for a month, with intermittent observation: after 10 days, EFA fell to some 20 cfm and remained there. These pellets were taken out and held for a week, and used again, when they showed 82 cfm EFA.

The response of the pellets was checked closely, and it was found that within two hours the initial high effectiveness was lost, if the concentration of sulfur dioxide was as great as 1.7 ppm. This was disappointing and a final study was made at a very low concentration: 0.10 ppm sulfur dioxide.
Continuous exposure of a new charge of Purafil to 0.10 ppm sulfur dioxide showed average values:

a. end of first 24 hours, 140 cfm EFA
b. end of first week, 50 cfm EFA
c. end of 2nd " , 50 " 

d. end of 3rd " , 50 " 

e. end of 4th " , 50 " 

It was concluded that the rate of surface sorption and reaction is too slow to respond to as low a concentration as 0.1 ppm SO₂, and, despite our best efforts and hopes, the Purafil unit was abandoned for the removal of sulfur dioxide from the air.
V. STUDIES WITH FORMALDEHYDE

Formaldehyde was chosen as a representative water-soluble gas; it does occur inside the hospital and also is representative of aldehydes occurring as extramural air pollutants. Although no recording equipment was available to us for monitoring aerial concentrations, an excellent wet-chemical method was available (see Appendix for details). Sampling procedures for formaldehyde were the same as those developed and employed for the sulfur dioxide studies. Formaldehyde was quantitatively introduced into the air by dropping diluted C.P. formaldehyde solution through No. 27 stainless steel needles from a constant head supply bottle onto a heated aluminum surface. The dispensing system was calibrated and, for continuous inputs, the quantity of formaldehyde could be determined from weight loss from the supply bottle.

A. REMOVAL BY DILUTION VENTILATION

Early studies on the use of fresh air to ventilate a single small input of formaldehyde from the chamber showed a first decay of 640 cfm EFA, or 21.3 ch/hr compared to the expected 23 ch/hr. The second decay showed only 103 cfm EFA, or 3.4 ch/hr. Subsequent experiments yielded erratic results, and after several weeks of wasted effort, it was realized that the entire chamber system had become coated with formaldehyde and its polymerization products. The observation was made when the concentration became so great as to be irritating to personnel even after a weekend of fresh air ventilation. Systematic studies within the chamber showed that the interior surfaces were liberating formaldehyde at the rate of 4 mg/minute for 24-36 hours when fresh air was supplied at 700 cfm (23 ch/hr). This rate dropped down to approximately 1 mg/minute after 36 hours. Such conditions had resulted from introduction of quantities of formaldehyde sufficient to achieve aerial concentrations of 20 µg/L. All subsequent work was carried out with one-tenth these quantities, but eventually the chamber system became coated and difficult to work with.

It was concluded that dilution ventilation is a very poor method for eliminating formaldehyde once the surfaces of an enclosure have become
coated with its polymeric products. Under these conditions, the rate of revolatilization is not more than the equivalent of 3.4 ch/hr. However, dilution ventilation seemed to be effective when formaldehyde was liberated in very small amounts.

B. REMOVAL BY CARBON FILTERS.

Two commercial activated charcoal filters, each rated and operated at 1,000 cfm, were located within the chamber during early studies with formaldehyde at relatively high aerial concentrations. The apparent effectiveness of these carbon filters against formaldehyde was less than one percent. Actually, after a week of exposure to formaldehyde, the carbon filters apparently acted as a source of formaldehyde.

C. REMOVAL BY PURAFIL

The Purafil unit (described in the section on sulfur dioxide) showed some promise in an early run: against a continuous input of formaldehyde sufficient to maintain 0.3 μg/L net concentration of formaldehyde, the unit showed 169 cfm EFA. However, subsequent decays showed not more than 35 cfm EFA. Because of problems of buildup of polymerization products on chamber surfaces, subsequent studies were conducted in a small chamber formed by polyethylene film, where surfaces were at a minimum. This chamber is 3' x 3' x 7', and is constantly ventilated at 25 cfm.

In the small chamber a fresh charge of 24 pounds of Purafil pellets was introduced into the unit and continuously exposed to the equivalent of 14 μg/L formaldehyde in the air for a total of 2 months (1430 hours). The following results were obtained:

a. End of first 24 hours: 130 cfm EFA  
b. End of first week, to end of sixth week: 75 cfm EFA  
c. Seventh and eighth weeks: 60 cfm EFA.

The total amount of formaldehyde taken up by the Purafil pellets was estimated to be some 400 grams. Although the single-pass efficiency was never very great (moving 450 cfm, maximum was 29 percent), the
ability to remove formaldehyde and the life of the pellets both were impressive. During the first 200 hours of operation the unit removed formaldehyde from the air at an average of 6.5 mg/minute, and for the next 1200 hours at nearly 4 mg/minute.

The Purafil unit was then evaluated under conditions of greater concentrations of formaldehyde. The challenge concentration was 67.5 μg/L of air, and samplings were made each 24 hours, after an initial sampling:

a. End of four hours: 313 cfm EFA
b. End of 24 hours: 57 cfm EFA
c. End of 48 hours: 25 cfm EFA
d. End of 72 hours: 19 cfm EFA
e. End of 120 hours: 17 cfm EFA

Finally, the Purafil unit was recharged and tested under conditions of low challenge - 2.0 μg/L of formaldehyde:

a. From start to 170 hours, average 225 cfm EFA.
b. For next 170 hours, average 100 cfm EFA.

This run showed a single-pass efficiency of 50 percent during 170 hours operation, which dropped back down to 22 percent after this.

Although there was no opportunity to conduct complete evaluations of Purafil against odorants other than formaldehyde, the results obtained with that compound indicate that such small units could be of considerable value in controlling odors within rooms. The single-pass efficiency of the Purafil pellets is too low to warrant their use in main air treatment systems.
VI. SUMMARY OF RATES OF REMOVAL OF COMPOUNDS FROM AIR BY DILUTION VENTILATION.

Retrospective analyses of the very large number of ventilation studies carried out with several different compounds, including both gasses and vapors, finally yielded a simple parameter which seems adequate to describe the relationship between dilution ventilation and compound being ventilated. This parameter is the equivalent ventilation constant, usually expressed in terms of changes per hour (ch/hr); changes per hour being determined from the quantity of ventilating air, divided by the volume of the ventilated space. In the present case the equivalent ch/hr is obtained from the cubic feet per minute of equivalent fresh air (cfm EFA) as actually determined from ventilation studies of a compound. In this relationship the size of the ventilated space is given consideration, in contrast to the statement for EFA, which considers only the rate of input of compound, regardless of the size of the ventilated space. In the original approach to these studies it was assumed that a statement for cfm EFA would describe the ventilation of odorants from enclosures, and a great deal of time and effort was expended in attempting to arrive at explanations for the anomalous results obtained for many of the compounds.

In analyzing the results obtained, a variety of physical parameters were examined; this examination suggested that differential revolatilization of condensed or sorbed vapors was the primary factor responsible for the otherwise unexplained results. The most straight forward statement which gives consideration to the surface of an enclosure is the ventilation constant, which relates quantity of ventilating air to room volume.

A summary has been made of the equivalent ch/hr determined for all of the compounds for which quantitative data were obtained. Such information was collected from spaces varying in volume from slightly less than 2,000 ft$^3$ (the chamber) to greater than 100,000 ft$^3$ (Radio Bio building). This information is tabulated below, showing: the compounds in order of ease of removal by dilution ventilation; the ventilated space; the actual ventilation effected by mechanical exchange of fresh air; and finally, the determined equivalent ch/hr for the compound, expressed as "Rate of removal of compounds ch/hr." These latter values are derived from the first decay determination following introduction of small amounts of the compounds.
Rates of removal of various compounds by dilution ventilation as determined by initial rates of disappearance following volatilization of small amounts.

<table>
<thead>
<tr>
<th>Compound</th>
<th>Ventilated Space</th>
<th>Mechanical Ventilation, ch/hr</th>
<th>Rate of Removal of compound, ch/hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulfur dioxide</td>
<td>Chamber</td>
<td>23*</td>
<td>25</td>
</tr>
<tr>
<td>&quot;</td>
<td>Workroom</td>
<td>5</td>
<td>5.5</td>
</tr>
<tr>
<td>Freon</td>
<td>Chamber</td>
<td>23</td>
<td>23</td>
</tr>
<tr>
<td>Helium</td>
<td>Workroom</td>
<td>23</td>
<td>23</td>
</tr>
<tr>
<td>Formaldehyde gas</td>
<td>Chamber</td>
<td>23</td>
<td>21</td>
</tr>
<tr>
<td>Methane</td>
<td>&quot;</td>
<td>21*</td>
<td>17</td>
</tr>
<tr>
<td>Water</td>
<td>&quot;</td>
<td>21</td>
<td>18</td>
</tr>
<tr>
<td>Laboratory gas</td>
<td>&quot;</td>
<td>21</td>
<td>17</td>
</tr>
<tr>
<td>&quot;</td>
<td>&quot;</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>&quot;</td>
<td>&quot;</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>&quot;</td>
<td>&quot;</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>&quot;</td>
<td>Workroom</td>
<td>5**</td>
<td>5</td>
</tr>
<tr>
<td>Diethyl ether</td>
<td>Chamber</td>
<td>23</td>
<td>14</td>
</tr>
<tr>
<td>&quot;</td>
<td>Workroom</td>
<td>5</td>
<td>5.5</td>
</tr>
<tr>
<td>&quot;</td>
<td>&quot;</td>
<td>Atomedic Bldg.</td>
<td>5.2</td>
</tr>
<tr>
<td>&quot;</td>
<td>&quot;</td>
<td>Radio Bio Bldg.</td>
<td>2.4</td>
</tr>
<tr>
<td>&quot;</td>
<td>&quot;</td>
<td>7.2</td>
<td>7.2</td>
</tr>
<tr>
<td>Ethyl alcohol</td>
<td>Chamber</td>
<td>23</td>
<td>14</td>
</tr>
<tr>
<td>&quot;</td>
<td>&quot;</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>&quot;</td>
<td>&quot;</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>&quot;</td>
<td>&quot;</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>&quot;</td>
<td>&quot;</td>
<td>5</td>
<td>5.5</td>
</tr>
<tr>
<td>&quot;</td>
<td>&quot;</td>
<td>Atomedic Bldg.</td>
<td>5.2</td>
</tr>
<tr>
<td>&quot;</td>
<td>&quot;</td>
<td>Radio Bio Bldg.</td>
<td>2.1</td>
</tr>
<tr>
<td>&quot;</td>
<td>&quot;</td>
<td>7.2</td>
<td>7.1</td>
</tr>
<tr>
<td>2-Octanol</td>
<td>Chamber</td>
<td>23</td>
<td>11</td>
</tr>
<tr>
<td>&quot;</td>
<td>Workroom</td>
<td>7</td>
<td>5.2</td>
</tr>
<tr>
<td>1-Butanol</td>
<td>Chamber</td>
<td>23</td>
<td>4.6</td>
</tr>
<tr>
<td>&quot;</td>
<td>&quot;</td>
<td>4</td>
<td>2.9</td>
</tr>
<tr>
<td>2-Hexanol</td>
<td>&quot;</td>
<td>23</td>
<td>3.8</td>
</tr>
<tr>
<td>&quot;</td>
<td>&quot;</td>
<td>4</td>
<td>1.2</td>
</tr>
<tr>
<td>Polymeric formaldehyde</td>
<td>&quot;</td>
<td>23</td>
<td>3.4</td>
</tr>
<tr>
<td>Naphthalene</td>
<td>Workroom</td>
<td>23</td>
<td>1.4</td>
</tr>
<tr>
<td>Isovaleric acid</td>
<td>Chamber</td>
<td>23</td>
<td>1.2</td>
</tr>
<tr>
<td>&quot;</td>
<td>Workroom</td>
<td>7</td>
<td>2.1</td>
</tr>
</tbody>
</table>

* For the chamber, mechanical ventilation of 23 ch/hr is for the bare chamber (1800 ft³ volume); mechanical ventilation of 21 ch/hr is for the complete chamber, with internal recirculation through ducts and filters.

** For the workroom, mechanical ventilation of 5 ch/hr is for the combined workroom and chamber (volume 8,000 ft³); 7 ch/hr is for the workroom with the chamber sealed off.
The information tabulated above has been employed as a basis for indicating the limiting rate of removal for various types of compounds with "fresh" air, where the concentration of the odorant in such "fresh" air is negligible. In any instance where the value for "Rate of removal of compound, ch/hr" is less than the value for "Mechanical ventilation, ch/hr," the compound will not be removed by dilution ventilation at the rate predicted from the rate of mechanical ventilation. For some compounds information is available for a lower rate of mechanical ventilation; in these instances it is possible to estimate the probable limiting value. For example, for laboratory gas, at 21 ch/hr mechanical ventilation, the determined rate of removal was 17 ch/hr (statistically significantly different from 21 ch/hr); when the rate of mechanical ventilation was reduced to 10 ch/hr there was no difference, as was the case for 8 or 4 ch/hr is the chamber, nor for 5 ch/hr in the workroom. Our interpretation of this information is that ventilating a space at rates greater than 17 ch/hr would not increase the rate of removal of laboratory gas by the predicted amount because of the uptake and subsequent revolatilization of various compounds in natural gas upon the surfaces of the ventilated space. For methane, water, and laboratory gas this effect is of little practical importance; nor is it a problem when only small amounts of formaldehyde gas are liberated.

The compounds of greatest interest are those which remain liquid or solid at room temperatures, and when dissolved in the air, their vapors readily condense or sorb upon all available surfaces. Odorants in general belong to this class of compounds. For such compounds the great differences between predicted rates of removal by fresh air and that observed are of considerable practical importance; such a difference indicates that there is a real limit to the utility of dilution ventilation in removing odorants from enclosures.

There is a wide range of responses of compounds in the tabulation given above. Diethyl ether shows 14 ch/hr instead of the expected 23, but matches at values of 7 ch/hr; the limiting value is more nearly located for ethyl alcohol, which shows 9 ch/hr at 10 ch/hr mechanical ventilation. For these two compounds, fresh air in excess of 9-10 ch/hr will not remove them at
the expected rate - that is to say, mechanical ventilation much in excess of 10 ch/hr would be an economic waste, insofar as the removal of such odorants is concerned, with a limiting value of the order of 14 ch/hr, no matter how great the rate of dilution ventilation with fresh air. However, this is not a great problem because 10 ch/hr is a high rate of ventilation for most occupied spaces, other than surgical suites and special purpose clean rooms (neither of which may be supplied with such large amounts of fresh air). On the other hand, the situation for isovaleric acid (a typical "body-odor" odorant) is extremely poor, with compounds such as 2-octanol occupying an intermediate position. In the case of isovaleric acid, naphthalene, 2-hexanol and 1-butanol, the rate of removal is significantly less than that predicted by mechanical ventilation, even down to rates of mechanical ventilation as low as 4, 5 or 7 ch/hr. Such rates of mechanical ventilation are within the range employed in patient care rooms and less than those employed in well-designed operating rooms. In all such cases as these, little if any odor removal can be expected by increasing the rate of dilution ventilation with fresh air, with a limiting rate of removal as low as 1-2 ch/hr, regardless of how great the rate of dilution ventilation with fresh air.

There is some external support for the interpretation given our findings here: a study made at The University of Pennsylvania School of Medicine, employing several gases to evaluate ventilation rates in a bare chamber, simulating an operating room, yielded results which we interpreted to show:

<table>
<thead>
<tr>
<th>Compound</th>
<th>Ch/hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulfur dioxide or Nitrous oxide</td>
<td>25.8</td>
</tr>
<tr>
<td>Carbon monoxide or Hydrogen Sulfide</td>
<td>22.2</td>
</tr>
<tr>
<td>Formaldehyde gas</td>
<td>19.9</td>
</tr>
</tbody>
</table>

The differences are statistically significant, and agree with our findings for gases.

*The original data were made available to us by G. J. McGarrity during the course of exchange of information on the COSA/TRON. The full study, including their conclusion that the COSA/TRON has little if any value in removing odorants, was published subsequently: "Gaseous Pollutant Evaluation of Hospital Clean Rooms," by Wohlers, et al., American Industrial Hygiene Journal, 32, 831 (1971).
The only information we obtained that might be of value in controlling odors arising within patient rooms is that odor-removing devices located within the room appear to have a greater effectiveness than the equivalent amount of fresh air supplied by mechanical ventilation to the room. This is consistent with our general findings because it would be expected that any odorant removed from the air before it was sorbed or condensed upon a room surface would not contribute to the long-lasting effect of the odorant observed with dilution ventilation. This conclusion falls within the general confines of the dictum that the best control of a problem is at the source.
APPENDIX I

HYDROCARBON ANALYZER AND MODIFICATIONS
CONTINUOUS DETERMINATION OF TOTAL HYDROCARBONS IN THE ATMOSPHERE

by: E. E. Weaver* and T. W. Kethley**
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Georgia Institute of Technology
Atlanta, Georgia

In the course of a study of intramural air quality¹ a need arose for continuously determining the total hydrocarbon content of room atmospheres. A Hydrocarbon Analyzer² employing hydrogen flame ionization was modified to meet this requirement. The commercial unit is designed to be operated under positive pressure, the sample being introduced either from pressurized lines directly, or from a sampling loop, or through a pump. For intermittent sampling of the ambient atmosphere, a sampling loop is feasible, but the necessary mechanical equipment or manual labor was considered too complex and costly for the problem at hand. Although the analyzer pump has been employed successfully for methane determinations from ambient atmospheres,³ previous experience in our laboratories has shown that only highly volatile organic substances can be introduced through a pump. In practice, we found that organic compounds having relatively low vapor pressures would at first be retained by the pumping system, and later be eluted, resulting in erratic, meaningless records from the hydrocarbon analyzer.

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¹/ Air treatment for odor control in the hospital; this study is supported by Public Health Service Demonstration Grant No. 1-R18-HM00565.

²/ Model 109A, Beckman Instruments, Scientific and Process Instruments Division, Fullerton, California.

It was suggested in discussion with a technical representative of a manufacturer of flame ionization burners that sampling from the ambient atmosphere might be accomplished with an ejector device built into a pressurized gas line introduced into the burner assembly, employing an inert carrier gas. In the Hydrocarbon Analyzer, both air and fuel are supplied under pressure. In our laboratory, detailed analysis of the situation indicated that incorporation of the sample into the existing fuel line was preferable to the addition of another gas line to the burner assembly, or to introducing the sample into the compressed air line. Although a greater quantity of air is introduced to the burner, fuel is fed directly into the burner tip, where combustion of hydrocarbons takes place. Further, it was decided that the desired objective could be attained most readily by effecting the minimum changes in the original commercial design. For this reason, the flow of fuel (40 per cent $H_2$, 60 per cent $N_2$) was maintained at 75 cc/min. (1.758 kg/cm$^2$ gauge or 25 psig at instrument regulator), and flow of compressed air at 325-385 cc/min. (1.758 kg/cm$^2$ gauge or 25 psig at instrument regulator). It was found necessary to increase the size of the burner tip to reduce the pressure drop across it; otherwise no changes were made in the burner assembly.

All components employed in modifications or accessories were composed of metal or teflon. Any fabricated component was cleaned prior to installation by degreasing, soaking in sulfuric-chromic acid cleaning solution, water washing, heating and placing, while hot, in a vacuum chamber for drying.

James L. McFadden, Gow-Mac Instrument Company, Madison, New Jersey.
Modification of the Hydrocarbon Analyzer. The burner tip was replaced with a 2.5 cm. length of 22 gauge hypodermic needle (stainless steel), set in a teflon base fabricated to duplicate the original base and burner tip. At the side of the burner housing, the sample capillary was removed and a brass screw plug inserted to seal off this entrance into the burner assembly. The fuel capillary was removed and experimental ejectors inserted in its place. Ejectors were designed to pass 75 cc/min. of fuel at 1.758 Kg/cm² gauge (25 psig), thus regulating the fuel flow at the original design level, and to draw in approximately 10 cc/min. of ambient air sample, maintaining a sample flow rate comparable to that recommended by the manufacturer. In Figure 1 is a section view, and Figure 2 is the exploded view of an ejector meeting these requirements. This ejector consists of a 2.5 cm. length of 22 gauge stainless steel needle with an inner jet formed from a 2.5 cm. length of stainless steel capillary 0.014 cm. O.D., and ca. 0.009 cm. I.D. The length of 22 gauge needle stock was welded into the exit of a cavity formed from 1.91 cm. (3/4") hexagonal brass stock; the smaller capillary was positioned in a teflon sleeve at the entrance to this cavity, and the sampling tube was connected to the body of this cavity with a tube fitting. The cavity can be taken apart and the small capillary removed from the teflon sleeve if cleaning is necessitated.

Accessories. The air sampling line of 0.635 cm. (1/4") O.D. stainless steel tubing was brought from the instrument case and inserted through the wall of the experimental room in which air quality studies are to be made. In this sampling line accessory connections and valves were inserted in order to introduce zero gas (nitrogen) or calibration gas (8.5 ppm propane in nitrogen), as desired. Airflow at 10 cc/min. was metered with a Magnehelic
gauge connected across a 0.02 cm. diameter orifice plate, and regulated with a needle valve. Inclusion of these components of necessity increased the volume of the sampling line, resulting in a detention time of something greater than 5 minutes in this system. All portions of the air sampling line, from the burner assembly to the end of the tubing in the wall of the experimental room, were wrapped with heating tape and kept warm (ca. 45°C) to prevent condensation of airborne hydrocarbons from the sampled air (ambient temperatures, 20-25°C). Inside the room, the sampling line projected 25 cm. from the wall, ending in a right angle bend downwards to prevent entrapment of particles which might clog the ejector.

Performance tests. The modified Hydrocarbon Analyzer was designed to measure continuously the total hydrocarbon content of intramural atmosphere in air quality studies. Because these studies are conducted in rooms equipped with ventilation controls, a thorough test of the capabilities of the instrument was most readily conducted by determining its performance in making ventilation studies employing hydrocarbons as tracers. For these tests the output of the Hydrocarbon Analyzer was introduced into a Linear/Log recorder.

During the course of early experiments it was observed that the response of the modified Hydrocarbon Analyzer was affected by variations in the temperature of the controlled environment room in which the instrument is housed, and in which experimental observations have been made. Under summer conditions, changing from air-conditioner operation to outside air


ventilation resulted in a shift from $23^\circ C$ to as high as $30^\circ C$, causing as great as $23\times1$ change in the zero of the analyzer record. The exact cause of this shift has not been determined. Because the analyzer zero remains stable for several hours under conditions of constant temperature, changes in temperature during a run have been avoided in studies conducted with this instrument.

Linearity of response was determined by introducing into the controlled environment room sufficient natural gas from a lab bench supply to yield a signal of approximately 50 divisions. The gas was then turned off, loss of gas due to sorption and leakage was recorded; finally the room was ventilated with a measured 19.8 cubic meters per minute of outside air, and the decay of gas concentration recorded. Such tests were run at instrument attenuations of $X30$, $X10$, and $X3$. For each test, the recorded decay of concentration, plotted on semi-log ordinates against lapsed time, yielded a straight line. From these data the average calculated mechanical ventilation was found to be 20.1 cubic meters per minute. For this type of experiment, the agreement between the measured 19.8 and the determined 20.1 cubic meters per minute is well within acceptable experimental error. However, the most significant feature of these tests was that linearity of response was proven for the modified Hydrocarbon Analyzer over a wide range of concentrations of hydrocarbons in intramural air.

Quantitative evaluation of the response was accomplished with known amounts of ethanol evaporated into the controlled environment room, with a water-washed air-conditioner operating, recirculating 56.7 cubic meters per minute. The Hydrocarbon Analyzer was zeroed with nitrogen zero gas and calibrated against 8.5 ppm propane in nitrogen, sampling at the predetermined
rate of ca. 10 cc per minute, yielding a value of 10 divisions per part per million of carbon. Exactly 1.0 ml. of ethanol was evaporated rapidly upon a preheated hot plate in the well-mixed air of the room; the resultant concentrations sensed by the Hydrocarbon Analyzer were recorded on semi-logarithmic ordinates against time. The maximum concentration computed, and determined graphically from the obtained data were each 1.6 ppm ethanol. Additionally, ethanol was evaporated at 1.0 ml. per minute, dropwise upon a heated plate, continuously for two hours. Equilibrium concentration of ethanol as recorded from the Hydrocarbon Analyzer was found to be 10.0 ppm; that calculated on the basis of the quantity evaporated, and the equivalent fresh air ventilating the room, was 9.8 ppm.

The results of these tests clearly indicate the ability of the modified Hydrocarbon Analyzer to monitor continuously and accurately the total hydrocarbon content of the air, sampling directly from the atmosphere. The sensitivity of response to fractional ppm concentrations of hydrocarbons with a range up to many ppm is excellent for the intramural studies planned; further modification to increase the volume of air sampled should make this system valuable in extramural studies also.
Figure 2. EJECTOR: Exploded View

- Tube Fitting
- Teflon Plug
- .014 cm. O.D. Capillary
- Brass Hex
- Teflon Washer
- 22 Gage Needle
- Threaded to fit Burner
Figure 1. EJECTOR: Section View
General views of the Beckman Hydrocarbon Analyzer, with modifications. Located adjacent to one wall of the chamber.
APPENDIX II

MAGNITUDE OF POSSIBLE ERROR IN SAMPLING HYDROCARBON VAPORS
Magnitude of possible error in sampling hydrocarbon vapors.

1. The problem: Ventilation constants determined in the simulated operating room have been observed to diminish with increasing molecular weight of the hydrocarbon employed as the test gas. No firm basis has been obtained for an explanation of this phenomenon. A possible source of error in determining the ventilation constants is the sampling system in the hydrocarbon analyzer. It seems possible that there might be a hold up in the sampling system with compounds of higher molecular weight.

2. Approach to the problem: The actual ventilation constant of the sampling system was determined employing 2-Octanol as the test gas; an equation was developed to describe two-compartment effects; various values substituted in the equation and the calculated values compared to expected values. The results indicated that the sampling system of the hydrocarbon analyzer is not a significant source of error in determining ventilation constants which are no greater than 0.6 in value. Although true ventilation constants as great as 1.0 would be underestimated by as much as 10 percent, none of the studies in question were made under conditions where the true K would be greater than 0.5.

3. Determination of ventilation constant of the sampling system. The OR was sealed and 8.2 gms 2-octanol (molecular weight, 130.23, boiling point, 178.5°C) evaporated slowly into the air of the OR. The hydrocarbon analyzer was sampling through the OR wall. After two hours the signal was some 50 x 30, and declining very slowly. At this time a Mylar bag was filled with zero air, the OR quickly opened and the bag clamped to the inlet of the analyzer sampling tube. The resultant record of decreasing concentration was employed to calculate the ventilation constant of the analyzer sampling system. The value obtained was 1.5; which is for the sweep-out of a high concentration of a high molecular weight hydrocarbon by means of zero air.

4. Equation for two-compartment effects. A single compartment is cleared of contaminant with pure air entering:

$$C = C_0 e^{-Kt}$$

This would be the case for the determination of the ventilation constant of the analyzer sampling system. It is also the case for the OR when ventilated with clean outside air. But, when the OR and the Sampling System both contain contaminant, and the OR is then ventilated with fresh air, we have two compartments. In this case only the first compartment (the OR) receives fresh air; the second compartment (sampling system) receives the partially diluted contaminant-laden air from the first compartment. Employing $K_1$ for
ventilation of the OR (first compartment) and \( K_2 \) for the ventilation of the Sampling System (second compartment), with both compartments initially filled with contaminant \( C_0 \), and fresh air supplied to the first compartment only:

**OR:** \[ C_1 = C_0 e^{-K_1t} \]

**Sampling System:**
1. by removal as if by pure air: \[ C = C_0 e^{-K_2t} \]
2. assuming \( K_2 > K_1 \); by addition from OR: \[ C = C_1(1-e^{-K_2t}) \]
3. the resultant concentration at the exit from the Sampling System is the sum of (1) and (2):
   \[ C_2 = (C_0)(e^{-K_2t}) + C_1(1-e^{-K_2t}) \]
   and \( C_1 = C_0 e^{-K_1t} \):

\[ C_2 = (C_0)(e^{-K_2t}) + (C_0)(e^{-K_1t})(1-e^{-K_2t}) \]

and, in terms of fractional reduction of concentration:

\[ \frac{C_2}{C_0} = (e^{-K_2t}) + (e^{-K_1t})(1-e^{-K_2t}) \]

For the Sampling System, \( K_2 \) was determined to be 1.5.

5. Application of the equation for two-compartment effects. In practice, the declining concentration recorded from the hydrocarbon analyzer is plotted and the time to decline by 90 percent determined. From this time, \( t_{90} \), \( K \) is calculated:

\[ K = \frac{2.3}{t_{90}} \]

As a result, readings employed for calculation of \( K \) are made when:

\[ \frac{C}{C_0} = 0.1 \]

and for the two-compartment system, observations are made when:

\[ 0.1 = (e^{-K_2t}) + (e^{-K_1t})(1-e^{-K_2t}) \]

and, \( K_2 = 1.5 \)

\[ 0.1 = e^{-1.5t} + (e^{-K_1t})(1-e^{-1.5t}) \]

and, in practice, an observed \( t_{90} \) would be converted into a value for \( K_1 \),
which might be in error; the true value for $K_1$ being indicated in the equation above. For the OR the greatest value of $K_1$ ever expected is 1.0; tabulated below are the true values of $K_1$, from 0.1-1.0, and the values which would be determined from observations made with the hydrocarbon sampling system.

<table>
<thead>
<tr>
<th>Observed $t_{90}$</th>
<th>Observed $K$</th>
<th>True $K$</th>
<th>$(\text{Obs}/\text{True}) \times 100$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.30</td>
<td>1.0</td>
<td>1.152</td>
<td>87%</td>
</tr>
<tr>
<td>2.55</td>
<td>0.9</td>
<td>0.992</td>
<td>90%</td>
</tr>
<tr>
<td>2.88</td>
<td>0.8</td>
<td>0.850</td>
<td>94%</td>
</tr>
<tr>
<td>3.29</td>
<td>0.7</td>
<td>0.722</td>
<td>97%</td>
</tr>
<tr>
<td>3.83</td>
<td>0.6</td>
<td>0.608</td>
<td>99%</td>
</tr>
<tr>
<td>4.60</td>
<td>0.5</td>
<td>0.503</td>
<td>99%</td>
</tr>
<tr>
<td>5.75</td>
<td>0.4</td>
<td>0.400</td>
<td>100%</td>
</tr>
<tr>
<td>7.67</td>
<td>0.3</td>
<td>0.300</td>
<td>100%</td>
</tr>
<tr>
<td>11.5</td>
<td>0.2</td>
<td>0.200</td>
<td>100%</td>
</tr>
<tr>
<td>23.0</td>
<td>0.1</td>
<td>0.100</td>
<td>100%</td>
</tr>
</tbody>
</table>

6. Conclusions.

The tabulation above shows that for sampling from the OR with the hydrocarbon analyzer, the observed value for the ventilation constant of the OR will be identical, or essentially identical, to the true OR ventilation rate when the true ventilation rate is 0.6 or less. This can be inferred directly from the equation: when the value of the term $e^{-1.5t}$ approaches 0.001, it will be negligible,

and $e^{-K_1t} \approx 0.1$

and $K_1t \approx 2.3$

which is the expected relationship for $t = t_{90}$, i.e. when $C/C_0 = 0.1$. However, for those conditions where the true value of the OR ventilation constant is as great as 1.0, there will be a significant error in the value of $K$ observed with the hydrocarbon analyzer sampling data. However, none of the observations in question have been made under such conditions, and it is concluded that the sampling system is not a source of error for these.
APPENDIX III

USE OF LABORATORY GAS, ETHANOL AND ETHER
IN VENTILATION SYSTEM OF BUILDING
USE OF LABORATORY GAS, ETHANOL AND ETHER  
IN VENTILATION SYSTEM OF BUILDING

In order to verify (or deny) a finding in the Atomedic Hospital that ethanol and ether ventilated at the same rate as did laboratory gas, similar studies were made on the first floor of the Radioisotopes and Bioengineering Building. These studies were made at nights and on weekends when there were either no opening of outside doors or it was at a minimum.

The first floor of the Radioisotopes and Bioengineering Building is shown schematically in the attached sketch, on which are circled the two labs which were employed in these studies: C-111 and C-102. For all studies, the HC analyzer was located in C-102, with sources of gas, ether or ethanol being located in either C-111 or C-102. Single quantities of compound were liberated and the history of the concentration recorded by the HC analyzer. From the HC analyzer record the compound decay was determined, and is expressed as EFA, in ch/hr.

During periods of low occupancy the building being studied is ventilated with something like 90 percent recirculation. There are three primary recirculating systems: the main one, supplying air to the laboratories in the central portion of the building, with return down the corridor; one each for offices located along the outside walls. However, the office units also intermix with corridor air, so there is a gradual mixing throughout the building.

The results obtained from a number of studies are shown below; for each ventilation study with ethanol or diethyl ether, an evaluation was made also with laboratory gas.

<table>
<thead>
<tr>
<th>Location of source of compound</th>
<th>EFA, ch/hr</th>
<th>Laboratory gas</th>
<th>Diethylether</th>
<th>Ethanol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room C-111</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.4</td>
<td>2.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.5</td>
<td>2.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.6</td>
<td>5.9</td>
<td></td>
<td></td>
<td>6.4</td>
</tr>
<tr>
<td>7.1</td>
<td>6.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Room C-102</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.0</td>
<td>1.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.4</td>
<td>7.1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
In addition, two runs were made with LP gas (such as used in the Atomedic studies); these agreed with the laboratory gas determinations.

Considering all the evidence accumulated, there appears to be no doubt that the vapors of compounds such as ethanol and diethyl ether condense or sorb upon intramural surfaces and revolatilize at a rate equivalent to at least 7 ch/hr EFA. This is to be contrasted to chamber studies where it was found that the revolatilization rate for these compounds is less than expected when the chamber is ventilated at 21 or 23 ch/hr mechanical ventilation.
Radioisotopes and Bioengineering Lab Floor Plan.
APPENDIX IV

WATER VAPOR DETERMINATIONS
Water Vapor

At various times short burst of steam had been introduced into the simulated OR and the decay of water vapor followed with a recording thermal conductivity measuring unit. In general, the measured decay, taken over one decade, agreed very well with that obtained from the ventilation of helium, as measured with the same thermal conductivity unit. Using short burst of steam the agreement with helium decoys were sufficiently satisfactory to warrant the use of steam for such things as evaluating uniformity of dispersion within the simulated OR. From an earlier study, the following summary was reported: Mechanical ventilation was nominally 10 ch/hr (300 cfm), with endwall grilles, a condition that previously had been shown by samples of airborne bacteria to yield a high level of uniformity of distribution. For the water vapor determinations, the temperature and dew point were maintained constant, then water vapor as steam injected into the incoming air duct for 2.0 minutes. The rate of disappearance of the water vapor was determined at each of 36 air sampling positions throughout the room by stationing a thermal conductivity unit at a sampling station and recording the decay. The entire process was then repeated until decay rates had been determined at all sampling stations.

The results obtained verified the findings obtained with the bacteriological air samples, to wit, there was no great difference in the ventilation rate between any of the areas of the room. For the 36 samples, the average value was 11.50 ch/hr with a standard deviation of 0.66. The 95 percent confidence limits were 11.2-11.8 ch/hr. Internally, there was a significant difference at the 0.05 level of probability between the average determination at the 2.0' level and at the 7.0' level, 11.2 versus 11.8 ch/hr; among the averages of the longitudinal sections of the room there was no significant difference.

It was observed that there was a "tailing" effect in the decay of water vapor and it is probable that the second decay, if measured, would have been significantly lower than the first. During the present work, water vapor was not investigated except at the last moment, and only casually. Steam was introduced into the chamber with full
recirculation through lined ducts and filters until drops of water were observed at the duct adjacent to the steam nozzle, which required 10 minutes. A decade decay was measured with the thermal conductivity unit; this yielded an EFA of 605 cfm in contrast to 734 from helium decays and 580 from methane decays. This was repeated several times and essentially the same results obtained each time. This information was considered to support the hypothesis - that reduced ventilation efficiency is due to desorption of compound from surfaces - in this case, the simple evaporation of condensed moisture from the surfaces of the chamber, ducts and filters.
APPENDIX V

EVALUATION OF COSA/TRON IN ATOMEDIC HOSPITAL
EVALUATION OF COSA/TRON IN ATOMEDIC HOSPITAL AT WOODSTOCK, GEORGIA

INTRODUCTION

Among the stated objectives of the present project was evaluation of air treatment systems which might have benefit to the hospital in removing odors; among the special items was the CRS Industries unit, the COSA/TRON. We were unable to obtain such a unit for installation in our laboratories. However, the Atomedic Hospital at Woodstock, Georgia contains a COSA/TRON in its air handling system, and we were able to conduct an evaluation of this unit. Woodstock is approximately 40 miles from our laboratories.

The Atomedic Hospital at Woodstock is one of two or three prefabricated hospitals which were constructed as demonstration units, one being on display at the World Fair in New York City. The present unit had been in operation as a childrens hospital in Alabama. The facility was dismantled and crated, eventually being taken over by the two members of the Woodstock Medical Clinic, Dr. A. Evan Boddy and D. J. T. Cooper. These men employed the same construction company foreman who had disassembled the facility to re-construct it at Woodstock. Through the assistance of Dr. Walter Bloom of the Georgia Institute of Technology special provisions were made by the Georgia State legislature to permit the operation of an essentially unorthodox hospital, placing the responsibility upon the Georgia State Public Health Service. The medical men were able to negotiate such exceptions to local codes as might be problems. They were most anxious to complete the facility and to occupy it as a proprietary hospital. As a result, it was necessary for us to work during the period following completion of the building when telephone and TV installations were being made. This imposed considerable restraints upon our working and in the end meant that useful data were obtained only the night hours or on Sundays when no workmen were present. The duct work for the ventilation system was reinstalled by local craftsmen and it was necessary for us to carry out most of the final checking of the ventilation system. This included use of student labor to test and secure all duct joints, balance off the system, measure air volumes and in some instances clean out ducts where acoustical material had fallen loose. The amount of this kind of labor was quite extensive and between the constraint of working in the absence of telephone and television installers the number of runs which were made were something less than desired. However, it was possible to make some half dozen complete runs consisting of a minimum of three sets of experiments each time.

The Atomedic Hospital concept is that of a circular organization. There is a single main entrance which opens into the outside corridor which circumscribes the building. This corridor constitutes the visitor access to the patient rooms which are twenty-two in number. Patient rooms have doors into the corridor and doors into the central core. With the doors to the
of this central core was estimated to be something over 33,000 cubic feet exclusive of the built-in cabinets and refrigerators; the volume of the supply, exhaust and return ducts add substantially to this, and for working purposes a value of 35,000 cubic feet was assigned to the space in which we would be carrying out our evaluation studies. This 35,000 cubic feet of volume is supplied with some 3600 cfm of treated air yielding a value of 0.1028 changes per minute or a little over 6 changes per hour. The actual make-up air constituting some 1600 cfm of fresh air then represents 0.0457 changes per minute or some 2.74 changes per hour in terms of outside air. The validity of these estimates was born out subsequently when ventilation constants were determined employing LP gas, ether and alcohol, as well as helium as tracers. These tracer studies showed that the measured equivalent fresh air entering the central core was approximately 1500 cfm. This value was obtained as the average of 13 different measurements made over the period between 20 June and 28 June 1969.

To recapitulate, by the 20th of June all ducts had been tightened and taped and the supply air directed into the central core through central grills and peripheral supply units. Air supplies to corridor, x-ray, admissions etc. were closed off, but the air from the peripheral units was free to leave through the patient rooms with the aid of the exhausts from these. All air flows had been measured with some accuracy and the ventilation constants estimated from the air flow and volumes of the central core and duct work. During the runs all doors were kept closed except once in a while an outside door was opened, but with patient rooms doors always closed to seal off the central core. There was no smoking in the central core during the runs and several hours prior to the runs. The outside conditions were hot and humid; the refrigeration compressors were running most of the time during runs. The COSA/TRON had been off for at least 24 hours prior to an "off" run and on at least 24 hours prior to an "on" run. When the COSA/TRON was on the meters were read at least once every 12 hours during the period it was on and always at the beginning and ending of a run; the high voltage meter usually indicated 27 within a few hours after start up and the RF meter 90.

Prior to the time of starting actual evaluation the needed equipment and materials were marshalled in the central core; Andersen samplers, Georgia Tech air hygiene monitors, a Beckman hydrocarbon analyzer with continuous sampler adapter and recorder, a thermal conductivity cell unit and recorder, compressed nitrogen tanks for the atomizers, atomizers, stock-cultures of the tracer microorganism, Andersen plates, settling plates, bottles of LP gas, sealed containers of ethyl alcohol and ethyl ether, a Royco Particle Counter with printout, temperature and humidity recorders. These and other items of equipment were gathered in order to measure the behavior of bacterial particles both indigenous and tracer, ventilation constants for gas, ethyl alcohol, ethyl ether, and odor removal using ethyl alcohol and ethyl ether as odorants both with the COSA/TRON on and off. Temperature and humidity were held essentially constant as shown in Table 1.
Table 2. Comparison of Royco* Particle Counts: Central Core of Atomedic Hospital and Georgia Tech Aerobiology Lab.

<table>
<thead>
<tr>
<th>Location and conditions</th>
<th>Approximate number of particles per cubic foot of air, in thousands</th>
<th>All sizes, ( (\geq 0.3\mu) )</th>
<th>Small sizes, ( (&lt; 0.5\mu) )</th>
<th>Large sizes, ( (\geq 0.5\mu) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Atomedic.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. CRS OFF for more than 24 hours:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Building empty, nite of 26 June</td>
<td>2,100</td>
<td>1,860</td>
<td>240</td>
<td></td>
</tr>
<tr>
<td>One person in bldg. afternoon of 21 June</td>
<td>1,800</td>
<td>1,560</td>
<td>240</td>
<td></td>
</tr>
<tr>
<td>b. CRS ON, building empty: on for 12 hours, early AM, 22 June</td>
<td>1,800</td>
<td>1,500</td>
<td>300</td>
<td></td>
</tr>
<tr>
<td>ON for 24 hours, early PM 22 June</td>
<td>2,400</td>
<td>2,100</td>
<td>300</td>
<td></td>
</tr>
<tr>
<td>ON for 28 hours, early AM 28 June</td>
<td>3,000</td>
<td>2,550</td>
<td>450</td>
<td></td>
</tr>
<tr>
<td>2. Aerobiology Lab, Georgia Tech, simulated operating room</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Fresh air from roof, no recirculation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overnite, 14-15 July</td>
<td>3,000</td>
<td>2,400</td>
<td>600</td>
<td></td>
</tr>
<tr>
<td>Daytime, 15 July</td>
<td>3,000</td>
<td>2,400</td>
<td>600</td>
<td></td>
</tr>
<tr>
<td>b. Partial recirculation, (95%-DOP filters)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overnite 15-16 July</td>
<td>900</td>
<td>710</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>One person in, 16 July</td>
<td>1,500</td>
<td>1,350</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>c. Total recirculation (95% DOP filters)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overnite, 17-18 July</td>
<td>4.5</td>
<td>1.0</td>
<td>3.5</td>
<td></td>
</tr>
</tbody>
</table>

*Royco Instruments, Model PC-202 Particle Counter, registered on a Hewlett-Packard, Model 560A Digital Recorder. We are indebted to the National Communicable Disease Center for the use of this equipment.

The data from the Royco given in Table 2 above are interpreted to mean that the air in the central core of the Atomedic Hospital during the period when we were carrying out studies is of quality comparable to the outside air obtained from the third floor of the roof of the Radiolabeling Laboratory at the Georgia Institute of Technology, insofar as the burden of particulate matter is concerned. In either case such air has a high burden of particulate matter compared to air partially recirculated through the 95% DOP filters and certainly much greater than that totally recirculated through 95% DOP filters. Because the filter used in the COSA/TRON unit at Woodstock is rated by the manufacturer at 67% NBS it would not be expected that there would be any significant effect upon the removal of particles much less than 5 microns in diameter and the comparison to good quality outside air probably is consistent with this. The fact that the particle count gradually rose during the period when the CRS unit was on, may or may not be significant. The trend is not great enough to warrant statistical significance but it may be a reflection of an actual situation. The implications of this are discussed.
For independent measurement of ventilation of rooms of varying sizes, determination of the exact volume of a room is required; in the case at hand we were working always in the same room, at a constant volume, and a good estimate of the value $V$ was considered adequate. This was taken as 35,000 ft$^3$ for the volume of the central core and ducting which comprised the air space in which work was conducted.

In order to establish base line information, EFA was determined with helium and with LP gas, both of which diffuse rapidly and have served as efficient tracers for ventilation work. Helium was dispensed from a compressed gas cylinder and the aerial concentration recorded from the change in signal from a pair of thermal conductivity cells, one of which was isolated over silica gel (zero signal) and through the other, room air flowed continuously. A bed of molecular sieve served to remove water vapor from the room air before it passed into the conductivity cell. The one run with helium indicated some 1900 EFA: a value in excess of expectancy (1600 cfm). Probably this was due to the highly diffusive character of the helium, allowing this gas to leak out of the system at a rate greater than air alone. There was no opportunity to pursue this further because the molecular sieve employed to remove water vapor allowed passage of other compounds, and it was not possible to employ this analytical system in the presence of other tracers, as had been planned. Because of this, the disadvantages of transporting additional cylinders of helium outweighed the advantages.

LP gas was available in 20 pound cylinders, and one of these furnished more than enough for all ventilation determinations. For a test, the valve of the LP cylinder was opened full for a few minutes inside the central core, and the aerial concentration recorded from the output of a Beckman Hydrocarbon Analyzer. This analyzer had been modified to aspirate continuously a small volume of room air directly into the hydrogen flame. The analyzer signal is that detected by an electrometer connected to electrodes at the hydrogen flame. Any hydrocarbon which can be burned to carbon dioxide affects this signal, and the response is linear over a wide range of concentration of hydrocarbon. In Table 3 the results of the four tests are shown.

<table>
<thead>
<tr>
<th>Date of run</th>
<th>$K$</th>
<th>EFA</th>
<th>Maximum signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>14 June - CRS off</td>
<td>0.0343</td>
<td>1,200</td>
<td>45 x 30</td>
</tr>
<tr>
<td>14 June - CRS off</td>
<td>0.0357</td>
<td>1,250</td>
<td>100 x 30</td>
</tr>
<tr>
<td>21 June - CRS off</td>
<td>0.0343</td>
<td>1,200</td>
<td>100 x 30</td>
</tr>
<tr>
<td>22 June - CRS on</td>
<td>0.0357</td>
<td>1,250</td>
<td>56 x 30</td>
</tr>
</tbody>
</table>

These results show a remarkable reproducibility, but values for EFA less than expected (1600 cfm). However, they are within the general range of the confidence that we would have under the circumstances. In Table 3 values for the maximum signal are given; these indicate that the signal was great enough that errors were at a minimum, being recorded from the X30 attenuation (X1 attenuation is maximum sensitivity). Also, the two higher maxima were obtained when the LP gas was introduced into the air only 15-20 feet from the analyzer; the two lower maxima when the gas was introduced some 40 feet away.
Table 5. Ventilation of Ethyl Ether

<table>
<thead>
<tr>
<th>Date of run</th>
<th>K</th>
<th>EFA</th>
<th>Maximum Signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 June - CRS off</td>
<td>0.0530</td>
<td>1,850</td>
<td>45 x 10</td>
</tr>
<tr>
<td>21 June - CRS off</td>
<td>0.0463</td>
<td>1,620</td>
<td>84 x 3</td>
</tr>
<tr>
<td>22 June - CRS on</td>
<td>0.0436</td>
<td>1,530</td>
<td>34 x 10</td>
</tr>
</tbody>
</table>

Taking into consideration the same factors as for ventilation of ethyl alcohol, it is concluded that the information presented in Table 5 yields no evidence that the CRS unit significantly aided in the removal of ethyl ether from the air of the central core of the Atomedic Hospital.

It was considered possible that some space effect might exist which would affect the removal of an odorant if the odorant was introduced into the space at a constant rate. To test this, ethyl ether was evaporated at a constant rate in the central core area. To insure constant rate of input, ether was dispensed drop by drop through a No. 27 stainless steel needle (1 inch in length) from a constant head reservoir. The drops of ether fell upon a heavy aluminum cup heated to approximately 150°C where they evaporated instantly. Aerial concentration was recorded by the hydrocarbon analyzer recorder system during a period of three hours of constant ether input. At the end of three hours of constant input of ether, the ether source was removed from the room, and the decay in concentration also recorded. The results of the two runs are presented in Table 6.

Table 6. Ventilation of Ethyl Ether, Constant Source

<table>
<thead>
<tr>
<th>Date of run</th>
<th>Avg. HC signal with ether input</th>
<th>Following ether input</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>K</td>
<td>EFA</td>
</tr>
<tr>
<td>26 June - CRS off</td>
<td>35 x 3</td>
<td>0.0322</td>
</tr>
<tr>
<td>28 June - CRS on</td>
<td>35 x 3</td>
<td>0.0375</td>
</tr>
</tbody>
</table>

The information presented in Table 6 yield no evidence that the CRS unit aided in the removal of ethyl ether from the air of the central core of the Atomedic Hospital. The ventilation values following the completion of the ether input are lower than those following simulated spills of ether or of alcohol. This is as might be expected because after three hours of constant input of ether, there would be an equilibrium between ether in the air and that on the surfaces of the ventilated area. As a result, subsequent ventilation determinations would be less affected by sorption losses than would those made following a short exposure to alcohol or ether.

Subjective evaluation of odor levels was possible only in the case of the two runs where ether was introduced at a constant rate over a period of three hours. The aerial concentration during these two runs was such (approximately 3 ppm) that two of the Georgia Tech personnel in the central core were able to sense that an odorant was present, but not able to identify it; they were aware a compound was being evaporated, but did not know whether it was ether or alcohol which was being evaporated. Subsequently during periods when this concentration was being maintained, personnel left the
particle concentration, apparently due to the cycling of one of the refrigeration compressors inside the core area. Plots of these data were made in the same manner as for gas concentration decays, and yielded apparent decay values for the particulate matter which were slightly less when the CRS unit was on in comparison to those when the CRS unit was off. However, these values showed too great a range of variation to permit statistical comparison. It was found that the Royco record for particles 0.5μ and greater (> 0.5μ), following atomization of the beef broth containing tracer bacterial cells yielded somewhat more consistent decay values in several instances. It should be pointed out that these particles are residues of beef broth solids, and all particles did not necessarily contain bacterial cells. The most consistent data are given in Table 7.

Table 7. Apparent ventilation constants for particles > 0.5μ, following atomization of the beef broth containing tracer bacterial cells.

<table>
<thead>
<tr>
<th>CRS OFF</th>
<th>CRS ON</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.15</td>
<td>0.075</td>
</tr>
<tr>
<td>0.115</td>
<td>0.083</td>
</tr>
<tr>
<td>0.088</td>
<td>0.058</td>
</tr>
<tr>
<td></td>
<td>0.052</td>
</tr>
</tbody>
</table>

Mean 0.117 0.067

There is statistical difference between the mean decay, CRS off compared to CRS on, at P = 0.05, but not at P = 0.025. As a result, an effect is suggested, but a study under more rigorously controlled conditions would be required to confirm or deny this.

b. Particles containing viable cells of *Serratia marcescens*.

In addition to observations on particulate matter as such, a great deal of work was accomplished with airborne particles containing viable (colony-forming) microorganisms. For these studies the Andersen 6-stage stacked-sieve was employed for all quantitative determinations of the aerial content. The Georgia Tech air hygiene monitor was employed in initial studies to obtain estimates of background levels and to indicate the expected levels following atomization of the tracer bacterial cells. It was employed also to monitor continuously during the course of most of the studies with viable particles. Qualitative evaluation of the decay of the tracer cells was made with the monitor by photographing the monitor trays after incubation of the bacterial colonies; these were consistent with the quantitative values obtained from Andersen samples, and were not considered further. Information as to settled particles containing viable microorganisms was obtained from exposed 150 mm diameter plates filled with nutrient agar. Distinction was made between tracer bacterial cells and indigenous microflora on the basis of colony color - colonies of *Serratia marcescens* are distinctively pink to red colored in contrast to colonies of normally observed microflora which ordinarily are colored white, sometimes yellow, with molds exhibiting a variety of hues, but seldom if ever being pink or red. In all instances standard bacteriological procedures were employed; aerosolization and air sampling techniques were those used in our laboratories for several years and described by us in existing technical literature.*

Comparing average values for the ventilation constant as presented in Table 8, there is no statistically significant difference between those obtained with the CRS on or off. In both cases, the values from the settling plate data are higher than from the Andersen samples, but subject to suspicion because of settling plates are greatly affected by larger particles, and Andersen samplers reflect the effect of all particle sizes. However, it can be concluded that no effect of the CRS unit was demonstrated in removing airborne tracer bacterial cells from the air of the central core of the Atomedic Hospital.

As indicated above, there was considerable variation in the values obtained for decay of airborne tracer bacterial cells, probably due to variations in the biological decay. In order to isolate this factor, a comparison was made between the various values obtained for ventilation constants; the basic assumption in the analysis being that any total, apparent ventilation constant represents the summation of all factors which are involved:

\[ K = K_v + K_f + K_b + K_z \]

where

- \( K_v \) = observed apparent ventilation constant due to mechanical ventilation
- \( K_f \) = " " " fall-out of particles
- \( K_b \) = " " " biological decay or death
- \( K_z \) = ventilation constant due to any other factor.

It then follows that if the summation of rational values for the known factors account for the observed total \( K \) value, then there are no unknown factors to be accounted for. As a first approach, the value for \( K_v \) was taken as 0.035 from the LP gas ventilation; \( K_f \) from the mean settling rate of 0.5 fpm (from comparison of aerial concentration in numbers per cubic foot of air to
the initiation of atomization of the tracer bacterial cells. These data have been processed, seeking any information which might indicate an effect attributable to operation of the CRS unit. There were two sets of runs for each condition from which sufficient data were available for analysis. It happened that in each instance, CRS unit on and CRS unit off, that during one of the runs there were two persons only in the Atomedic Hospital, and during the other run there were four persons. It was assumed that the aerial burden of indigenous microflora would be related to the number of persons present, and comparisons were made on this basis. The counts from Andersen samples taken prior to atomization of the Serratia are presented in Table 10.

Table 10. Average numbers of colony-forming particles per cubic foot of air in the central core, from Andersen samples taken prior to atomization of Serratia.

<table>
<thead>
<tr>
<th></th>
<th>CRS OFF</th>
<th>CRS ON</th>
<th>All Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two persons (nights):</td>
<td>12.5 (N=12) *</td>
<td>8.9 (N=12)</td>
<td>10.7 (N=24)</td>
</tr>
<tr>
<td>Four persons (days):</td>
<td>7.3 (N=8)</td>
<td>6.9 (N=11)</td>
<td>7.1 (N=19)</td>
</tr>
<tr>
<td>All data:</td>
<td>10.4 (N=20) *</td>
<td>8.0 (N=23)</td>
<td></td>
</tr>
</tbody>
</table>

The data in Table 10 are arranged to show the results of two-way analysis of variance, CRS off compared to CRS on, and two persons in compared to four persons in (there were no evidence of interaction between the two factors). Values in parentheses are for the number of 10 minute Andersen samples from which the averages were determined. An asterisk between two values indicates a statistically significant difference.

Inspection of Table 10 reveals that the aerial content of microbial contamination was significantly greater with 2 people in the building than with 4 people; that it was significantly greater when the CRS unit was off than when it was on, both for the overall, and with two people in the building, but not with four people in the building. Although statistically significant the differences are small, and the probable sources of such differences, as set forth below, illustrate the difficulty of controlling exactly all experimental variables.

(1) A possible explanation for the higher counts with 2 people in is that these two runs were made during night hours when the microbial content of outside air is much greater than during daylight hours when the runs with 4 people in were made. The microbial content of outside air was not monitored, but the results of a few samples at night showed as many as 20 colony-forming particles per cubic foot of air. This is indeed a high level of microbial contamination, and much of this could be carried into the central core of the Atomedic Hospital through the 67 percent NBS filter. No samples were taken of outside air during daylight hours, but sunlight and lower humidities generally effect a marked reduction in the microbial content of air as compared to night conditions in the absence of sunlight and with humidities approaching saturation values.
Table 13. Sedimentation rates in feet per minute from the averages of aerial concentration and numbers settling presented in Tables 11 and 12.

<table>
<thead>
<tr>
<th></th>
<th>CRS OFF</th>
<th>CRS ON</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two persons (night):</td>
<td>0.38</td>
<td>0.58</td>
</tr>
<tr>
<td>Four persons (day):</td>
<td>1.50</td>
<td>1.10</td>
</tr>
</tbody>
</table>

The data in Table 13 show that the particles carrying microbial contamination were larger when 4 persons were present than when 2 persons only were in the central core. This is consistent with previous observations reported by us*. Increased personnel activity produces airborne microbial contamination of fairly large particles, having a mean settling rate as great as 2.4 feet per minute. Persons working quietly (as was the case with two people only in the building) will produce airborne microbial contamination in much smaller particles. No other significance should be attached to the values shown in this table because they are derived from averages some of which showed significant differences, others which did not.

The implications of the information obtained from observations upon the indigenous microflora of the central core of the Atomedic Hospital have been examined in some detail above, especially in the paragraphs following Table 10. The data appear valid and consistent with prior experience.

It was concluded that no evidence was obtained that operation of the CRS caused any reduction in microbial burden of the air during daylight hours when it is expected that the source of microbial contamination is internal, but there was a slight but significant reduction in the microbial burden during night hours when much of this burden arises from air outside the hospital. This effect although less than expected from medium to high efficiency filters, might warrant further investigations.

**SUMMARY AND CONCLUSIONS**

Possible effects of operation of a CRS unit were examined in the central core of the Atomedic Hospital at Woodstock, Georgia during the month of June 1969. These examinations were made after the air handling system and the CRS unit had been established in working condition, comparable to original design, except that the air system as operating handled 6500 cfm instead of the supposed design of 8000 cfm. Observations were made, with the CRS unit on and with it off, upon: ventilation of gases, ventilation of ethyl ether and ethyl alcohol vapors as odorants typical of the hospital, ventilation of airborne particulates, both total and those carrying viable microorganisms, and levels of contamination of airborne microbial contamination. The obtained data have been examined in detail and found to be valid and consistent with prior experience. From statistical analysis of these data the following conclusions are drawn.

1. No evidence was obtained that operation of the CRS unit had effect upon the removal of the odorants, ethyl alcohol and ethyl ether, from the

*Contamination Control Journal, VI, No. 6 (1967).
APPENDIX VI

PHYSICAL PARAMETERS OF COMPOUNDS
<table>
<thead>
<tr>
<th></th>
<th>Thermal Conductivity of Gas (0°C)</th>
<th>Density of Liquid</th>
<th>Van der Waals Constants</th>
<th>Npr</th>
<th>Nsc</th>
<th>Viscosity of Gas (25°C)</th>
<th>Tc</th>
<th>Pc</th>
<th>Vc</th>
<th>v.p. at 26°C (mm Hg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Helium</td>
<td>.0818</td>
<td>.03412</td>
<td>.02370</td>
<td>0.71</td>
<td>0°C</td>
<td>.019cp</td>
<td>5.26°K</td>
<td>2.26 atm</td>
<td>57.8 ml/m</td>
<td></td>
</tr>
<tr>
<td>Methane</td>
<td>.0176</td>
<td>2.253</td>
<td>.04278</td>
<td>0.75</td>
<td>100°C</td>
<td>.0109cp</td>
<td>190.7°K</td>
<td>45.8 atm</td>
<td>99.3 ml/m</td>
<td></td>
</tr>
<tr>
<td>Diethyl ether</td>
<td>.714 20/20</td>
<td>17.38</td>
<td>.1344</td>
<td>1.70</td>
<td>.0083cp</td>
<td>193.8°C</td>
<td>35.5 atm</td>
<td>282.4 ml/m</td>
<td>540 mm</td>
<td></td>
</tr>
<tr>
<td>Ethanol</td>
<td>.0077</td>
<td>.789 20/4</td>
<td>12.02</td>
<td>.08407</td>
<td>1.30</td>
<td>.0090cp</td>
<td>243.1°C</td>
<td>63.1 atm</td>
<td>167.2 ml/m</td>
<td>59 mm</td>
</tr>
<tr>
<td>Isobutanol</td>
<td>.809 20/4</td>
<td>19.05</td>
<td>1.88</td>
<td>287°C</td>
<td>48 atm</td>
<td>9 mm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-Hexanol</td>
<td>.810 25/4</td>
<td></td>
<td></td>
<td>326°C</td>
<td>4 atm</td>
<td>9 mm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Naphthalene</td>
<td>1.145 24/24</td>
<td>39.74</td>
<td>.1937</td>
<td>2.57</td>
<td>475.2°C</td>
<td></td>
<td>.08mm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>1.00</td>
<td>5.464</td>
<td>.03049</td>
<td>1.06</td>
<td>100°C</td>
<td>.0099cp</td>
<td>647.3°K</td>
<td>217.7 atm</td>
<td>56.6 ml/m</td>
<td>23.8 mm</td>
</tr>
<tr>
<td>Sulfur dioxide</td>
<td>.0050</td>
<td>6.714</td>
<td>.05636</td>
<td>1.28</td>
<td>.0123cp</td>
<td>430.7°K</td>
<td>77.8 atm</td>
<td>122 ml/m=4 atm (5 atm at 32.1°C)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freon 12</td>
<td></td>
<td></td>
<td></td>
<td>.0123cp</td>
<td>112°C</td>
<td>39.6 atm</td>
<td>218 cc/g</td>
<td>6.71 atm</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### PHYSICAL PARAMETERS

<table>
<thead>
<tr>
<th>COMPOUND</th>
<th>MOLECULAR WT.</th>
<th>(°C) BOILING POINT</th>
<th>(°C) MELTING POINT</th>
<th>(g/100g H₂O) H₂O SOLUBILITY</th>
<th>(x10⁻¹⁸ esu) DIPOLE MOMENT APPLICABLE AT 25°C</th>
<th>DIFFUSION COEFFICIENT (Air) at 25°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulfur dioxide</td>
<td>64.06</td>
<td>-10</td>
<td>-72.7</td>
<td>22.8 (0°C) 0.58 (90°C)</td>
<td>1.63 ± .01</td>
<td>.145</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>30.03</td>
<td>-21</td>
<td>-92</td>
<td>(CH₂O) - v.s. (CH₂O)₃ meta 21 (25°C) (CH₂O)ₓ x H₂O Para 20-30 (18°C)</td>
<td>2.27</td>
<td>.153</td>
</tr>
<tr>
<td>Naphthalene</td>
<td>128.2</td>
<td>217.9</td>
<td>80.2</td>
<td>0.003 (25°C) 0.1</td>
<td>0</td>
<td>.0611</td>
</tr>
<tr>
<td>Camphor</td>
<td>152.23</td>
<td>209.1 (sublimes)</td>
<td>176</td>
<td>0.1</td>
<td>0</td>
<td>.065</td>
</tr>
<tr>
<td>Isovaleric acid</td>
<td>102.13</td>
<td>176</td>
<td>-37.6</td>
<td>4.2 (20°C) 1.74</td>
<td>.065</td>
<td>.132</td>
</tr>
<tr>
<td>Ethanol</td>
<td>46.1</td>
<td>78.4</td>
<td>-112</td>
<td>oo</td>
<td>1.69</td>
<td>(351-499°C)</td>
</tr>
<tr>
<td>Diethyl ether</td>
<td>74.1</td>
<td>34.6</td>
<td>-116.2</td>
<td>7.5 (20°C) 1.15</td>
<td>.093</td>
<td></td>
</tr>
<tr>
<td>Ethane</td>
<td>30.07</td>
<td>-88.6</td>
<td>-172</td>
<td>4.7 cc/100g H₂O (20°C) 0</td>
<td>0</td>
<td>.139</td>
</tr>
<tr>
<td>Methane</td>
<td>16.04</td>
<td>-161.4</td>
<td>-182</td>
<td>0.35 cc/100g H₂O (20°C)</td>
<td>≈1.6</td>
<td></td>
</tr>
<tr>
<td>2-Octanol</td>
<td>130.23</td>
<td>179-180</td>
<td>-38.6</td>
<td>v.s.s.</td>
<td>≈1.6</td>
<td></td>
</tr>
<tr>
<td>2-Hexanol</td>
<td>102.2</td>
<td>137-8</td>
<td>-</td>
<td>s.s.</td>
<td>≈1.6</td>
<td>.059 (hexyl alcohol)</td>
</tr>
<tr>
<td>Benzyl alcohol</td>
<td>108.13</td>
<td>204.7</td>
<td>-15.3</td>
<td>4 (17°C) 1.67 ± .02</td>
<td></td>
<td>(385-490°C)</td>
</tr>
<tr>
<td>1-Butanol</td>
<td>74.1</td>
<td>117.5</td>
<td>-79.9</td>
<td>9 (15°C) 0.16</td>
<td></td>
<td>.084</td>
</tr>
<tr>
<td>Acrolein</td>
<td>56.06</td>
<td>52.5</td>
<td>-87.7</td>
<td>40</td>
<td>3.04</td>
<td>(377-478°C)</td>
</tr>
<tr>
<td>Lactic Acid</td>
<td>90.08</td>
<td>122 (14 mm)</td>
<td>16.8</td>
<td>oo</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>18</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td></td>
<td>.260</td>
</tr>
</tbody>
</table>

Dissociation constants of acids in aqueous solutions:

Isovaleric, $1.7 \times 10^{-5}$ (25°C)

Lactic, $1.55 \times 10^{-4}$ (25°C)
APPENDIX VII

PROCEDURE FOR SULFUR DIOXIDE DETERMINATIONS

(from: Philip W. West and G. C. Gaeke,
"Fixation of Sulfur Dioxide as Disulfitomereurate (II) and Subsequent Colorimetric Determination,"
Analytical Chemistry, 28, 1816 (1956).)
Procedure for SO₂ Determination
(6 September 1968 TWK from Larry Miller)

USE FRESHLY BOILED AND COOLED DISTILLED WATER THROUGHOUT

1. Preparation of Reagents.
   a. Pararosaniline hydrochloride (PRA) reagent weigh 1.0 gm dye from bottle of Fischer pararosaniline hydrochloride (labelled for SO₂ and HCHO determination) into a flask, add 100 ml distilled water; shake, stopper, leave overnight, next morning, shake and filter through 15 cm qualitative filter paper (Southern Scientific No. 7679) in a glass funnel. A second filter paper and funnel may be necessary to complete the filtration if the first one becomes too clogged. Collect the filtrate (a saturated solution of the dye) in a 125 ml flask. Keep this for making the PRA reagent as below.

   Take 4.0 ml of the above filtrate into a 100 ml volumetric flask; add 6.0 ml concentrated HCl; let stand for 10 minutes then dilute to volume with distilled water. This is the PRA reagent for the SO₂ determination; it is stable for several months.

   b. .04M Potassium Tetrachloro Mercurate (TCM) absorbing reagent) - weigh 5.96 gm Potassium chloride into a 1 liter volume flask, add ca 300 ml distilled water and shake until dissolved. Weigh 10.90 gm Mercury II Chloride, add to this flask and dilute to volume. It will not dissolve immediately, but should after ca 10 min. of shaking. This solution is stable for several months. Caution: poisonous.

   c. 0.3 Percent Sulfamic acid reagent - weigh 0.30 gm of sulfamic acid into a 100 ml volume flask and dilute to volume. With distilled water shake until dissolved. This reagent will keep several days if protected from air.

   d. 0.2 Percent formaldehyde reagent - pipette 1.0 ml of ACS 40 percent formaldehyde into a 200 ml volumetric flask and dilute to volume with distilled water.
Prepare daily.

2. Collection and computation of aerial concentration.

Place 10.0 ml TCM reagent into midget impinger bottle. For concentrations of ca 1 PPM SO₂, collect for 10 min. at ca 1 LPM, employing a critical orifice on the vacuum side. Do not use frits.

Computation:

\[
\text{vol. of air sampled} = \text{Sampling time, min.} \times \text{sampling rate, LPM}
\]

\[
\frac{\mu g \text{ SO}_2 \text{ determined by analysis}}{\text{vol. of air sampled}} = \mu g \text{ SO}_2 \text{ per liter of air}
\]

NOTE: 1.0 µg/L is identical to 1.0 mg/m³, and for SO₂ \((1.0 \mu g/L)(2.62) = \text{PPM SO}_2 \text{ in air.}

3. Analysis.

To sample collected in TCM Reagent in midget impinger bottle:

a. Add enough TCM reagent to bring volume to exactly 10.0 ml (be sure bottle is at (room) temperature).

b. Add 1 ml Sulfamic acid reagent; mix.

c. Let stand 10 minutes.

d. Add 1 ml formaldehyde reagent; mix.

e. Add 1 ml PRA reagent; mix.

f. Let stand 30 minutes.

g. Transfer enough of the final solution to Spectronic tube to fill to BL trademark.

h. Read absorbance on Spectronic 20 at 560 mp (see instructions for operating Spectronic).

i. Determine quantity of SO₂ from calibration curve.


Take 1.0 ml of freshly standardized SO₂ solution (see Standardization Procedure below) into a 100 ml volumetric flask and dilute to volume with TCM reagent. This
is "stock" SO₂ solution, containing 3.2-4.0 µg/ml. In midget impinger bottles, make up the following:

1. 0.0 ml SO₂ + 10.0 ml TCM reagent. This is the blank.
2. 1.0 ml "stock" + 19.0 ml TCM reagent (take 10.0 ml for analysis).
3. 1.0 ml stock SO₂ + 9.0 ml TCM reagent.
4. 2.0 ml "" + 8.0 ml "".
5. 3.0 ml "" + 7.0 ml "".
6. 4.0 ml "" + 6.0 ml "".
7. 5.0 ml "" + 5.0 ml "".
8. 6.0 ml "" + 4.0 ml "".

Analyze each of these according to the steps in section 3 above. Compute the exact concentration of SO₂ in µg/10 ml in each solution from conc. in standard SO₂ solution as follows:

\[
\frac{\text{(µg/ml Standard SO₂ soln.) (ml stock/10 ml soln.)}}{100} = \text{µg/10 ml}
\]

plot the exact quantities, µg/10 ml, vs. absorbance on linear graph paper. The resultant data points should yield a straight line. This is the calibration curve.

NOTE: Further experience will indicate whether it is necessary to employ all 6 data points, and how often calibration is required.

5. Standardization of SO₂ solution for calibration.

Use freshly boiled and cooled distilled water for all solutions.

Standard SO₂ solution: 0.40 gm sodium sulfite into 500 ml volumetric, up to volume with H₂O.

N/10 Iodine and N/10 Sodium Thiosulfate: prepare from concentrate, as directed on label. Store in glass, stoppered bottles in a dark cabinet, where they will keep for at least a month. Date the label.
Starch indicator: ca 2 gm potato starch, mix with a small amount of cold H₂O to a thin paste. Add ca 200 ml boiling H₂O, constantly stirring. Transfer to a dropping bottle, add ca 1 ml Hg, shake. Should keep indefinitely.

Check titration: pipet 10.0 ml N/10 Iodine into flask. Titrate with N/10 Thiosulfate from 10 ml buret. Titrate until brown iodine color is faint, then add a drop or so of starch indicator, then slowly titrate dropwise until blue color disappears. Should check within 0.05-0.1 ml; if not, prepare a new N/10 solution of the weaker one and repeat. N.B. it is possible that there will be evidence of a "blank"; that is, will take a drop of thiosulfate in XS to decolorize starch.

SO₂ solution standardization: 100.0 ml of SO₂ solution into a flask, add 20.0 ml N/10 Iodine and mix. Immediately after adding iodine, take 1 ml SO₂ solution into 100 ml vol. flask and dilute to volume with TCM reagent for "stock" SO₂ solution. Back titrate with N/10 thiosulfate from 10 ml buret. Titrate until brown color is faint, add a few drops of starch indicator, slowly titrate to disappearance of blue color. If the check titration indicated a "blank", subtract this from the volume of thiosulfate required.

Calculation: 20.0 - ml N/10 thiosulfate for back titration = ml N/10 Iodine consumed by 100 ml SO₂ solution.

1.0 ml N/10 = 3.203 mg SO₂; and

\[
\frac{(\text{ml N/10 Iodine consumed})(3.203) \times 1,000}{100} = \text{micrograms SO₂ per ml of solution.}
\]

It is expected that the obtained value of micrograms SO₂ per ml of solution will be within the range 320-400.
APPENDIX VIII

PROCEDURE FOR FORMALDEHYDE DETERMINATIONS

Procedure for formaldehyde determination
(6 September 1968 TWK from Larry Miller)

USE FRESHLY BOILED AND COOLED DISTILLED WATER THROUGHOUT

1. Preparation of Reagents.
   a. PRA reagent - weigh 0.16 gm pararosaniline hydrochloride (from bottle labelled for SO₂ and HCHO determination) into a 100 ml volume flask, add 24.0 ml conc. HCL; mix; let stand 10 minutes. Dilute to volume. This is PRA reagent for HCHO determination; it is stable for several months.
   b. Sulfite reagent. Weigh 0.20 gm Sodium sulfite into a 50 ml flask and dilute to volume with .04 M TCM (prepared as in SO₂ determination, above) unstable - prepare daily.

2. Collection and computation of aerial concentration.
   Place 10.0 ml water into midget impinger bottle. For expected concentrations of ca 1 ppm HCHO, collect 10 minute samples at ca 1.0 LPM, employing a restrictive or critical orifice on the vacuum side. DO NOT USE FRITS.
   Computation: \( \text{(Sample time, min)} \times \text{(Sampling rate, LPM)} = \text{vol. of air sampled, Liters} \)

\[ \frac{\text{\( \mu g \) HCHO determined by analysis}}{\text{volume of air sampled}} = \frac{\text{\( \mu g \) HCHO per Liter of air.}} \]

Note: 1.0 \( \mu g/L \) is identical to 1.0 mg/m³, and for HCHO

\[ (1.0 \ \mu g/L)(0.815) = \text{ppm HCHO in air.} \]

3. Analysis.
   To sample collected in distilled water in midget impinger bottle:
   a. Add enough distilled water to bring volume to exactly 10.0 ml (be sure temp. is proper).
   b. Add 1.0 ml sulfite reagent; mix.
   c. Add 1.0 ml PRA reagent, mix.
   d. Let stand 30 min.
e. Transfer enough of the final solution to Spectronic tube to fill to BL trademark.

f. Read absorbance at 560 μm on Spectronic 20. (see instructions for Spectronic 20).

g. Determine quantity of HCHO from calibration curve.


Pipet 5 ml of ACS formaldehyde into a tared aluminum weighing dish on the analytical balance. Quickly weigh exactly (record weight), and immediately transfer to a 2000 ml volumetric flask and make up to volume with water. Take 10.0 ml from this dilution into a 100 ml vol. flask and dilute to volume. This is the "stock" solution, containing approximately 100 μg of formaldehyde per ml. Make two dilutions from the "stock":

A. Take 10.0 ml of "stock" into a 100 ml vol. flask, dilute to vol. This solution contains approximately 10 μg/ml.

B. Take 10.0 ml of "stock" into a 1000 ml vol. flask, dilute to vol. This solution contains approximately 1.0 μg/ml.

In midget impinger bottles, make up to 10.0 ml, the following:

1. 0.0 ml formaldehyde. This is the blank.

2. 2.0 ml solution B; ca 2 μg formaldehyde.

3. 4.0 ml " ; " 4 " "

4. 6.0 ml " ; " 6 " "

5. 8.0 ml " ; " 8 " "

6. 10.0 ml " ; " 10 " "

7. 1.0 ml Solution A; " 10 " "

8. 2.0 ml " ; " 20 " "

9. 3.0 ml " ; " 30 " "
Analyze each of these according to the steps in section 3 above. Compute the exact micrograms of HCHO on the basis of the original weighing (analysis of the ACS formaldehyde has confirmed the content of this to be 37.1-37.2 per cent by weight):

\[(\text{weight of 5 ml ACS formaldehyde})(0.371) = \text{grams of HCHO}\]

This quantity has been diluted 2,000; then 10, to make the "stock", a total of 20,000 dilution. Multiplying grams \(x 10^6\) to yield micrograms, and cancelling:

\[\frac{(\text{grams HCHO weighed})(100)}{2.0} = \mu\text{g/ml in "stock"}\]

Use this amount as a factor to convert the approximate values for micrograms into exact quantities by dividing it by 100, and multiplying each approximation by it.

Now plot the exact quantities, \(\mu\text{g}/10\text{ ml}\) versus absorbance in linear graph paper. The resultant data points should yield a straight line. This is the calibration curve.

NOTE: further experience will indicate whether or not it is necessary to employ all 9 data points, and also how often a calibration is required.