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VENTILATION REQUIREMENTS

(Part 2)

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BOSTON, MASS.

This is the second progress report of research sponsored by the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS in cooperation with the School of Public Health, Harvard University.

IN a previous paper [1] it was found that the number of persons occupying a room, or the air space per occupant, is a very important factor affecting the per capita outdoor air supply for the control of body odors. In a room with a net air space of 1410 cu ft, an outdoor air supply of 7 cfm per capita was found to be required when the room was occupied by three adult persons of average socio-economic status; 16 cfm per capita when occupied by seven persons and 25 cfm each with fourteen persons in the room.

Additional work presented in the present paper reveals two important factors responsible for this variation: (a) spontaneous disappearance of body odors with time and (b) changes in efficiency of ventilation and odor removal with changes in the amount of air supplied. A third factor suspected at first, namely, adsorption of odors on room surfaces, was found to be of little or no significance.

SPONTANEOUS DISAPPEARANCE OF ODORS IN AN UNVENTILATED ROOM

Disappearance of Body Odor

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.

All observations of body-odor disappearance rate were carried out in two

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[1] Ventilation Requirements, by C. P. Yaglou, E. C. Riley and D. I. Coggins, A.S.H.V.E. TRANSACTIONS, Vol. 42, 1936.

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adjoining rooms, which were separately conditioned,[2] by shutting off all ventilation in the experimental room immediately after the subjects were dismissed, and smelling the strength of body odor at intervals by comparing it with the smell of air kept at threshold-odor intensity in the control room, as in the previous work.[3] The only significant leakage in the closed room was that occasioned in passing back and forth from the control room for determining

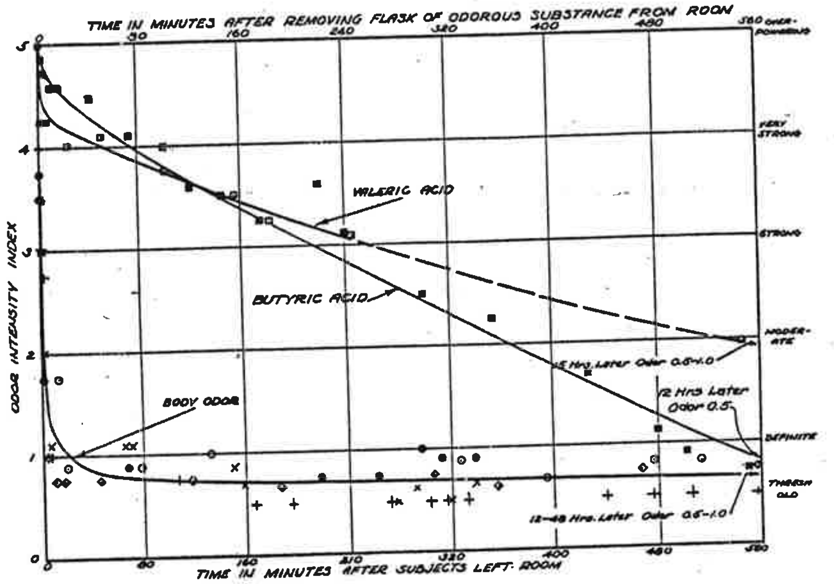

Fig. 1. Disappearance of Body Odor, Valeric and Butyric Acid, in a Closed Room

the odor intensity. By carefully opening and shutting the small door connecting the two rooms, this leakage was kept at a minimum.

In the control room the ventilation rate was maintained at 50 cfm per person throughout, as in the previous work, with not more than two persons in the room at a time. These were the judges who compared odor intensity. All experiments on body-odor disappearance rate were started about 12:30 p.m., after the subjects had been in the room for 3½ hours, from 9:00 a.m. to 12:30 p.m. Observations were continued to 6:00 p.m. or later. At night, the experimental room was closed tight and observations were resumed the following morning, with the normal rate of ventilation in the control room (50 cfm per occupant).

In the lower part of Fig. 1 are shown the results of four experiments carried out under representative conditions in winter and summer with respect to temperature, humidity, clothing, and other factors. It can be seen that in all

[2] Loc. Cit. See Note 1.
[3] Loc. Cit. See Note 1.

four instances the strength of body odor fell abruptly from an initial value between 3.5 and 4.0 to the allowable intensity of 2 in less than 4 min after the subjects left the room. Twenty minutes later the odor index was about 1. From then on, the rate of disappearance became very slow, and finally equilibrium was reached at an intensity between 0.5 and 1.0. By this time the odor lost much of its characteristic *human smell* and after 48 hours it was difficult to identify it as such in the presence of other weak odors coming from other sources in the room. A certain minimum amount of ventilation was always necessary to clear out this residual odor, which persisted indefinitely with the room kept tightly closed.

The explanation for the abrupt disappearance rate of body odor is not quite clear. Oxidation would seem to be a most plausible cause. It is possible that some constituents of the body-odor complex are extremely unstable, leaving behind other less odorous but relatively stable constituents which can be smelled for days. The loss of moisture from the organic material to the atmosphere may also have something to do with the loss of odor. Schroeder [4] recently presented some evidence of his own and others, indicating a chemical change in organic matter of expired air after washing with sulphuric acid. The alteration was attributed to dehydration, as the sulphuric acid did not remove an appreciable quantity of organic material. On the other hand, liquid condensed in the present experiments by cooling odorous air to about 35 F was odorless, clear and neutral in reaction. This is not necessarily contradictory with the work of Gant and Shaw,[5] who froze out odors from the air with dry ice and presumably succeeded in determining their relative strength several days later by the use of an osmoscope. The odors Gant and Shaw worked with were mainly those from tobacco smoke, foods and various kinds of liquors, whereas those in the experiments described in this paper were body odors alone.

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 odor. The time element is so small that it is difficult to draw a satisfactory odor balance from the odor intensity in the room, number of occupants, air supply, and room dimensions. Even an error of half a minute or more in estimating the time taken by the ventilating current to pass over the occupied zone might make a great difference in the loss of odor and odor balance.

Disappearance of Other Odors

That the rapid loss of odor is due to a characteristic of body odor itself rather than to diffusion by leakage was ascertained by studying the disappearance rate of other stronger odors, such as valeric and butyric acid, tobacco smoke, and ozone, all capable of completely masking body odor. In the upper half of Fig. 1 are shown results with valeric and butyric acid, obtained by exposing in the center of the experimental room a small flask of the odorous substance, with the stopper removed, until the odor intensity rose to 5. With

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[4] Elimination of Organic Products in Air Conditioning, by W. K. Schroeder, *Refrigerating Engineering*, 29, 294, Dec. 1933.
[5] Odor Concentration in Air-Conditioned Structures, by V. A. Gant and H. D. Shaw, *Industrial and Engineering Chemistry*, 9, 16, Jan. 15, 1937.

valeric acid it took 25 min, and with butyric acid 30 min to raise the odor strength from 0 to 5. The flask was then removed and observations of odor intensity made at intervals, as in the case of body odors. By comparison with the body-odor curve in the lower half of Fig. 1, the rates of disappearance of valeric and butyric acid are much too slow, lending little support to the assumption often made that body odors are mainly composed of these two substances.

The disappearance characteristics of tobacco smoke are shown in Fig. 2. Curves *A* and *B* were obtained by having subjects smoke one or two cigarettes each inside the experimental room, with no ventilation at all. At the end of the smoking period, after the smokers left and the ash trays were removed, the odor intensity was determined at intervals as shown in previous tests.

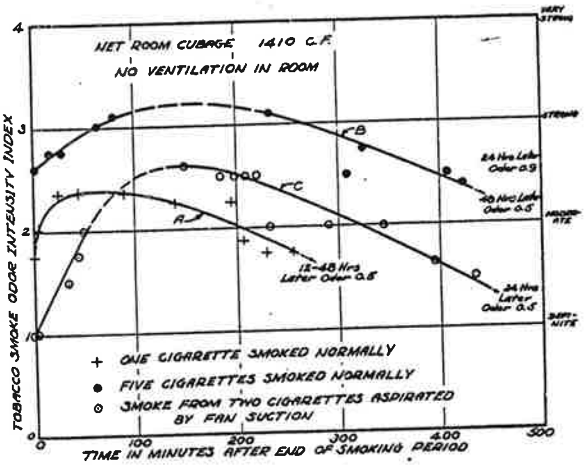

Fig. 2. Disappearance of Tobacco Smoke in a Closed Room

Plot *C* (Fig. 2) was obtained with tobacco smoke from two cigarettes produced by fan suction, in order to check the characteristics of the other two curves. After the smoking period the fan and cigarette butts were removed from the room. In all three instances there was a bluish haze at first, particularly when smoke was produced by fan suction, gradually thinning out and changing to whitish color. This suggests flocculation to larger and larger particles, and eventual settling out of the particles.

Unlike body odor, the odor of tobacco smoke (Fig. 2) not only remained longer in the room, but its intensity increased in a peculiar manner during the first three hours following the smoking period. From then on, the intensity began to decrease gradually, finally reaching a stable level of 0.5 after 17 to 48 hours, according to the number of cigarettes smoked.

The rise in odor intensity after smoking seems to agree with common observation that the odor of stale tobacco smoke is more offensive than the odor of fresh smoke. Alterations in physical characteristics of the smoke in passing through the respiratory tract are probably not responsible for this, as shown by curve *C*. Presumably, it would be advantageous to make smoking rooms as small as is practicable and ventilate them fast. The chemical and physical properties of cigarette smoke were recently reviewed by Bradford et al.[6]

Even ozone, which readily decomposes to O_2 and O, appears to be relatively more stable than body odor, as shown in Fig. 3. It is, however, the only one of the odoriferous substances studied by us that eventually disappeared completely without leaving a trace of residual odor of its own. Ozone for the tests was produced by corona discharge between concentric cylindrical electrodes, ⅝ in. apart, kept at a potential difference of 15,000 volts, a-c, 60 cycles. The outer cylinder was glass, lined with metallic foil on the outside. The apparatus was essentially a Cottrell precipitator as modified by Drinker,[7] for small-scale quantitative determination of dusts in air.

The decomposition rate of ozone on a volumetric basis was studied by Ewell[8,9] in a large closed box and in cold-storage rooms. The general char-

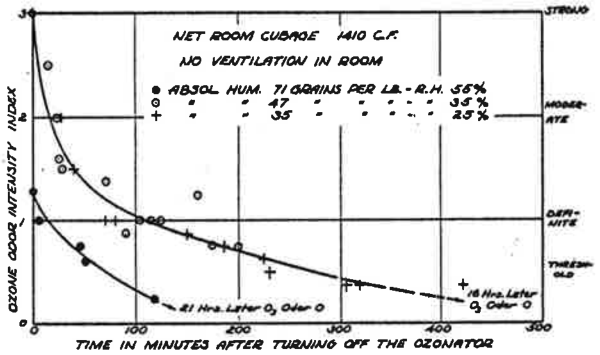

FIG. 3. DISAPPEARANCE OF OZONE IN A CLOSED ROOM

acteristics of Ewell's curves are quite similar to those obtained in the tests described in this paper.

CHANGES IN VENTILATION EFFICIENCY

Aside from body-odor disappearance rate, the amount of air supply and the number and arrangement of occupants in a room with reference to the location of supply and exhaust openings affect also the efficiency of odor removal. With supply openings near the ceiling located centrally over the occupied zone, as in this system, and a constant air supply per person, an increase in the number of occupants would have two opposing effects on ventilation efficiency. On one hand, it would tend to increase efficiency by spreading out the occupied

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[6] Nature of Cigaret Smoke, by J. A. Bradford, E. S. Harlow, W. R. Harlan and H. R. Hanmer. *Industrial and Engineering Chemistry, 29*, 45, Jan. 1937.

[7] Alternating Current Precipitator for Sanitary Air Analysis, by Philip Drinker, *Jour. Industrial Hygiene, 14*, 364, 1932.

[8] The Disappearance of Ozone in Cold-Storage Rooms, by A. W. Ewell, *Refrigerating Engineering, 26*, Dec. 1930.

[9] The Decomposition of Ozone, by A. W. Ewell, *Ibid., 29*, Aug. 1933.

zone; on the other hand, the greater volume of air needed would allow less time for diffusion over the occupied area, the air passing quickly to the exhaust without removing a full share of odor, CO_2, and moisture.

The problem was studied by determining the relative efficiency of the ventilation system at various rates of air supply and with 3, 7, and 14 persons in the room.

Efficiency of ventilation for the purpose of this study was taken as the ratio of *effective* air supply to the total air supply. *Effective* air supply is that passing over the occupied zone, and capable of removing the products of respiration and transpiration. It was determined from measurements of carbon dioxide in representative areas, in the breathing zone between the seats of occupants. Most of the experiments were carried out with seven adult persons in the room

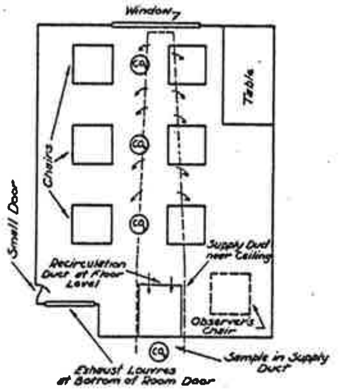

FIG. 4. PLAN OF EXPERIMENTAL ROOM SHOWING LOCATION OF SUBJECTS AND SAMPLING STATIONS

(see Fig. 4), the observer himself serving as subject. All experiments lasted 3½ hours, and the air samples were collected near the end of each test. Carbon dioxide analysis was made by means of a 20 cc modified Haldane apparatus for CO_2 only. The relative ventilation efficiency was computed from the following formula:

$$\text{Ventilation Efficiency}^{10} = \frac{\dfrac{0.01}{(CO_2)_r - (CO_2)_s}}{\text{Cfm per occupant}}$$

where

0.01 = cubic feet of CO_2 given off per person per minute.
$(CO_2)_r$ = average CO_2 of air in occupied zone, per cent by volume.
$(CO_2)_s$ = CO_2 in the air supply, per cent by volume.
Cfm per occupant = air supply per occupant in cubic feet per minute measured by means of standardized orifice meters.

It can be seen in Fig. 5 that with airflows under 5 cfm per person, ventilation efficiency was practically 100 per cent, decreasing progressively as the air supply increased. With 30 cfm per person, the efficiency was about 75 per cent.

[10] To obtain ventilation efficiency in per cent the ratio should be multiplied by 10,000, as Professor West suggests in the discussion at the end of this paper.

From the standpoint of efficiency, it would seem that rate of air supply is more significant than number of occupants in a room, but the data with three and fourteen persons are too few to draw a conclusion.

The important thing to emphasize is the advantage of large rooms over small ones, as they act like reservoirs, allowing body odor to disappear, with a minimum air supply and maximum ventilation efficiency. Reducing the size of a room entails an increase of ventilation rate and a simultaneous decrease of ventilation efficiency.

Adsorption of Body Odors on Room Surfaces

Adsorption is generally regarded as a physical, rather than a chemical phenomenon consisting in condensation of gas molecules on the surfaces of solid

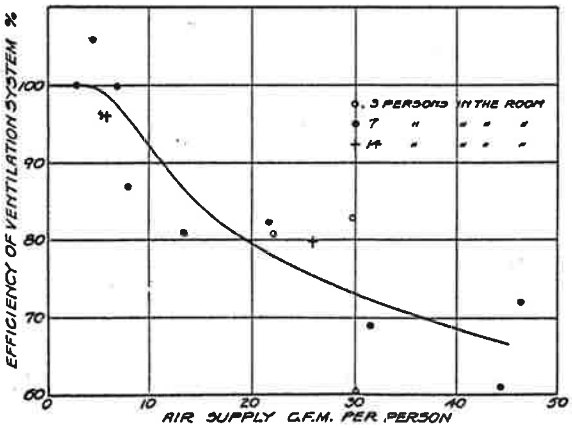

Fig. 5. Efficiency of Ventilation System of Experimental Room at Various Airflows

bodies with which they come in contact. The amount of gas adsorbed depends upon its pressure, the chemical natures and potentials of the adsorbents and adsorbate and the physical state of the adsorbing surface. For a great number of systems, adsorption is believed to be complete when the adsorbing surface is completely covered with a unimolecular layer of the adsorbent.[11] Normally, equilibrium is quickly reached when the rate of evaporation just balances the condensation rate. Exceptions occur when diffusion is slow, or when there is chemical interaction between the adsorbent and adsorbate. The length of time over which the condensed molecules will remain on the surface depends on the strength of the attractive forces between the surface and adsorbed molecules, and the temperature.

Under the conditions of the present experiments, adsorption of body odors on surfaces of walls, ceiling and floor did not seem to be a factor affecting odor intensity and ventilation requirements per occupant, when equilibrium

[11] International Critical Tables, McGraw-Hill Book Company, New York, *3*, 250, 1926.

conditions prevailed. This conclusion was arrived at by increasing the amount of adsorbing surface in the room and redetermining the equilibrium time, equilibrium intensity, and rate of disappearance of body odor under the new conditions. All other factors were kept approximately the same in each series of tests.

Plot *A* in Fig. 6 shows the normal variation of odor intensity in a control test with the normal amount of adsorbing surface of walls, ceiling, and floor aggregating 780 sq ft approximately. Odor equilibrium was reached about 50 min after the subjects entered the room, and the equilibrium intensity index averaged nearly 3.5. The disappearance rate in this control test is that already shown in Fig. 1 by similar points.

Plot *B* was obtained under identical initial conditions as plot *A*, except

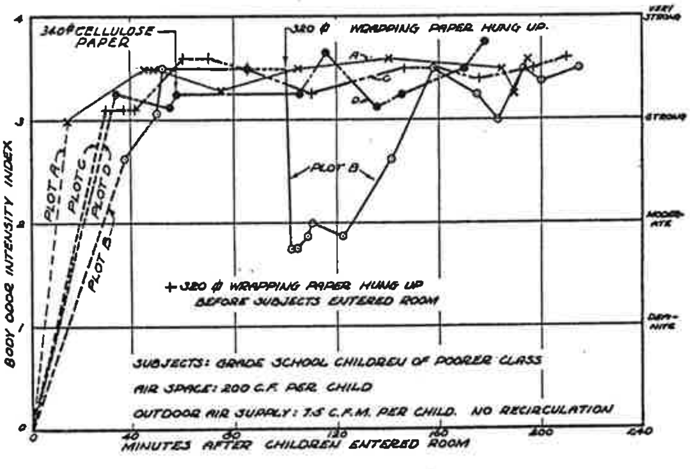

Fig. 6. Equilibrium Time and Intensity of Body Odor with and without Additional Adsorbing Surface in the Room

that near the middle of the test the adsorbing surface in the room was increased by 320 sq ft by hanging up sheets of semi-gloss brown wrapping paper vertically over the occupied zone and parallel to the air flow. The lower edges of the sheets hung down to shoulder height of the subjects.

The sudden decrease of odor intensity immediately after hanging up the sheets (Fig. 6) is probably due to a strong static charge acquired by the paper when it was unrolled freshly from a big roll just before hanging it up. The effect was transient, and the odor intensity soon rose to its former level, as can be seen in Fig. 6.

In plot *C* the same paper sheets were hung up in the room 16 hours before the subjects entered, with no apparent effect throughout the test period.

In plot *D* sheets of a spongy cellulose paper used in air filters were employed instead of wrapping paper, with negative results again.

Two experiments with an airflow of 30 cfm per person, instead of 7.5, likewise yielded negative results. The rate of disappearance of body odor at the end of the tests was substantially the same as in Fig. 1.

Summary

Body odors are not stable but tend to disappear rapidly in a closed room within a few minutes after the occupants leave. A weak residual odor persists for days unless the room is ventilated.

The unusually rapid disappearance rate is a characteristic of body odor itself, differing greatly from disappearance characteristics of other odors, such as butyric or valeric acid, tobacco smoke, and ozone, all capable of completely masking body odor.

Unlike body odor, the odor of tobacco smoke not only remains longer in the air but its intensity increases during the first three hours following smoking.

Air space per occupant in a room not only affects the disappearance rate of body odors and hence ventilation requirements, but also the efficiency of ventilation systems. Large rooms have an advantage over small ones, as they act like reservoirs, allowing body odors to disappear with a minimum outdoor air supply and maximum ventilation efficiency. A small room would require a greater air supply per occupant for the control of body odor. An increased air supply entails a loss of ventilation efficiency, as the air passes quickly to the exhaust without removing a full share of odors, heat, and moisture.

On the other hand, the problem of tobacco-smoke control would seem to consist in making rooms as small as is practicable and ventilating them fast.

DISCUSSION

Dr. W. J. McConnell [12] (Written): Ventilation requirements for the elimination of odors have long been a matter of guesswork. The desirability of removing the causes of odors is recognized, but scarcely ever obtained.

The authors of this paper have materially contributed to our knowledge of the complex subject of odors and have offered practicable measures of reducing odor concentration to the point where it is no longer noticeable, when complete removal is impossible.

The charts indicating the disappearance of certain odors are extremely instructive in the absence of scientific instruments for satisfactorily measuring odors.

The report is a valuable addition to the studies conducted by Schroeder, Gant, Shaw and others on this important subject.

J. J. Aeberly (Written): There are several reasons why a person about to discuss a technical paper should have the privilege of dealing in anticipations. It is in this sense that I wish to consider the data presented by Professor Yaglou and Mr. Witheridge.

The study of the character and minimization of odors is one of the moot questions within the society. The striking fact brought out in this presentation is that the odors under consideration are not gases; at least they do not follow some of the physical laws relating to vapor pressure and diffusion as do butyric and valeric acids when found in a vaporized state. The authors appear a little reluctant to state definitely that the odors are due to either liquids or solids; yet we may imply from the statement made in the text that some credence should be given to the thought that the rapid decline in odor intensity may be due to dehydration. To my way of thinking this explanation, namely, dehydration, is a much more reasonable deduction than the idea that oxidation may be the major cause of the rapid odor decline.

This work presents some new thoughts in relation to odors and the Society may

[12] Assistant Medical Director, Metropolitan Life Insurance Co., New York, N. Y.

do some useful research work to determine exactly the physical and chemical characteristics of the substances causing the odors. The new micro technique developed in the field of industrial hygiene makes this problem less intricate than it has appeared in the past. In general, the authors have done a constructive piece of work.

I would like to call attention to the statement made in the summary: "An increased air supply entails a loss of ventilation efficiency as the air passes quickly to the exhaust without removing the full share of odors, heat and moisture." This statement is based upon calculations using a formula which involves the action of a gas and in varying concentrations. These concentrations are 24 parts per 10,000 parts of air in the case of an air supply of 5 cfm, and seven to nine parts when 30 cfm is used.

In view of the fact that the substances under consideration are not gases and since these data appear to relate especially to a small room the authors should indicate that this statement should not be taken too generally in its application. It is evident that the ratio of the floor area occupied by the persons in the room in question to the total floor area is less than the ratio that obtains in an auditorium or other place of public assembly and it is this ratio that in all probability has materially influenced the result.

I am still of the opinion that the efficiency as defined and measured by the authors is more closely related to the design of ventilating systems with a view to perfect distribution than in any variation of air supply. The authors, no doubt, will agree with me that if we had a uniform downward flow throughout an auditorium the efficiency of the ventilating system would be constant as measured and defined by the authors regardless of the varying air supplies that are generally used in ventilating systems.

C. M. ASHLEY (WRITTEN): Professor Yaglou's and W. N. Witheridge's paper clears up the large question mark left by the results given in an earlier paper and rounds out very admirably the work done on this highly important subject.

One result of this investigation, for which I think we can be particularly grateful to the authors, is that it effectively explodes the myth of air change based on room volume as a measure of ventilation. I consider it a real step forward if the idea of air change on a room volume basis can be eliminated from our thinking.

It seems to me that the next logical step which should flow from this work is to attempt to set up a formula or method by which various grades of room odor intensity can be predicted for any given installation. It should thus be possible to set up the standards necessary to produce a Class A, B or C job from the standpoint of odor. Doubtless this work will be carried on through a committee of the Society, but such an attempt to set up an odor standard may reveal further gaps in our knowledge which have not as yet been covered by Professor Yaglou's and Mr. Witheridge's work. This work should, I believe, act as a guide in any future work which they carry on.

I have been somewhat concerned about the amount of infiltration which might be permitted through the small door used by the observer and I have wondered if a refinement of technique could not be made by using only an opening sufficient in size to permit the observer's head to project through from one room to another. It seems to me fairly certain that some of the diminution of odor intensity must be due to infiltration of air, although the marked difference between the results for body odor and various other odor sources indicates the impossibility of assigning a large role to this cause.

It seems to me that the question of surface adsorption of odor deserves somewhat further study if an unqualified answer is to be given, although I am not sure that the practical importance of this justifies more effort. Is it not possible that there is an adsorption to an equilibrium condition beyond which the effect of additional surface is not apparent? This suggestion would necessarily assume that the rate of decay of odor on a surface was not appreciable. This question undoubtedly must be answered by further study of the character of body odor.

Prof. Perry West (Written): This is unquestionably a most interesting paper and is no doubt pointing the way to some very new and valuable conceptions of ventilation requirements.

The general conclusions that a larger room volume per occupant will permit a smaller per capita air supply from out-of-doors for the control of body odors, while a smaller room volume per occupant with greater per capita out-of-door air supply is more efficient for the control of odors from tobacco smoke, etc., are quite interesting and useful.

I feel, however, and the authors will no doubt agree, that enough work has not been done on these subjects to properly define the exact effect that the room volume has upon either of these conditions.

In the previous paper referred to, where the room volume was 1410 cu ft, the cfm from out-of-doors required for the control of body odors would work out as shown in Table A.

The variation here is quite wide and somewhat out of keeping with what we have come to consider good ventilation. For instance in a theater where the cubic contents might range from 200 to 300 cu ft per person the air supply from out-of-doors will range from 10 to 7 cfm per person, instead of from 16 to 11 as the above might indicate.

I note in connection with Fig. 4 that there is a window and a door in the test room employed in these experiments and there are no doubt other sources of air leakage, including the natural cracks and pores in the walls, floor and ceiling.

No mention is made of any account having been taken of the natural air movement

Table A

No. of Occupants	Room Vol. Cu Ft per Occupant	cfm Required from Out-of-Doors per Occupant to Control Body Odors
3	470	7
7	201	16
14	100	25

Table B

No. of Occupants	Room Vol. Cu Ft per Occupant	Natural Air Change cfm per Occupant	Additional cfm Required to be Forced in from Out-of-Doors per Occupant to Control Body Odors	Total cfm Required per Occupant from Out-of-Doors
3	470	8	7	15
7	201	3.3	16	19.3
14	100	1.7	25	26.7

into and out of the room upon which the tests for determining the effect of room space upon air supply was based.

In a small room of this character where the volume per occupant is relatively small as compared with office space, anything like a normal air leakage would, of course, have considerable weight upon the results.

If, for instance, we should figure one air change per hour the results would be as shown in Table B.

If such a condition should obtain, then in the first case, as shown in Table A, the ventilation requirements would vary 360 per cent per capita and the ventilation efficiency would vary from 100 per cent down to 28 per cent, whereas from Table B the ventilation requirements would only vary 175 per cent and the efficiency from 100 to 50 per cent.

I note in this connection from Fig. 5, that the ventilation efficiency varies from about 97 per cent for 7 cfm per person to about 77 per cent for 25 cfm per person, which is a difference of 20 per cent, whereas the difference in efficiency indicated by the requirements of 7 cfm and 25 cfm per person is 72 per cent.

This difference might be explained, as the authors suggest, by the rapid spontaneous disappearance of body odors and the fact that this rate of disappearance is supposed to be a function of the room volume per capita, but I fail to find much data to support this, since all of the tests upon which curves in Fig. 1 are based were apparently made with the same number of occupants in the room.

Under the heading of "Changes in Ventilation Efficiency" I do not understand the formula—

$$\text{Ventilation Efficiency} = \frac{\dfrac{0.01}{(CO_2)r - (CO_2)s}}{\text{cfm per occupant}}$$

As an example take the following:

cfm per occupant = 5
$(CO_2)r$ = 0.2 per cent
$(CO_2)s$ = 0.0 per cent

Then—

$$\text{Ventilation Efficiency} = \frac{\dfrac{0.01}{0.2 - 0.0}}{\dfrac{5}{1}} = 0.01$$

Whereas the authors say that the efficiency for 5 cfm = 100 per cent.
It would seem, therefore, that this formula should read—

$$\text{Ventilating Efficiency in per cent} = \frac{\dfrac{0.01}{(CO_2)r - (CO_2)s}}{\text{cfm per occupant}} \times 10{,}000$$

Take as another example —

cfm per occupant = 5
$(CO_2)r$ = 0.24 per cent
$(CO_2)s$ = 0.04 per cent

Then —

$$\text{Ventilating Efficiency in per cent} = \frac{\dfrac{0.01}{0.24 - 0.04}}{\dfrac{5}{1}} = 0.01$$

which again must be multiplied by 10,000 to give results in per cent.
Would it not be simpler to write the formula —

$$\text{Ventilation Efficiency in per cent} = \frac{\dfrac{0.01 \times 10{,}000}{(CO_2)r - (CO_2)s}}{\text{cfm per occupant}} = \frac{\dfrac{100}{(CO_2)r - (CO_2)s}}{\text{cfm per occupant}}$$

Some further enlightenment on the above points will be of greatest interest to me and I believe to some of our other members.

PROF. C. P. YAGLOU: Most of Mr. Aeberly's comments on the identity of the body-odor complex are, I believe, too speculatory to be discussed at this time with the limited knowledge that we have. It would, however, be more reasonable to assume that body odors may be due to gaseous, liquid, and solid matter, than to any one of the three at the exclusion of the other two.

I also cannot agree with Mr. Aeberly's belief that the ventilation efficiency, as defined in the text, should remain constant regardless of changes in the air supply. If we make simultaneous observations of absolute humidity or carbon dioxide in the occupied zone and in the exhaust of a tight room supplied with any given distribution system, we shall find that our measurements under equilibrium conditions are invariably higher in the occupied zone than in the exhaust. The greater the air flow, the greater the difference between the two sets of measurements. If the room is cooled in warm weather, the temperature, too, will often be lower in the exhaust than in the occupied zone, except when the walls are considerably warmer than the air. The main reason appears to be that air diffusion is not perfect, except under very low air flows, and the greater the air supply to a given room, the poorer the diffusion, because the fresh air has less and less opportunity to mix with the room air. The data in Fig. 5 speak for themselves. They apply to the experimental rooms under consideration and to the given distribution system. In any other system, the efficiency may vary over wide limits. In a series of tests carried out in Massachusetts public schools by Mr. McPherson, Dr. Keenan, Professor Holt, and myself, ventilation efficiencies varied from 20 to 90 per cent depending largely on the type of system, location of supply and exhaust registers, and quantity of air supplied.

Professor West, apparently, has missed an important point in the first report on ventilation requirements, where it is stated that all cracks and crevices in the experimental rooms were carefully sealed with plasticene and adhesive tape, and that the only significant leakage occasioned was that through the small connecting door when the *judges* passed from the control to the experimental room, once every hour, or so. This door closed tightly against heavy felt strips and the main room door was sealed tight and kept locked. The walls and ceilings of the rooms were painted with two coats of glossy enamel and the concrete floor was covered with linoleum cemented in place.

Under such conditions, Professor West will, I believe, agree with me that his Table B does not hold. Natural air leakage that may occur in an ordinary room should be subtracted (instead of added) from the air requirement for the control of body odor in order to estimate the probable outdoor air supply by fan. Moreover, when a spray washer is used and the spray water is changed daily, the ventilation requirements are considerably lower than those in Table A, as shown in the first report of the series. This has a direct bearing upon Professor West's reference to lower practical requirements of theaters.

Professor West is perfectly correct in assuming that the right hand side of the equation for ventilation efficiency should be multiplied by 10,000 in order to express the result in per cent.

In closing, I should like to make clear that the main purpose of this laboratory study was to ascertain the factors affecting odor intensity in occupied rooms under controlled conditions, and to study suitable methods of odor control. Insofar as I know, no claim has ever been made that the data can be applied directly to practice, although there is considerable evidence to suggest that better results can be secured by the application of such fundamental data than by the use of rule-of-thumb methods in arriving at the probable outdoor air supply for body-odor control in various buildings. Field observations that have been in progress for some time will undoubtedly be of value in a final coordination of basic principles with practical facts.