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VENTILATION AND EXHAUST AIR REQUIREMENTS FOR HOSPITALS— PART II: ODORS

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ABSTRACT

Standards for ventilation of occupied spaces have been set primarily on the basis of odor level. Hospital ventilation is somewhat of an exception, wherein there is a risk of airborne infection and the release of chemical contaminants, some toxic. A large fraction of hospital space is relatively free of airborne bacteria and chemical pollution; further transmission of infection by air motion is considered minor by many medical authorities compared to direct contact.

This study reports on the odor levels and odor acceptability of the air circulated to hospital patient rooms, as judged by a panel of college students. Patient Tower 1 of a university hospital (a recently constructed modern facility) was used as the test site. Toilet exhaust from half of the patient tower was reduced, while the "control" half of the tower remained at normal exhaust. Panelist judgements of odor levels are quantified against the Dravnieks binary dilution (butanol) olfactometer. The results suggest that reductions in current standards of hospital ventilation (and toilet exhaust) may lead to odor levels with a high percentage of unacceptability.

INTRODUCTION

Standards for ventilation of occupied spaces have been set primarily on the basis of odors. Hospital ventilation is somewhat of an exception, wherein there is the risk of airborne infection and the release of many chemical contaminants, some toxic. In a companion paper (1) the author has presented an organized survey of the medical findings and thinking on the role of air in hospital-acquired infections. The paper also discusses in some detail the ASHRAE and federal standards for hospital ventilation.

It has been suggested that a large fraction of hospital space is relatively free of airborne bacteria and chemical pollution. Consequently, ventilation requirements for those areas could be reduced toward values set for commercial buildings. A space classification study of a university hospital confirmed that upwards of 80% of its spaces fell into a category termed "clean".(1)

An objective of this ASHRAE-sponsored research project was to investigate and recommend minimum exhaust air rates for toilet spaces in hospitals. Evidently the criterion by which such minimum rates would be set is perceived odor. In the space classification study of the hospital's patient bedtowers, it was determined that the great preponderance of "dirty" spaces was toilets.(1) It was further determined (see Table 8 and its discussion in Reference 1) that a toilet exhaust air requirement of 50 cfm (24 L/s) or 10 air changes per hour (ach) as set by ASHRAE Standard 62-81(2) or the federal Hill-Burton Standard(3), is the controlling factor for outside air ventilation. As a consequence, Patient Bedtower 1 was selected as a prime site for conducting a study of minimum exhaust air rates. A panel of university students was used to judge odor levels and acceptability.

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LITERATURE SURVEY

An extensive literature survey on hospital ventilation was conducted under the sponsorship of the U.S. Department of Energy. Chapter 6 of the report[4] setting forth the results of the survey is concerned with odor: how the nose senses odors, the many variations in quality and intensity of odors, the differences that exist from person to person in rating odors, the difficulties of odor measurement, and the relationships of ventilation to odor in buildings. Some pertinent quotes from the report are:

> Odors are either liked or disliked based upon previous experience with the odor or a similar odor. Pleasant odors conjure up in our minds visions of pleasant things while unpleasant odors can create discomfort. Odors have a significant bearing on human interaction in today's society. Persons are categorized by their odors whether the odor is real or not, and the odor emanating from the individual is used to indicate moral purity, social status and living standards. The entire nervous system is affected by odors. Different odors react to influence our heartbeat, respiration, and other reflexes and calm us or put us on the defensive.
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> One of the major problems with odors is that the personal likes and dislikes of people and cultural groups cause a particular odor to be classified as pleasant or unpleasant. A given odor that is preferred by a majority can still be disliked by some minority, and some odors no matter how repulsive to a majority might still appeal to some minority. Such unintentional biases may reduce the validity of investigator's results in sensory testing. Yet any data developed by other than the human nose is not capable of revealing the pleasure/displeasure quality of the odor, nor of reflecting secondary effects caused by interactions. Odorants may not always be recognized as odor producing. For example, air that may be characterized as stale or stuffy is usually contaminated with a conglomeration of occupied space odorants producing a depressing physiological or psychological response rather than the sensation of odors. It is difficult then to set standards and limits for such a subjective concern. It must be recognized that hospital odors are a problem that does cause patient and staff discomfort and that ventilation rates must be considered when dealing with odor control.
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> Individuals vary in ability to detect odors either due to specific anosmia or intra-individual sensitivity. Sensitivity to odors should follow a Gaussian distribution when concentration is expressed in logarithmic form.
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> Odor thresholds of different chemicals varies immensely. Odor threshold determination of 53 odorant chemicals as tested by Leonardos *et al*. showed that Trimethyl Amine has a threshold of .00021 ppm versus Acetone with a threshold of 100 ppm. This would indicate that extremely low concentrations of a particular chemical in the hospital can be associated with an odor problem while much higher concentrations of a different odorant might yield no problem.
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> All odor measurement techniques that are in use at the present time rely on the human nose. The sensory attributes that can be measured are the acceptability, quality, intensity and pervasiveness. When measuring for malodors within the hospital it is better to measure the objectionability threshold rather than the intensity threshold. These two numbers can be vastly different with the intensity threshold always lower than the objectionability threshold, because the odor must be perceived before it can be objected to. In the hospital it is usually sufficient to control objectionability rather than to eliminate the odor entirely. This is a general principle which could be used in all dwellings to conserve energy.

The first definitive studies of odor and ventilation rate were conducted principally by C. P. Yaglou and associates.[5,6] Their concern was with occupancy odor, and they applied simple psychophysical scaling to the question of how the level of odor depended on ventilation. In the most often cited work and the one on which the earlier ASHRAE ventilation standards were based, Yaglou, Riley, and Coggins[5] charted odor as a function of density of occupancy, age, socioeconomic status, personal hygiene, and ventilation rate. It was determined that density of occupancy and ventilation rate were the most important.

Figure 1 presents the results (as adapted by Cain[7]) for adult subjects. The ordinate in the figure is from a sensory intensity scale of body odor developed by Yaglou, as presented in Table 1. If the criterion of acceptability of odor is taken as 2 on Yaglou's scale of intensity (dashed line of Figure 1), then a relationship of outdoor air ventilation rate to air space per person can be established. Such a relationship is shown by curve "C" in Figure 2. The estimates of odor level that led to the construction of Figure 1 (and curve C of Figure 2) came from a few observers who entered the chamber momentarily from a fresh air room.

Cain[7] has this comment on Yaglou's results:

> It seems strange that ventilation requirements should have failed to vary proportionally with density of occupancy, an outcome that would have allowed the rate <u>per person</u> to remain constant with changes in density. Yaglou recognized the anomaly and suggested two possible causes: 1) progressive inefficiency in the clearance of contaminants as nominal ventilation rate increased, and 2) instability of occupancy odor, i.e., rapid decay of this particular odor even without dilution--Yaglou's estimates of ventilation requirements have withstood the test of time. That is, few persons have argued that the recommended rates fall <u>below</u> that required for sedentary, nonsmoking occupancy. During the time that <u>energy</u> has increased rapidly in price, some have wondered whether the recommended rates fall <u>above</u> the rate necessary.
>
> Blind adherence to recommendations based exclusively on control of body odor from normal persons has relatively little justification. Indeed, Yaglou and associates took pains to point out that personal hygiene alone could exert a powerful influence on ventilation requirements.
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> These and other considerations, such as the presence of odorous contaminants other than body odor in indoor spaces, have conspired to push ventilation rates above those recommended by Yaglou. A contaminant such as tobacco smoke odor may prove so dominant that it dwarfs the contribution of other odorous contaminants. Yaglou addressed this problem two decades after his initial research[9]. Shortly after the first study, however, Yaglou in collaboration with Witheridge inquired into whether body odor behaved like a typical odorous contaminant[6]. Much to their consternation it did not and led them to make the following statement: "Heretofore body odor in the air of occupied rooms was regarded as a more or less stable entity, and the problem of odor control was thought to be mainly one of plain dilution with clean outside air. Evidence obtained during the past two years does not support this view, but indicates that body odors are very unstable, tending to disappear rapidly with time, much faster than most odors with which the ventilating engineer is confronted in public buildings."
>
> This conclusion arose from results like those depicted in Fig. 3 which shows how odor declined in the still air of an unventilated chamber after removal of the source of odor. Body odor decayed abruptly from <u>very strong</u> to <u>definite</u> within 4 min after occupants left the chamber. By contrast, the odor of valeric acid decayed to <u>definite</u> only after a number of hours. Indeed, body odor decayed far more rapidly than the highly reactive substance ozone. The peculiar behavior of body odor even prompted the conclusion[6]: "The influence of per capita air space on ventilation requirements from the standpoint of body odor would, therefore, seem to be explainable, almost entirely, by the rapid disappearance of body odor". In essense, this statement disclaimed the general usefulness of Yaglou's recommendations in Fig. 2.
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> According to Yaglou and Witheridge, the other odors they studied (valeric and butyric acid, tobacco smoke, and ozone) were all capable of masking body odor completely. This presumably meant that each might generate its own "ventilation requirements function" of different shape and level than the curve in Fig. 2. This would seem particularly true of tobacco smoke odor. As Fig. 3 shows, in an unventilated chamber, tobacco smoke odor actually increased for approximately 3 hours after cigarettes were removed. Hence, whereas the control of body odor seemed accomplished most easily in a large room with low air flow, the control of tobacco smoke odor would seem accomplished more easily in small rooms with fast ventilation.

In 1980-81 odor studies were conducted by Cain and Lederer[7,8] in a specially constructed ventilation chamber of 1200 ft^3 (34 m^3),* the main factors in the investigation of

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*The chamber was constructed of aluminum with a perforated plenum beneath the floor. Air entered via the plenum allowing a volume flow of up to 2000 cfm (1000 L/s) with low velocity and very rapid mixing with the air in the chamber.

occupancy odor included three levels of occupancy (4, 8, and 12 occupants), four ventilation rates (5, 10, 15, and 20 cfm [(2.5 to 10 L/s]) per occupant, and four temperature and humidity conditions. The main factors in the investigation of tobacco smoke odor included three rates of smoking (4, 8, and 16 cigarettes/hr by four smokers), six ventilation rates (11, 16, 20, 25, 35, and 68 cfm [(5.5 to 34 L/s] per occupant), and again four temperature and humidity conditions.

Over 200 persons participated in the experiments, which involved sniffing the chamber air at a station outside the chamber and making judgements of odor intensity and acceptability. Odor intensity was judged by a psychophysical matching to one of the eight odor ports of a Dravnieks binary dilution (butanol) olfactometer (see Figure 11).

Results of Cain and Lederer's(7,8) experiments are shown in Figure 4. These results are taken across environmental conditions and thereby focus on ventilation rate and occupant density. They demonstrate two major findings, namely: (1) in contrast to the findings of Yaglou, occupant density has no apparent effect on odor level for a given ventilation rate per occupant; (2) increasing the ventilation rate above 10 cfm/person (5 L/s•person) had almost no effect on the judgement of odor level.

Figure 5 compares acceptability of occupancy (body) odor and tobacco odor by the panelists to magnitude level of butanol from the eight ports of the Dravnieks olfactometer. For occupancy odor, even the lowest port, no. 1 (with a butanol concentration of 16 ppm at or near the threshold limit for good noses), rated only 85% acceptable. The panelists found occupancy odors matching levels 2 and 3 acceptable 80% of the time and between levels 3 and 4 acceptability dropped sharply. Cain, et al.(7) offered the opinion: "An absence of clear level dependency suggests the matching levels 1 through 3 may reflect merely 'noise-level' dissatisfaction that would occur if odor level ever exceeded threshold. Butanol matching functions obtained with ventilation rates of 5 and 10 cfm per occupant, however, exceeded level 3. These functions raise the question of how high odor must climb before it fails to meet a reasonable criterion of acceptability. According to the acceptance function [Figure 5], the odor levels achieved with 5 and 10 cfm per occupany would fall at about 70% and 78% respectively."

Results of magnitude estimation of odor by visitors during a smoking rate of four cigarettes per hour in the chamber are presented in Figure 6. After smoking began (at 15 minutes) the odor level rose sharply over the next 15 minutes and persisted at a higher level for one hour after smoking stopped. At a ventilation rate of 68 cfm (34 L/s) per occupant it was not possible to reduce the odor level to nonsmoking conditions, nor did this highest ventilation rate provide much improvement of odor intensity over a 35 cfm (17.5 L/s) per occupant rate.

As in the case of occupancy odor, high humidity conditions (RH $\geqslant$ 70%) resulted in higher judgements of odor level. High humidity also caused tobacco odor to persist longer after smoking ceased. Smoking rates of 8 and 16 cigarettes per hour produced very similar results to those of Figure 6. However, a ventilation rate of 68 cfm per occupant was necessary to bring the butanol odor level down to 4.

Generally, cigarette smoking produced a matching intensity odor of between 4 and 5 on the butanol scale when ventilation rates were in the range of 25 cfm to 35 cfm (12.5 L/s to 17.5 L/s) per occupant. With reference to the dotted curve of Figure 5, this corresponds to a 63% to 66% acceptability by visitors. The acceptability rating by smokers in the chamber was 80%.(7)

PATIENT TOWER ODOR STUDY SITE

Figure 7 is an isometric schematic of the eight-floor Patient Tower 1 of the university hospital. The general path of the exhaust and return air duct system has been traced on this sketch. Note that there are two roof exhausts, labelled exhaust "A" and exhaust "B," each serving one-half of the tower area. Similarly, the return air from the periphery zone is divided equally into two return air chases (see floor level 2 in Figure 8), which mix just prior to entry to air-handling unit 27 on level 1. This "split" exhaust and return system offers a near ideal setup for studying the effects of reduced toilet exhaust.

With the cooperation of university Medical Center operations and the health safety office, experiments were planned to reduce the exhaust air to the patient rooms served by exhaust "A." Exhaust "B" was to operate normally and serve as an unmodified standard for comparison.

The supply, return, and exhaust air rates for patient rooms are identified in Figure 8. The south-facing rooms receive 190 cfm of conditioned air, exhaust 50 cfm through the toilet, and return 130 cfm. The excess 10 cfm supply over the sum of exhaust and return provide for a positive pressure differential to the adjacent spaces. The supply and return rates are lower for the northeast-and southwest-facing rooms. Corner rooms have still different rates because of size and orientation. The patient isolation room maintains a return and exhaust air rate equal to or greater than supply to create a negative pressure differential.

In Figure 9 air-handling unit (AHU) 27 and its associated ductwork serving the periphery zone of Patient Bedtower 1 is illustrated at floor level 1. An odor-sampling station was set up next to the inlet of AHU 27. The three odor-sampling points used were: outside air, indicated as point (1); return air from chase A (section with reduced toilet exhaust), indicated as point (2); and return air from chase B (at normal toilet exhaust rates), indicated as point (3).

In many ways the configuration of the ventilation system in Patient Tower 1 offered considerable advantages for an odor study. The sampling points for outdoor air and return air from the patient rooms were available very near the sampling station, permitting short duct runs and, thereby, avoiding any odor absorption or contamination in transit. The outdoor air sampling could be used to obtain a "clean" nose by the panelists. The accumulation and mixing of the return air from one-half of the patient rooms provided a condition similar to recirculating part of the toilet exhaust air. The side-by-side location of the sampling ports in a "neutral" mechanical space permitted comparative judgements on odor intensity and acceptability without the preconditioning that would occur in visits to patient rooms and toilets through other odiferous spaces.

ODOR-SAMPLING TEST PROGRAM

Sample Station Setup

The configuration of the odor sampling station is illustrated in Figure 10 by a photograph made during the test program. Four 4-inch-diameter, 45-degree elbows of chemical resistant glass were used for the sniffing ports*. The sample air was delivered by the fans of four hairblower-dryers. The blower discharge was connected to the glass sniffing ports by a flexible steel metal duct of 4-inch diameter, which was advertised as free of any odor. Preliminary tests conducted with the ducting confirmed no noticeable odor addition to outdoor air samples. The metal was further considered to be of a hardness and quality that would not absorb odors.

As shown in Figure 10, the four sniffing ports were mounted on a plywood panel so that about one-half of the 45° glass elbow extended in front and one-half behind the board. The flexible ducts were connected to the glass elbows behind the board and, hence, were not visible to the odor panelists. The duct connections were changed after each test; hence, air from outside or from a return duct could be presented through any one of the four ports labeled as A, B, C, and D.

On a table located a short distance from the odor sniffing ports was a Dravnieks binary dilution olfactometer. In the photograph of Figure 10, a panelist is bent over the olfactometer. A close-up view of a panelist sampling from one of the olfactometer ports is shown in the photograph of Figure 11.

Exhaust and Ventilation Rates

Before starting any odor tests, a check was made on the airflow rates in a random selection of patient rooms in Patient Tower 1. The measurements were compared with the design values as taken from the HVAC drawings, and, in almost every case, the measured flow rates were below the design. In the case of toilet exhaust air measurements, the flow was often so low it would not give an indication on the box anemometer or on a small hand-held anemometer at the grille face. Our findings were reviewed with hospital engineering and operations staff, and maintenance personnel were directed to check and adjust airflows in Patient Tower 1. Additional airflow checks were made before and during the odor tests from which it was

*The design of the odor sampling station including; sampling points, size of ports, and sample air velocity; were based on recommendations of Dr. William S. Cain.

concluded that toilet exhaust air rates were generally within 70% to 110% of the design value of 50 cfm under normal roof exhaust fan operation.

The exhaust air from the toilets on the west side of Patient Tower 1 are served by roof exhaust fan A and those on the east side by exhaust fan B (Figure 7). As the isolation rooms (Figure 8) are in the north end of the zone served by exhaust fan B and return air chase B, that side was chosen as the control zone. The exhaust air volume was maintained at or near the design flow rate. In the zone served by exhaust fan A and return air chase B, the exhaust fan speed was varied from 100% of design to 33% and in one test was shut off for 15 hours.

Table 2 presents the exhaust fan speed settings and outside air intake damper positions used for eight odor tests. Test numbers 1 and 4 were discarded; the first test was a training test for the panelists and Test 4 had too few panelists to give a reasonable statistical sampling. Examination of Table 2 will show six different operational conditions. Tests 2 and 7 are duplicates at "design" conditions. Likewise tests 5 and 6 are duplicates with exhaust fan A at 33% of normal speed and with the normal outside air damper setting. Tests 3 and 8 are with exhaust fan A at 50% of normal speed, but they differ in the outside air damper position. Test 8 reduces ventilation air to a 28% damper position to compensate for the reduced exhaust air rate. Test 9 was made after a 15 hour shutdown of exhaust fan A. Test 10 was again made at normal design conditions, but three hours after the end of the shutdown of Test 9.

Odor Panel and Balloting

The odor panelists were recruited from among the student body, and, the tests were conducted during the late summer months (July and August). Consequently, it was somewhat difficult to recruit students who would be available continuously for the six weeks of testing. Of the 20 panelists selected, the mean age is 22 with the oldest 31 and the youngest 18. There were 13 male and 7 female panelists. Only 2 of the 20 were smokers and those two were "light" smokers, admitting to only one to five cigarettes per day. Three of the students were identified as of foreign nationality: from Venezuela (Spanish background), Japan, and China. Only three responded positively to the question: "Do you have any respiratory problems or allergies?" The allergies stated were cats and pollen.

The panelists were given an orientation session, which consisted of the following instructions and demonstrations:

1. They would be performing odor judgements on air in the supply and return ventilation system of the university hospital.

2. There was no health risk involved nor would they be sampling obnoxious, putrid, or other "bad" smells. The air samples presented would be those in "normal" use in a hospital.

3. Four odor-sampling stations would be presented. One would always be identified to them as "outside" air taken from an area just outside the building. The other three sample stations would not be identified as to their source.

4. The odor judgement to be rendered at each sample station was a choice among:

   (a) None - No perceptible odor or very faint, barely detectable, usually imperceptible.

   (b) Definite - Slight odor, readily detectable but not objectionable.

   (c) Moderate - Neither pleasant nor disagreeable, little or no objection.

   (d) Strong - Regarded with disfavor, objectionable.

5. The Dravnieks binary dilution olfactometer was described and demonstrated. A judgemental matching of the "intensity" of an odor at a hospital air-sampling station to one of the eight ports on the olfactometer was to be made as a part of each test.

6. The "ballot" to be used in all of the odor judgement tests was distributed to the

panelists and the procedure for completing it described. The "ballot" is presented here as Figure 12.

7. A visit was made to the mechanical room on the first level of Patient Tower 1 (Figure 10) to view the odor-sampling stations and review the procedures to be used in completing the "ballot."

The panelists were instructed to begin with sampling port A then proceed systematically to B, C, and D. The port identified as "outside air" during each test could be used to "cleanse" the nose of a strong or lingering odor before proceeding to the next odor judgement. The "ballot" required three trials to be made at each sampling port. On the third trial, the odor was to be rated as "Acceptable" or "Not Acceptable" and the matching of intensity made to one of the ports on the olfactometer.

TEST RESULTS

The results of the eight odor tests conducted are summarized in Table 3 and Figure 13. In Table 3 the "ballot" voting on each of the three trials is tabulated under the columns of odor judgement in the four categories: "none," "definite," "moderate," and "strong." The numbers shown in these columns are the number of panelists expressing a judgement of that odor level. Using 0, 1, 2, and 3 as an assigned "value" for the four levels of odor, an average is computed. An average value of 1.5 would represent an odor level midway between "definite" and "moderate." The last two columns of Table 3 give the panelist votes on the acceptability and nonacceptability of the odor sampling.

Figure 13 presents the same odor judgement results in the form of a bar graph or histogram. An additional result presented in this figure is the mean matching odor level of butanol from the Dravnieks binary dilution olfactometer. The "butanol level" scale on the right hand side of the figures is in terms of the eight ports on the olfactometer. Thus a "4" level means port 4 or 125 ppm of butanol.

The results presented in Table 3 and Figure 13 have the following characteristics:

1. Outside air, whether identified or not identified to the panelists, was judged as having an odor level of "none" by approximately 75% of the panelists and of "definite" (i.e., slight odor) by the other 25%. Except for one panelist - and then only in the first two tests - the outside air was never judged to have an odor level higher than "definite" and was always found to be acceptable.

2. Tests 2, 7, and 10 were conducted with exhaust fans and outside ventilation ducting in the normal or design operating condition (see Table 2). Thus the return air through system A and system B is coming from patient rooms that have the same level of patient toilet exhaust (approximately 50 cfm). Test 10 is somewhat different in that three hours prior to that test the exhaust fan for system A had been off for 15 hours. There could have been a buildup of a higher than normal odor level that three hours of operation at design exhaust conditions was not sufficient to remove. Examination of the results of these three "normal" exhaust tests shows panelist votes at all levels from "none" to "strong." The average vote is around 1.75 or a bit below "moderate." In Test 7, which may be the best representation for the design operating condition, return system B shows a considerably higher odor level than return system A, 1.84 vs. 1.27. That same test shows 14 unacceptable votes for return air B vs. 6 unacceptable votes for return air A from a total of 17 panelists participating in the test. The half of the patient tower served by return system B and used as a "control" appears to have a higher odor level.

3. Test 3 and Test 8 were with the system A exhaust fan at one-half speed. Test 3 used a normal outside ventilation damper setting (37%) and Test 8, a reduced damper setting (28%). Table 4 shows the results of box anemometer measurements on exhaust air grilles in selected patient toilet rooms. The measurements confirm that exhaust air rates in the area served by exhaust fan A and return air system were about one-half those of system B.

   The odor judgements in Test 3 again produce the result that the air sampled from return system B has a higher odor level than that sampled from return system A. The votes ranged from "none" to "strong," with one panelist marking "very strong" for system B on the ballot. System B was rated at an average odor level 1.88, whereas System A had an average level of 1.44. Further, 6 out of 13 panelists found return air B unacceptable in odor level, whereas only 3 out of 13 found return A at an unacceptable odor level, even though it returned air from the patient rooms with reduced toilet exhaust.

Test 8 produces results more nearly in line with what had been expected, i.e., an increased odor level in the air from return air system A, with only one-half the toilet exhaust rate of system B. The average odor level for A is 1.89 and 8 out of 18 unacceptable votes versus B at 1.80 and 11 out of 18 unacceptable odor votes. The matching butanol levels are 2.9 for A and 3.0 for B.

4. Test 5 and Test 6 are with the exhaust fan in system A at one-third speed and the same normal outside air ventilation damper setting, 37%. Test 5 odor judgement results show both systems at about the same level of odor and acceptability. However, Test 6 again produces the reverse result expected. System B is judged to have a significantly higher odor level (2.00 average) than system A (1.51 average). System B also has a lower percentage vote of acceptability than A, 46% vs. 67%, and a higher butanol matching odor level (Figure 13d).

5. Test 9 was conducted after the exhaust fan in system A had been shut down for 15 hours. The odor panelists found system A slightly higher in odor level than system B, which had continuous operation at normal toilet exhaust air rates. The difference, however, was considerably smaller than might have been expected. The average odor level vote for return air sampled from system A was 1.72 and the percentage acceptance by the panelists was 53%. For system B the comparable figures were 1.58 and 62%, not a significant difference.

The odor level in return air system B was to be used as a control or standard in relative odor judgements to return air system A, where the exhaust air rate was reduced to one-half, one-third, and zero percentage of normal or design values. Unexpectedly, system B sometimes produced the higher odor level. No plausible explanation for this anamolous result can be offered other than the possibility that some unidentified hospital activity or practice generated more odor in the "B" section of the patient tower.

In the literature survey, a field study on odor/ventilation relationships in public buildings(10) was found that made use of a questionnaire distributed to building occupants. The questionnaire sought a rating on seven environmental factors: air temperature, humidity, air motion, air freshness, air odor, noise level and comfort. Such a subjective rating by building occupants, with some adaptation to the environment, seemed like a reasonable method to compare the acceptability of odor by visitors versus occupants in the hospital patient tower.

Figure 14 presents the results of the questionnaire rating by nine panelists during a visit to a patient room. Five of the nine panelists marked the odor as midway between "no odor" and "strong odor." The other four panelists found a lesser odor level. All nine marked their ballot "acceptable" on odor.

The votes on odor level had a greater spread at the nurse's station and at the visitor alcove, which are in the central portion of Patient Tower 1 and near its entrance, respectively. All nine panelists again found the odor acceptable at the nurse's station, although three marked the ballot at an odor level above the midpoint. At the visitor's alcove, the odor levels were comparably judged, but two panelists now found the odor unacceptable.

Figure 14 shows the patient room was judged to be cool with a tendency to be "drafty." Balloting at the nurse's station and visitor alcove were at a more "neutral" air temperature and acceptability. Judgements of noise level varied greatly among the panelists. The majority marked the ballot about halfway between "comfortable" and "uncomfortable," presumably on the basis of the six environmental factors that had been previously marked.

Figure 15 presents the "averaged" vote by the panelists for the eight odor tests. Averaged votes for the hospital air sampled from return duct A and return duct B show an odor level from moderate to about midway between moderate and definite. Reducing the exhaust air rate from the patient rooms through the toilets had little, if any, effect on the judgement of odor level in return duct A. Tests 7, 3, 6, and 9 are consistent in showing a slight trend upward in odor level as the exhaust on side A of the tower is reduced. Tests 7, 3, and 6 further suggest that side B of the tower, where the exhaust air rate was unchanged, releases more odiforous material than side A.

Figure 16 summarizes the panelist votes on odor level for the air sampled from return duct A and for the outside air. Again this figure demonstrates little to no effect on odor level by decreasing the toilet exhaust air rate. Test 8, at a 27% outside air damper setting, shows an upward trend of odor intensity compared to Test 3, with a damper setting of 38%. The significance is in the change of votes for a "strong" odor from 1 to 5.

Test 9, taken from 6:30 a.m. to 7 a.m. following an overnight shutdown of exhaust fan A, shows no votes of a "strong" odor. The significance here is that odor generation was probably at a reduced level during the shutdown period. It suggests that reduced exhaust and ventilation rates at nighttime could affect energy cost savings without reducing indoor air quality.

CONCLUSIONS AND RECOMMENDATIONS

1. The "averaged" panelist ratings on odor of the hospital room return air were above "definite" (slight odor, readily detectable but not objectionable) and below "moderate" (neither pleasant nor disagreeable, little or no objection). The "average" matching intensity rating on the Dravnieks binary dilution olfactometer was near 3, i.e., at 63 ppm of butanol. By prior odor studies(7,8) these ratings might have been expected to produce an "acceptability" rating of the odor environment in the 70% to 80% range. The acceptability ratings were considerably lower, ranging from a low of 21% to a high of 77%, and averaging about 55%. Table 5 summarizes the panel judgements on acceptability of hospital odors.

2. Subjects asked to evaluate six environmental factors while present in a hospital patient room or adjacent area found the "acceptability" of odor greater than 90%. This result can be viewed as a high rate of acceptability by "occupants" as compared to the 50% to 60% acceptability rating by "visitors" coming out of a fresh air environment. Standards for acceptable odor level will need to recognize the distinct differences for these two classes of hospital personnel.

3. Based on the odor study conducted here, indications are that toilet exhaust rates could be reduced without a significant change in odor level. In all but one of the eight odor tests conducted, the ventilation rate was not changed when the exhaust rate was reduced. Additional odor testing will be necessary to more clearly establish the relationship of odor level to exhaust and ventilation rates and the ability to reduce both while maintaining an acceptable odor environment.

4. One of the more promising prospects for additional energy conservation in a hospital is the reduction of exhaust and ventilation rates during the late evening and overnight. Odor and chemical contaminant generating activities are at a minimum during these hours. One test conducted in this study, with overnight shutdown of toilet exhaust, produced no higher judgements of odor level than during normal daytime operations. Additional odor testing together with airborne chemical load measurement are needed to establish the limitations for reduced nighttime ventilation rates.

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5. C. P. Yaglou, E. C. Riley, and D. I. Coggins, "Ventilation Requirements," ASHVE Transactions, 42, 133, 1936.

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8. W. S. Cain and B. P. Leaderer, "Ventilation Requirements in Occupied Spaces During Smoking and Nonsmoking Occupancy," Environmental International, Vol. 8, pp. 505-514, 1982.

9. C. P. Yaglou, "Ventilation Requirements for Cigarette Smoke," ASHRAE Transactions, 61, 25, 1955.

10. "Odor/Ventilation Relationships in Public Buildings," Duffie, Jann, Flesh, and Cain, presented at 73rd Annual Meeting of the Air Pollution Control Assoc., Montreal, June 1980; John B. Pierce Foundation, COLLECTED PAPERS, Vol. XXI, 1979-80, p. 91.

ACKNOWLEDGMENTS

The cooperation of the Duke University Medical Center in the conduct of this odor study is gratefully acknowledged. Mr. Andy Blalock, maintenance engineer for the Duke Hospital North Division, arranged for changes in exhaust fan operation and assistance in the measurement of airflow rates. Dr. Jane Elchlepp, assistant vice president for health affairs, was a constant source of assistance in gaining the cooperation and approval of hospital authorities and in providing good counsel. Dr. William S. Cain of the John B. Pierce Foundation Laboratory shared his expert knowledge on odor testing in the design of the sampling station and sampling procedures. Mr. David Nelson, research assistant in mechanical engineering, provided skillful assistance in the conduct of the odor studies. Mr. Charles Madson, chairman, and members of the ASHRAE sponsoring technical committee on Large Building Air Conditioning were responsible for defining the requirements of the study.

TABLE 1

Yaglou Sensory Intensity Scale of Body Odor

Odor Intensity Index	Characteristic Term	Qualification
0	None	No perceptible odor.
1/2	Threshold	Very faint, barely detectable by trained judges; usually imperceptible to untrained persons.
1	Definite	Readily detectable by all normal persons but not objectionable.
2	Moderate	Neither pleasant nor disagreeable. Little or no objection. Allowable limit in rooms.
3	Strong	Objectionable. Air regarded with disfavor.
4	Very strong	Forcible, disagreeable.
5	Overpowering	Nauseating.

TABLE 2

Hospital Odor Test Conditions

	Exhaust Air Conditions					Air Temp's.	
	System A		System B				
Test No.	Fan RPM	% Normal	Fan RPM	% Normal	Air Intake Damper Position	OA F	RA F
2	963	100	1045	100	37%(1)	86	83/81
3	520	50	1059	100	37%	87	82
5	350	33	1059	100	37%	-(2)	-
6	350	33	1059	100	37%	85	82/80
7	963	100	1059	100	37%	85	82/79
8	520	50	1059	100	28%	84	81/80
9	OFF(3)		1050	100	18%	79	80/79
10	960(4)	100	1050	100	37%	84	81/80

Notes:

1) Normal outside air damper position for summer cooling operation is 37% open

2) Temperatures not recorded in Test No. 5

3) Exhaust Fan A turned off at 3:30 p.m., odor test 15 hours later at 6:30 a.m. on 8/6/82

4) Exhaust Fan A turned on at 8:30 a.m. after 15-hour off-period, test three hours later at 11:30 a.m. on 8/6/82. Air intake changed 18% to 37% open at 8:30 a.m.

TABLE 3

Odor Test Results

Test No.	Odor Sample[a]	Exhaust Fan Speed	0 None	1 Definite	2 Moderate	3 Strong	Average[b]	Accept.	Not Accept.
2	0*		8,7,7	3,4,4			0.33	10	1
	A	Full		5,4,4	5,5,5	1,2,2	1.74	4	7
	B	Full		8,4,3	2,7,6	1,0,2	1.62	4	7
	0		9,9,9	1,1,1	1,1,1		0.27	10	1
3	0*		11,10,9	2,3,4			0.23	12	1
	A	One-Half	1,1,0	7,7,7	4,4,5	1,1,1	1.44	10	3
	B	Full	2,0,0	3,3,2	6,8,9	2,2,2c	1.88	7	6
	0		9,9,8	4,4,5			0.32	13	0
5	0*		11,11,11	4,4,4			0.27	15	0
	A	One-Third	0,1,1	9,5,5	4,7,7	2,2,2	1.62	9	6
	B	Full	1,0,1	6,6,6	7,7,5	1,2,3	1.64	8	7
	0		10,10,10	5,5,5			0.33	15	0
6	0*		12,11,12	1,2,1			0.10	13	0
	A	One-Third	2,1,1	7,7,6	1,2,3	3,3,3	1.51	9	4
	B	Full		4,2,3	6,8,7	3,3,3	2.00	6	7
	0		9,9,11	4,3,2			0.24	13	0
7	0*		13,15,15	4,2,2			0.16	17	0
	A	Full	1,1,1	11,12,12	4,2,2	1,2,2	1.27	10	6
	B	Full		3,4,3	11,13,13	2,1,1	1.84	3	14
	0		15,16,16	2,1,1			0.08	17	0
8	0*		17,17,17	1,1,1			0.05	18	0
	A	One-Half		4,6,8	10,7,5	4,5,5	1.89	10	8
	B	Full		4,4,4	12,12,13	2,2,1	1.80	7	11
	0		11,13,14	7,5,4			0.28	18	0
9	0*		11,11,11	2,2,2			0.15	13	0
	A	Off		3,2,5	10,11,8		1.72	8	5
	B	Full	1,0,0	6,6,7	4,6,4	2,1,2	1.58	10	3
	0		9,11,11	4,2,2			0.19	12	1
10	0*		17,17,16	0,0,1			0.02	17	0
	A	Full[d]		5,3,6	7,11,9	5,3,2	1.86	9	8
	B	Full		7,7,5	8,9,9	2,1,3	1.72	10	17
	0		15,16,17	2,1,0			0.06	17	0

Notes: a) 0* is outside air identified to panelists, A and B are patient room return air, 0 is outside air not identified as such.

b) Based on 0 (None), 1 (Definite), 2 (Moderate), and 3 (Strong).

c) One panelist marked the odor "very strong."

d) Three hours on after a 15-hour off-period.

TABLE 4

Measured Toilet Exhaust Rates

Test No. 3

Rooms served by exhaust fan A operating at one-half speed		Rooms served by exhaust fan B operating at full speed	
Room No.	Exhaust CFM	Room No.	Exhaust CFM
2123	below 20	2104	42
4117	21	2107	42
4119	25	2112	20
4128	21	4103	42
6118	30	6103	51
6127	21	6105	40
8117	21	8105	45
8125	21	8107	49

TABLE 5

Percent Acceptability of Hospital Odors

Test No.	Outside Air Identified	Outside Air Not Identified	Return Air A	Return Air B
2	91	91	41	36
3	92	100	77	54
5	100	100	63	57
6	100	100	69	46
7	100	100	68	21
8	100	100	58	42
9	100	92	65	77
10	100	100	53	62
Av.	98	98	62	49

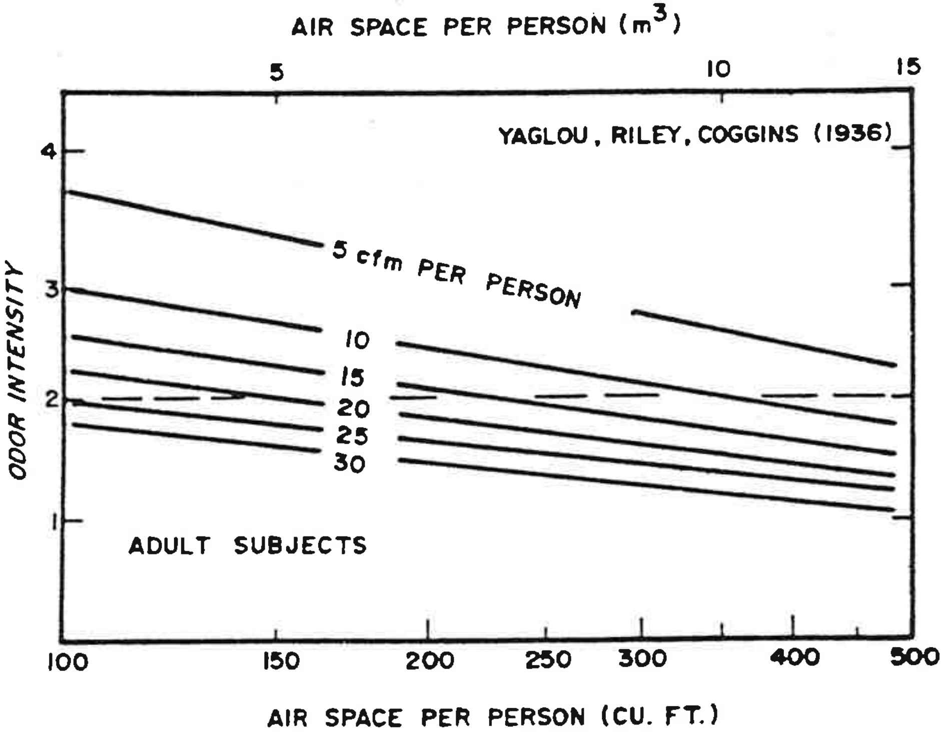


Figure 1. *Odor intensity vs. air space per person at rates of fresh air supply from 5–30 cfm per person by Yaglou, Riley, and Coggins (1936)*

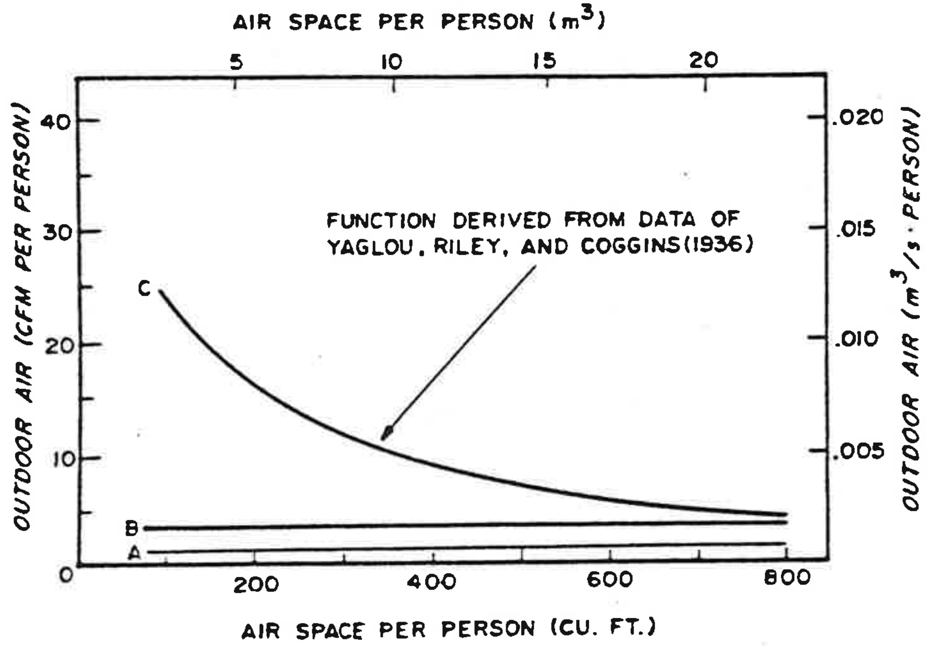


Figure 2. *Relation between ventilation rate and air space per person according to three criteria: A, maintenance of oxygen; B, control of carbon dioxide to a level of 0.6%; C, control of body odor at a moderate level under sedentary conditions of occupancy, no smoking. Function for body odor was erected from judgments of observers who briefly entered a chamber occupied by persons of normal hygiene for up to 3.5 hours*

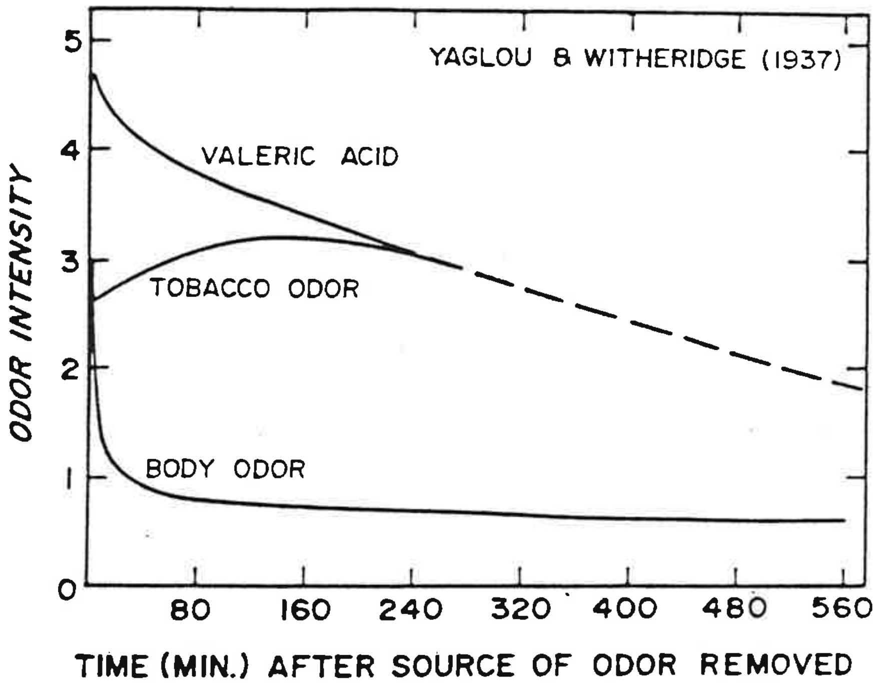


Figure 3. Showing how odor decayed in still air in a chamber after (a) an open flask of valeric acid had been removed, (b) five cigarettes had been smoked, (c) previous occupants (nonsmoking) had left the chamber (function labeled body odor). Observers entered the unventilated chamber periodically in order to rate intensity

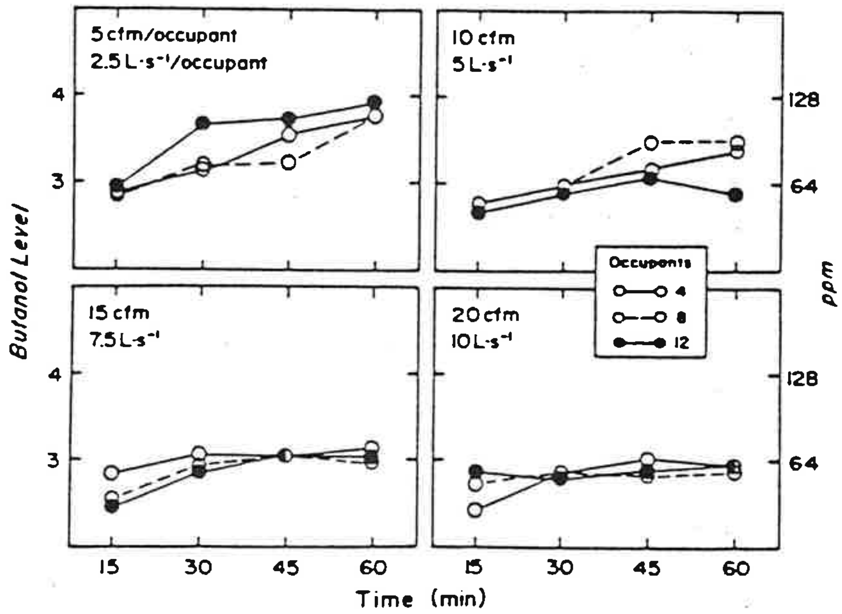


Figure 4. Butanol matching functions taken across environmental conditions in order to explore whether odor level varied systematically with number of occupants at various ventilation rates. Data of Cain and Lederer (1982)

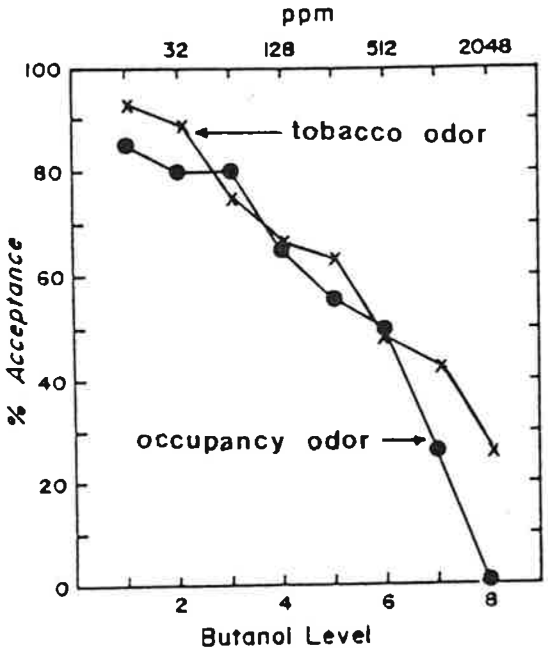


Figure 5. Showing how acceptance of occupancy odor and tobacco odor to visitors varied with equivalent (i.e., matched) level of butanol. Data of Cain Lederer (1982)

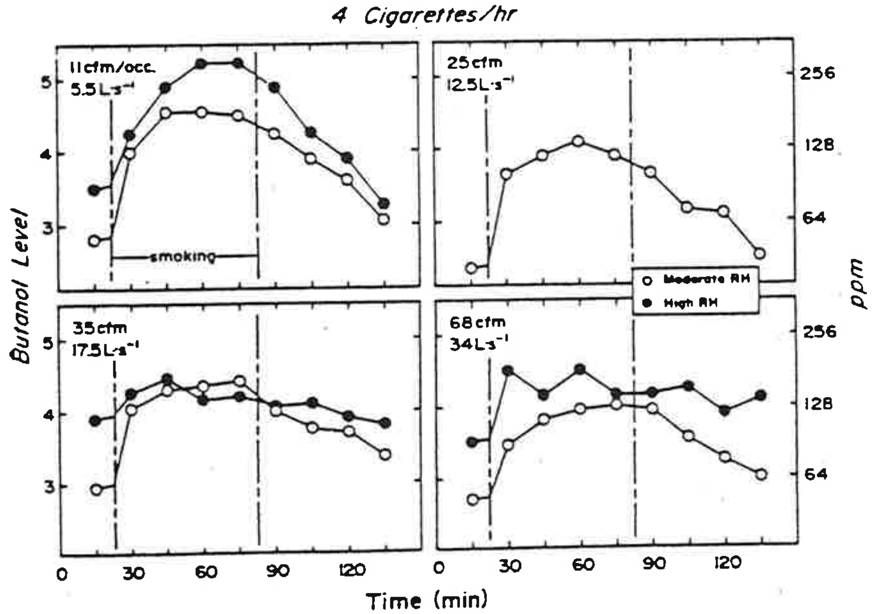


Figure 6. Butanol matching functions averaged across conditions of moderate RH (open circles) compared with functions obtained at 25.5°C and high RH (closed circles). Data of Cain and Lederer (1982)

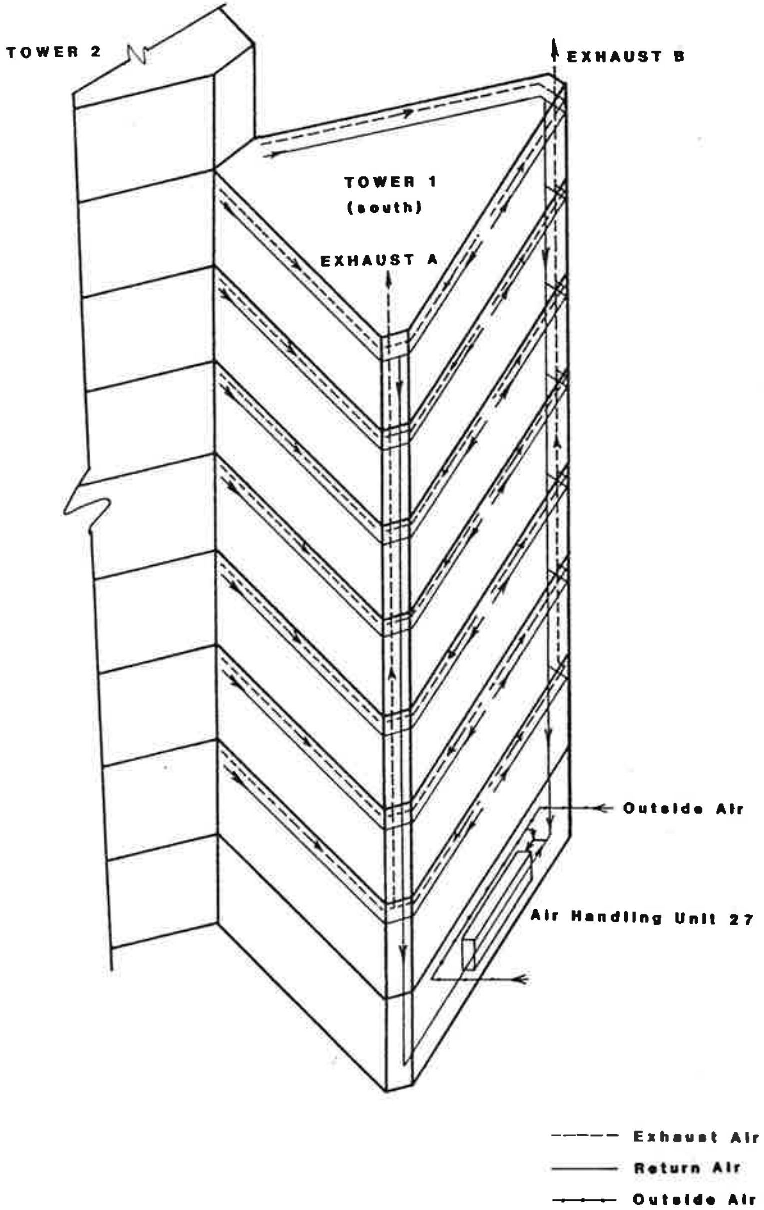


Figure 7. *Schematic of return air and exhaust air paths of patient tower 1*

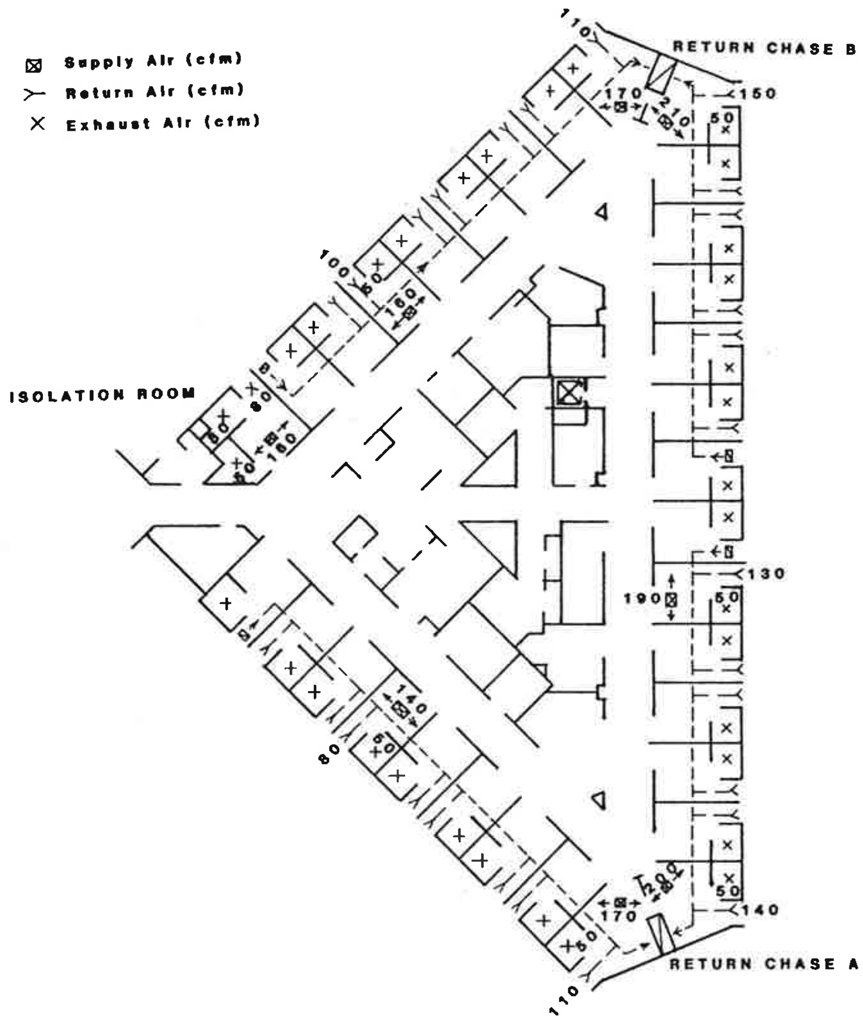


Figure 8. *Typical room layout for patient tower 1 with supply, return, and exhaust air rates*

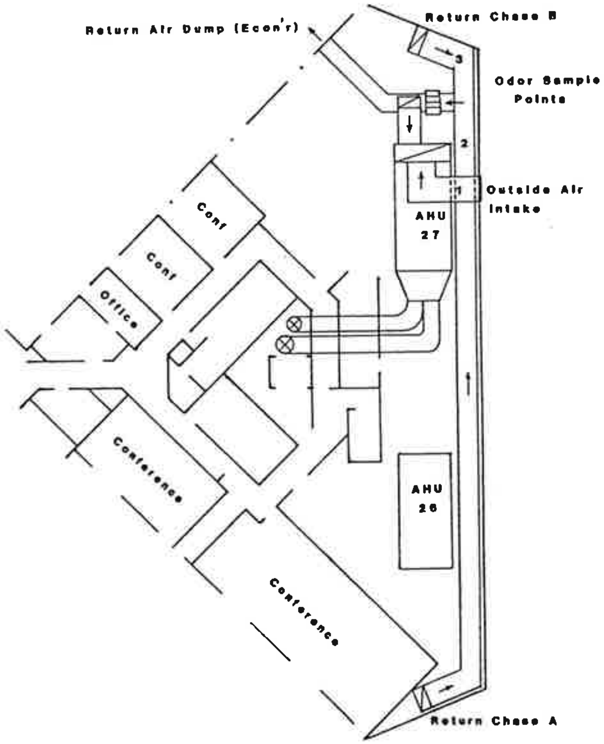


Figure 9. Ground-floor level of patient tower 1 with location of odor sampling points

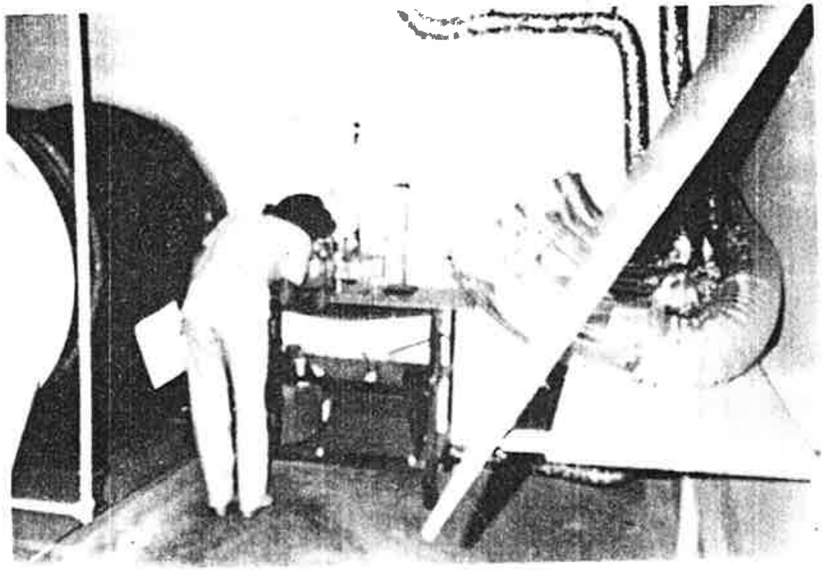


Figure 10. View of odor sampling station

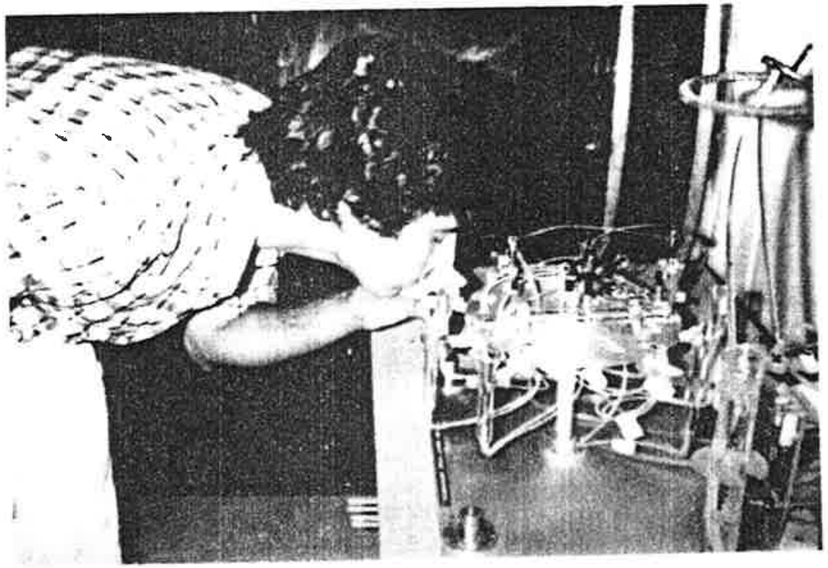


Figure 11. View of binary dilution (butanol) olfactometer for odor intensity matching

Test No: ________ Date: ________________ Time: __________

Subject Identification No. ______

Non-Smoker _____ Smoker ______ Time of last smoke __________

Do you have a cold or allergy reaction today? ________________

JUDGEMENT OF ODOR LEVEL

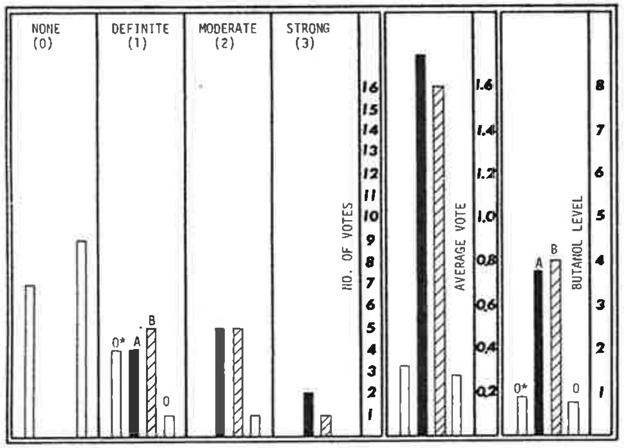
Trial	Station No.	None	Definite	Moderate	Strong
I.	A	____	____	____	____
	B	____	____	____	____
	C	____	____	____	____
	D	____	____	____	____
II.	A	____	____	____	____
	B	____	____	____	____
	C	____	____	____	____
	D	____	____	____	____

Acceptable		Not Acceptable	Station No.	None	Definite	Moderate	Strong
____	III.	____	A	____	____	____	____
____		____	B	____	____	____	____
____		____	C	____	____	____	____
____		____	D	____	____	____	____

MATCHING INTENSITY OF ODOR

Station No.	Olfactometer Port Number 1	2	3	4	5	6	7	8
A	___	___	___	___	___	___	___	___
B	___	___	___	___	___	___	___	___
C	___	___	___	___	___	___	___	___
D	___	___	___	___	___	___	___	___

Figure 12. Odor ballot

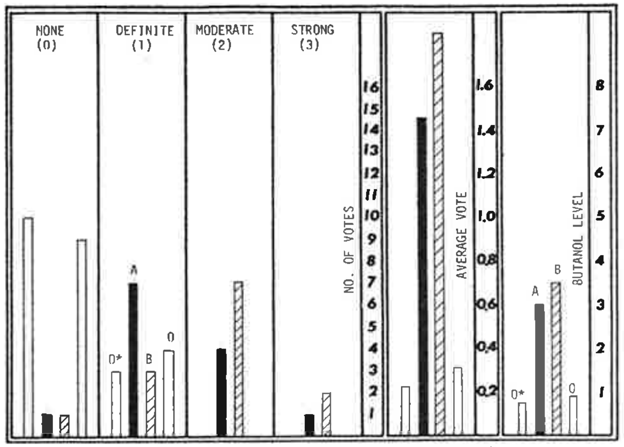


PANEL VOTES ON ODOR LEVEL AND MATCHING BUTANOL LEVEL

PANEL VOTES ON ODOR ACCEPTABILITY

Sample	Acceptable	Unacceptable	% Acceptance
0*	10	1	91
A	4	6	41
B	4	7	36
0	10	1	91

Figure 13a. *Test 2. Exhaust fan operation: A = full speed, B = full speed; odor acceptability: O* = 91%, O = 100%, A = 41%, B = 36%*

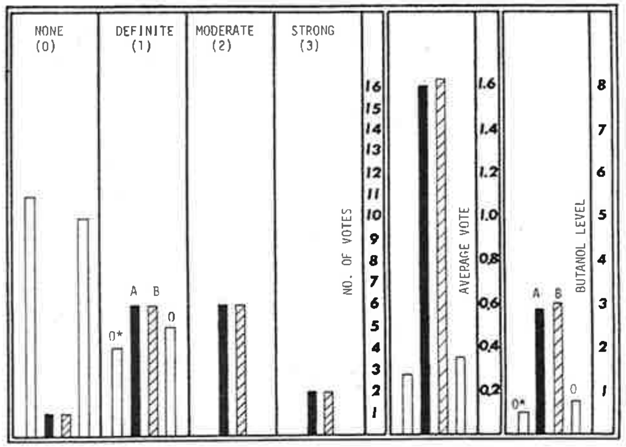


PANEL VOTES ON ODOR LEVEL AND MATCHING BUTANOL LEVEL

PANEL VOTES ON ODOR ACCEPTABILITY

Sample	Acceptable	Unacceptable	% Acceptance
0*	12	1	92
A	10	3	77
B	7	6	54
0	13	0	100

Figure 13b. *Test 3. Exhaust fan operation: A = 1/2 speed, B = full speed; odor acceptability: O* = 92%, O = 100%, A = 77%, B = 54%*



PANEL VOTES ON ODOR LEVEL AND MATCHING BUTANOL LEVEL

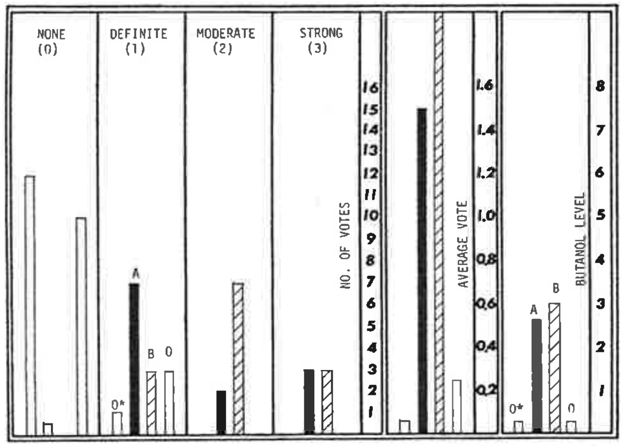
PANEL VOTES ON ODOR ACCEPTABILITY

Sample	Acceptable	Unacceptable	% Acceptable
0*	15	0	100
A	9	5	63
B	8	6	57
0	15	0	100

Figure 13c. *Test 5. Exhaust fan operation: A = 1/3 speed, B = full speed; odor acceptability: O* = 100%, O = 100%, A = 63%, B = 57%*

Figure 13. Odor intensity judgments

O = outside air identified to odor panel*
A = return air from chase A
B = return air from chase B
O = outside air not identified to panelists

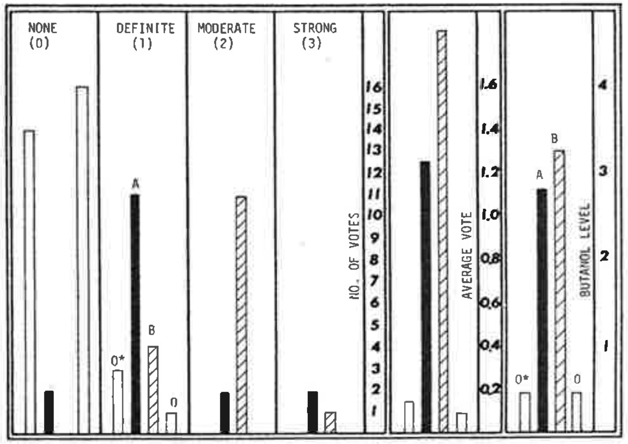


PANEL VOTES ON ODOR LEVEL AND MATCHING BUTANOL LEVEL

PANEL VOTES ON ODOR ACCEPTABILITY

Sample	Acceptable	Unacceptable	% Acceptance
O*	13	0	100
A	9	4	69
B	6	7	46
O	13	0	100

Figure 13d. *Test 6. Exhaust fan operation: A = 1/3 speed, B = full speed; odor acceptability: O* = 100%, O = 100%, A = 69%, B = 46%*

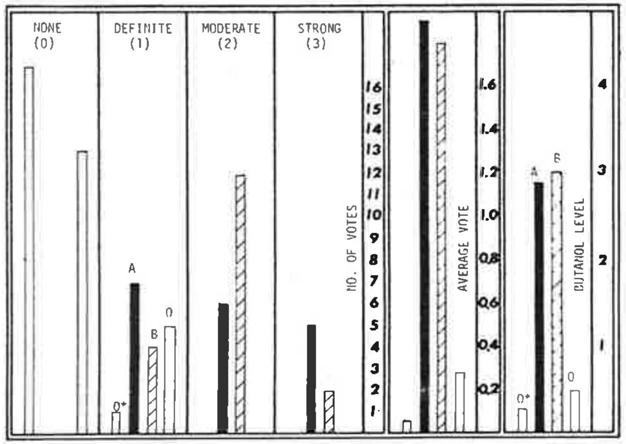


PANEL VOTES ON ODOR LEVEL AND MATCHING BUTANOL LEVEL

PANEL VOTES ON ODOR ACCEPTABILITY

Sample	Acceptable		Unacceptable	% Acceptance
O*	17		0	100
A	10	2	4	68
B	3	1	13	21
O	17		0	100

Figure 13e. *Test 7. Exhaust fan operation: A = full speed, B = full speed; odor acceptability: O* = 100%, O = 100%, A = 68%, B = 21%*



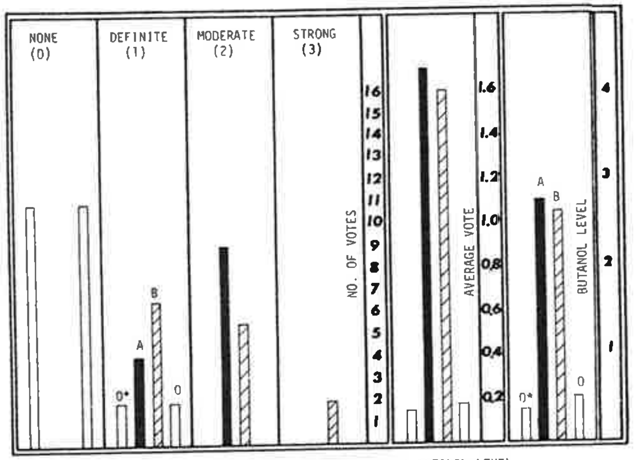
PANEL VOTES ON ODOR LEVEL AND MATCHING BUTANOL LEVEL

PANEL VOTES ON ODOR ACCEPTABILITY

Sample	Acceptable		Unacceptable	% Acceptance
O*	18		0	100
A	10	1	7	58
B	7	1	10	42
O	18		0	100

Figure 13f. *Test 8. Exhaust fan operation: A = 1/2 speed, B = full speed; odor acceptability: O* = 100%, O = 100%, A = 58%, B = 42%*

Figure 13 continued

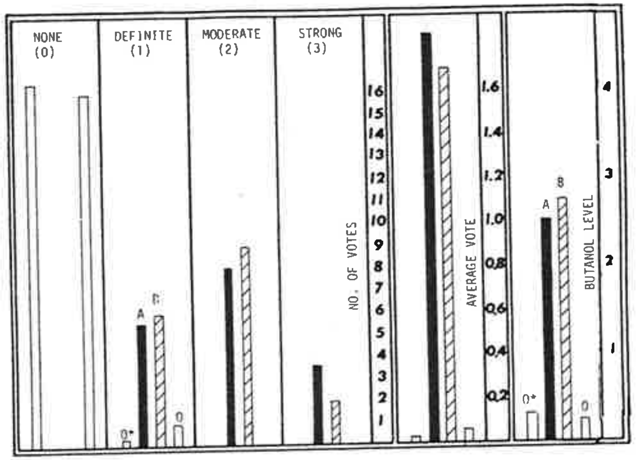


PANEL VOTES ON ODOR LEVEL AND MATCHING BUTANOL LEVEL

PANEL VOTES ON ODOR ACCEPTABILITY

Sample	Acceptable	Unacceptable	% Acceptance
0*	13	0	100
A	8	4	65
B	10	3	77
0	12	1	92

Figure 13g. Test 9. Exhaust fan operation: A = off, B = full speed; odor acceptability: O* = 100%, O = 92%, A = 65%, B = 77%



PANEL VOTES ON ODOR LEVEL AND MATCHING BUTANOL LEVEL

PANEL VOTES ON ODOR ACCEPTABILITY

Sample	Acceptable	Unacceptable	% Acceptance
0*	17	0	100
A	9	8	53
B	10	6	62
0	17	0	100

Figure 13h. Test 10. Exhaust fan operation: A = full speed, B = full speed; odor acceptability: O* = 100%, O = 100%, A = 53%, B = 62%

Figure 13 continued

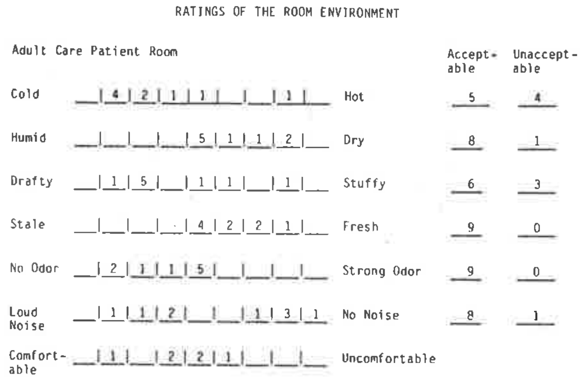


Figure 14. Panelists' ratings of room environment in adult-care patient room

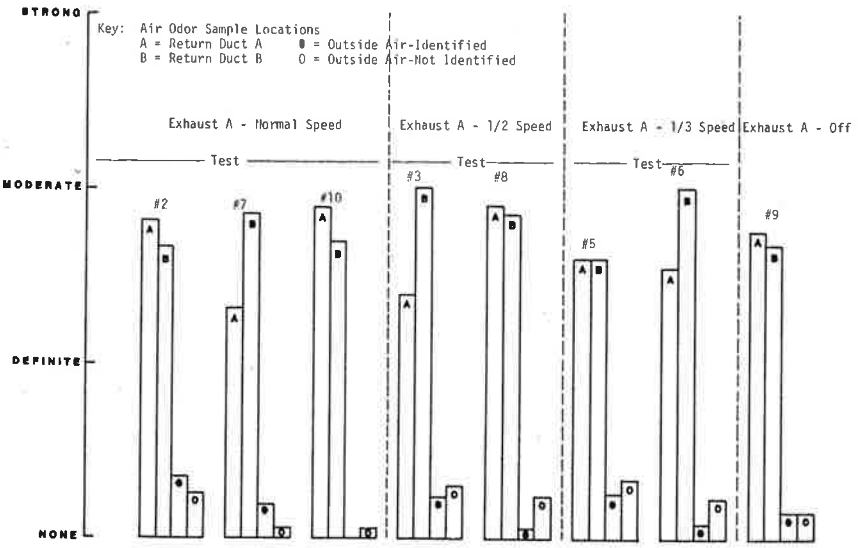


Figure 15. Average odor level judgments (all tests)

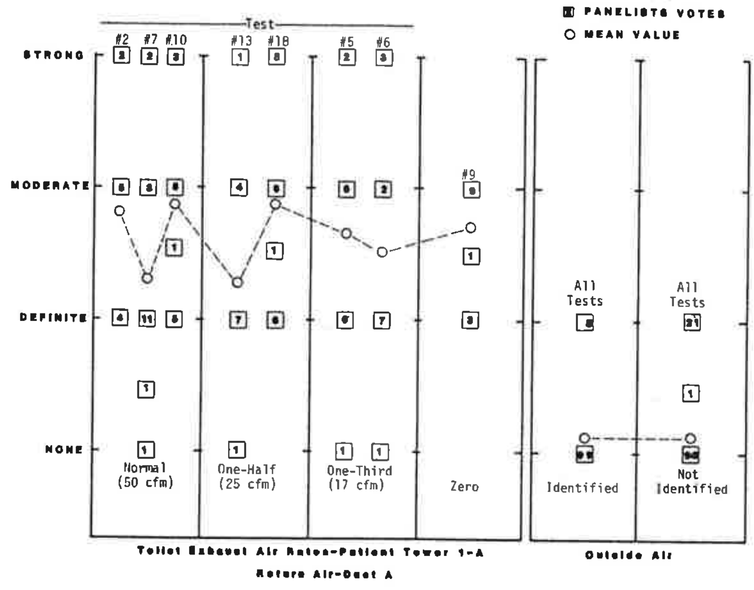


Figure 16. Panelists' voting and average vote for air in return duct A and for outside air

Discussion

M.J. PHILLIPS, Naval Medical Command, Washington, DC: Chapter 7 of the 1982 Applications states: "Practical experience has shown that health facilities, with the possible exception of nursing homes, having central toilet exhaust systems, generally have sufficient dilution to render the toilet exhaust air practically odorless. For this reason, plus the need to conserve energy, it is recommended that consideration be given to recirculation of up to 50% of toilet room air where central systems with appropriate conditioning and filtration equipment are employed." Does your research support this recommendation? If not, what change does your research suggest?

J.B. CHADDOCK: The quotation you have given from the ASHRAE Handbook - 1982 Applications is a footnote (d) to Table 3, Chapter 7, page 7.6. It refers to exhausting 10 air changes per hour (ACH) from toilet rooms. That table also recommends 2 minimum ACH of outdoor air for most hospital spaces, in conforming with the federal Hill-Burton standard. As shown in Part I of this study, analysis of space and ventilation requirements for a modern university hospital shows that it is this 2 ACH that determines the outdoor ventilation rate and not the exhausting of 10 ACH through the toilets. To conserve energy by recirculating toilet exhaust, the outdoor ventilation rate must be reduced, which would probably result in a rate below 2 ACH for most hospitals.

The odor-sampling tests reported in Part II of this study resulted in the panelists rating the acceptability of the hospital odor environment at 50% to 60% (see Table 5). These tests were conducted with outdoor ventilation at near 2 ACH. Considering the results of these (limited) tests and the characteristics of the hospital environment with its significant odor and chemical contaminant activities, I would not recommend reducing the outdoor ventilation rate from that of the current Hill-Burton standard without broader field study data. Recirculating a fraction of the toilet exhaust, by itself, will probably not affect odor level significantly, but a corresponding reduction of outdoor ventilation rate is likely to produce an unacceptable odor environment by visitors and some increased health risk to highly susceptible patients.