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Air-movement control for treatment and isolation rooms

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A supply of filtered air has been shown to be effective in the reduction of airborne cross-infection in operating theatres (Shooter, Taylor, Ellis & Ross, 1956; Blowers, Mason, Wallace & Walton, 1955) and dressing rooms for burns (Lowbury, 1954). The provision of air conditioning, or even mechanical ventilation, in ward areas has not yet been generally accepted in Britain, but the ventilation of more specialized ward areas such as isolation and treatment rooms is becoming more common. In the case of isolation rooms, it is often thought necessary to keep patients in a bacteriologically clean environment and to prevent the movement of pathogenic micro-organisms to or from the isolation room. The isolation of transplant and other patients with low resistance to infection has received much attention lately, and Woodruff, Nolan, Bowie & Gould (1968) described an isolation unit designed for this type of patient. The same bacteriological requirements can be said to hold true for treatment rooms where the patients' wounds or infections can be dressed or inspected at a central point away from the rest of the ward activities.

The following series of tests were undertaken to assess and measure the factors which influence the control of air movement in these areas.

MATERIALS AND METHODS

The treatment room and isolation rooms were those at the Hairmyres Experimental Ward Unit, which is described in detail elsewhere (Report, 1968).

The treatment area

This area (as shown in Fig. 1) consisted of a treatment room, an air lock and a dirty utility room. The quality and quantity of the air supplied to and extracted from each room in the area could be accurately controlled. Normally, the treatment room had an air supply of 390 ft.^{3}/min. and the air lock 560 ft.^{3}/min., both being supplied through ceiling diffusers. The dirty utility room had an air extraction of 340 ft.^{3}/min. but no supply of air. A pass-through damper was fitted in the wall between the treatment room and the air lock; this could be opened or closed as required. Pressure relief flap dampers were fitted in the sliding doors between the air lock and the ward corridor.

Extract grilles were fitted at low level in the treatment room and the air lock. By varying the extraction rate in these areas various air movement control systems

could be obtained. The treatment room, with a constant air supply rate of 390 ft.^{3}/min. could be, with respect to the air lock: (*a*) positive—air extraction rate of zero; (*b*) balanced—air extraction rate of 390 ft.^{3}/min.; or (*c*) negative—air extraction rate of 780 ft.^{3}/min. This meant that for a positive system 390 ft.^{3}/min. flowed from treatment room to air lock via the pass-through damper and/or the door. For a negative system the direction of airflow was reversed and, under balanced conditions, there was no designed air flow through the doorway or pass-through damper. Similarly, the air lock could be positive or balanced with respect to the ward corridor.

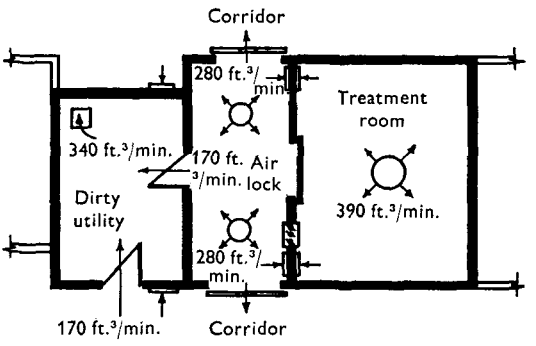

Fig. 1

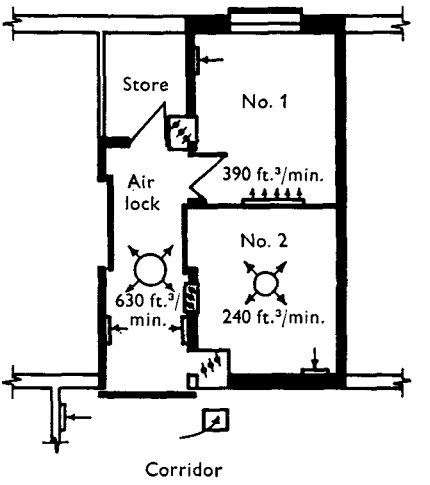

Fig. 2

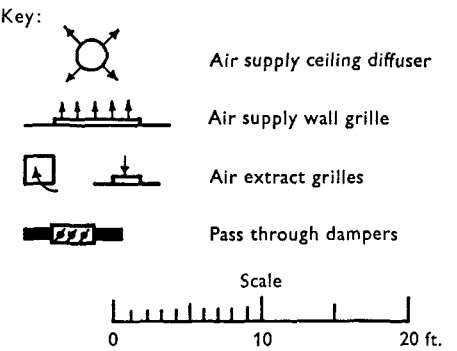

Fig. 1. The treatment area.
Fig. 2. The isolation rooms.

The system could also be operated at about two-thirds of its designed air-flow capacity when the supply rates to treatment room and air lock were 240 and 370 ft.^{3}/min. respectively. Tests were run under these conditions, the air extraction rates being reduced proportionately.

These air-supply rates of 390 and 240 ft.^{3}/min. were equivalent to a nominal 15 and 10 air changes/hr., respectively, in the treatment room under a balanced or

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positive system. When a negative system was selected an additional 15 or 10 air changes/hr. were drawn in from the air lock to give a total of 30 or 20 air changes/hr.

The isolation rooms

The two isolation rooms, together with their associated air lock, are shown in Fig. 2. Isolation room no. 1 had an air supply of 390 ft.^{3}/min. and isolation room no. 2 had 240 ft.^{3}/min. These rates were the same as the alternative supply rates to the treatment room. The air lock had a constant supply of 630 ft.^{3}/min. Pass-through dampers were fitted between each of the isolation rooms and the air lock and between the air lock and the ward corridor.

By extracting air through grilles at low level in a similar way to that described above for the treatment area, each of the isolation rooms could be positive, balanced or negative with respect to the air lock and the air lock could be positive or balanced with respect to the corridor.

Method of assessing the efficiency of the air movement control systems

Nitrous oxide was used to simulate airborne bacteria throughout these tests. The gas was released at a constant rate over a period of 2 or 3 hr. in one room of the treatment or isolation areas. The atmosphere was sampled in both it and the adjacent rooms and the concentration of nitrous oxide determined by infra-red analysis. The tests were repeated under a variety of conditions. The efficiency of any system was given by

$$\text{system efficiency} = \left(1 - \frac{\text{gas concentration in the sampling room}}{\text{gas concentration in the source room}} \times 100\right)\%$$

this being an expression of the system's ability to prevent transfer of tracer gas to or from a room. This meant, for example, that if a gas concentration of 5 parts/million was measured in the sampling room, while the source room had 100 parts/million, the system efficiency would be 95%. Most of the tests were carried out with the rooms in normal use.

The use of bacteria as a tracer substance was considered less convenient in view of the large number of observations required to obtain reliable quantitative results. The use of nitrous oxide gas simulated the worst conditions possible as it did not allow for natural sedimentation or loss of viability. However, the distance the gas or bacteria would have to travel was only a few feet and the efficiencies quoted must be close to, although probably less than, those which would be achieved with naturally occurring bacteria.

RESULTS

The following variables were measured during each test: (*a*) the air supply and extract volumes; (*b*) the air flow through the doorway; (*c*) the length of time the door was open; (*d*) the number of times the door was opened and shut; (*e*) the temperature difference between the rooms.

It was thought that these variables might influence the systems' efficiencies. The results of all the treatment and isolation room tests were analysed by a

multiple regression technique on a K.D.F. 9 computer and the following over-all prediction equations obtained.

A variable was considered to influence the air flow through the door if it reached a 5 % level of significance.

Air supply rate = 390 ft.³/min.—treatment room and isolation room no. 1

Positive and negative schemes (air flow through door = 390 ft.³/min.):

$$\text{efficiency } (\%) = 98{\cdot}53 - 0{\cdot}027T \pm 1{\cdot}19C; \quad (1)$$

Balanced schemes:

$$\text{efficiency } (\%) = 93{\cdot}60 - 0{\cdot}105T \pm 3{\cdot}01C \quad (2)$$

Air supply Rate = 240 ft.³/min.—treatment room and isolation room no. 2

Positive and negative schemes (air flow through door = 240 ft.³/min.):

$$\text{efficiency } (\%) = 97{\cdot}87 - 0{\cdot}032T; \quad (3)$$

Balanced schemes:

$$\text{efficiency } (\%) = 89{\cdot}58 - 0{\cdot}158T, \quad (4)$$

where T = percentage time the door was open (this ranged from 0 to 100 % throughout the tests), and C = a comparison factor between isolation room no. 1 and the treatment room.

Temperature differences did not influence the results. This was not surprising as they had been kept to a minimum in this series of experiments. However, it would be wrong to discount this possible factor since room temperatures inevitably differ in practice. In a subsequent series of as yet incomplete tests conducted in the isolation rooms, it was found that a 5° F. temperature difference, in conjunction with a balanced system, would cause an air transfer of around 400 ft.³/min. in each direction through the fully opened doorway. Even when a flow of 390 ft.³/min. of air was passing through the doorway as would be the case with the positive or negative ventilation systems used here, a 5° F. temperature difference caused around 250 ft.³/min. of air flow in through the top of the doorway while 640 ft.³/min., i.e. 250 + 390 ft.³/min. of air passed out through the bottom.

Contrary to what one might expect, especially in the case of swing doors, it was found that the number of times the doors opened and shut had no significant influence on the efficiencies and gave no hint of doing so. Comparison of the swing and sliding doors showed that there was no difference between them so far as isolation efficiency was concerned.

The method of air distribution was found to influence the efficiencies of the systems. At the higher air supply rates and where ceiling diffusers were being used, air could be directed out through the open doorway. The use of high-level wall grilles (as in isolation room 1), which did not blow the supply air out of the door, gave improvements in efficiency of the order of 2 % for positive and negative systems and 6 % for balanced systems. This is indicated by the comparison factor C in equations (1) and (2). In the case of equation (1), the factor 1·19 should be added to the constant factor 98·53 to give the efficiency equation for isolation room no. 1. To obtain the corresponding equation for the treatment room, 1·19

should be subtracted from the constant factor. The same applies to equation (2), describing the balanced systems with an air supply rate of 390 ft.^{3}/min., the difference between the two being just over 6 % in this case, as stated above.

In addition to those tests previously described, where the release room and sampling room were next to one another, further tests were conducted where the tracer gas was released in the corridors. The purpose of those tests was to assess the effectiveness of the air lock.

The barrier afforded by the air lock was found to be fairly effective. As measured by the quantity of tracer gas detected in the air lock, its efficiency was about 90 %, falling to between 60 % and 70 % for the treatment area with two doors and to 84 % for the isolation area with one door, if the doors were left open. Samples taken in the treatment and isolation rooms simultaneously with those taken in the air lock indicated that the provision of an air lock did little to improve the over-all efficiency of the system. Under average-use conditions, over-all efficiency figures in the order of 88–95 % were obtained for gas released in the corridor. The corresponding figures for gas released in the air lock were in the range 83–99 %, depending on the system in operation. The over-all figures include systems with the air lock both positive and balanced with respect to the corridor, and with the treatment or isolation rooms both positive and balanced with respect to the air lock. The figures for systems with the room negative and the air lock balanced were not included since these systems are intended to prevent air escaping from the room. However, even in these cases, over-all efficiencies of the air lock in preventing air entering from the corridor into the isolation or treatment rooms were of the order of 75 %.

In another set of tests, tracer gas was released in the dirty utility room and sampled in the treatment room. It was found, under all the ventilation schemes, that the concentration in the treatment room rarely exceeded 1 % of that in the dirty utility room.

DISCUSSION AND CONCLUSIONS

A large demand exists for positively ventilated treatment and isolation rooms in order that patients susceptible to infection are not contaminated with pathogenic organisms from the ward environment. This demand has been satisfied in a number of new hospitals by supplying air to the room and allowing the air to be pushed out from the room through pressure-relief-flap dampers in the door. From our prediction equations it can be seen that this type of system will afford a very high degree of protection to the patient from external contamination. Provided the method of air distribution is satisfactory, and temperature differences are kept to a minimum, when the door is shut, efficiencies of over 99 % will be obtainable with an air supply rate of 390 ft.^{3}/min. (fifteen air changes), and over 97 % with an air supply rate of 240 ft.^{3}/min. (ten air changes). Even if the room door is left open all the time these efficiencies would not fall by more than about 3 %.

In new hospitals, provision is usually made for patients with infective areas to be nursed in isolation rooms. The patients' dressings may then be changed away from the ward environment. A report presented by the Newcastle Regional

Hospital Board (Report 1965) stated that in a general surgical unit 22 % of patients would require some form of isolation; 10 % because they were potential sources of infection. At present, few wards would have sufficient isolation rooms to meet these requirements. Where patients with infective areas must be dressed or inspected in a central treatment room we envisage three possible solutions.

The first of these is to provide a separate 'dirty' treatment room with a negative air-movement control system. In our experimental system negative ventilation was achieved by keeping the same air supply as under positive ventilation and extracting more air than was supplied. From our results an airflow of between 250 and 400 ft.^{3}/min. through the doorway would appear to give a high degree of protection to areas outside the room. With isolation rooms, an extract system would be sufficient to maintain isolation requirements but some air supply would be necessary to give comfortable conditions in the room. With treatment rooms an additional air supply would be necessary in order that the pathogenic bacteria disseminated from dirty areas could be quickly reduced to a reasonable level. In our case the total amount of air extracted under a negative ventilation system was 780 ft.^{3}/min., which was around 30 air changes/hr., 15 of them being filtered air. The use of a separate room for clean and infected wounds is uneconomical unless treatment rooms are centralized so that they serve a number of wards.

The second solution would be to equip a single treatment room with a ventilation system capable of providing a positive or a negative air-movement control scheme as the need arose. This would place the perhaps undesirable onus on the nursing staff of ensuring the correct system was in use.

The third solution would be to provide a balanced ventilation system to the treatment room. Although balanced systems are not quite so efficient, for the same rate of air supply, as positive and negative systems, they do have the advantage of simplicity, with fewer problems of design and maintenance. In addition, when the door is shut, the air within the room is fairly effectively sealed in, and the provision of an air lock to dilute contamination approaching or leaving it is not so necessary as with positive or negative systems. However, care must be taken to ensure that the system is correctly balanced, i.e. the same amount of air is extracted as supplied.

The test results indicated that, for efficiencies in the range 90–95 % one would require about double the air supply rate to achieve the same efficiency as the positive and negative systems. However, for higher efficiencies the difference in air supply rate would not be so great. A slight extrapolation of the test results indicates, for example, that a balanced system with an air supply rate of 520 ft.^{3}/min. would give about the same efficiency as positive and negative schemes with about 460 ft.^{3}/min. The reason for this is that the efficiency of isolation is mainly influenced by the air supply rate, and the higher this rate the less the effect of the duration of door opening.

An air lock was shown to be of little advantage in preventing the transfer of air in an already efficient system but would be of advantage in diluting the contaminants coming out of the room when under positive pressure or going into the room under a negative system. One of the main functions of an air lock may well be in

acting as an 'environmental lock', preventing adverse conditions of temperature and pressure affecting the rooms in question. Differences in temperature are expected to have a large effect and this 'environmental lock' would be necessary if rooms were installed in a naturally ventilated ward especially if a balanced system was contemplated.

We have so far discussed the requirements to ensure that there is no adverse movement of contamination in or out of rooms. What has not been considered is the quantity of air required to provide a 'safe' level of bacteria in the rooms. As a treatment room is only used for an hour or two each day and the ventilation system can be shut off at other times, or reduced in volume, it would probably be economical to supply air volumes of around 500–1000 ft.^{3}/min. to control the higher levels of bacterial contamination and the residual contamination carried over from patient to patient in these rooms; we found that the bacterial concentration was around 3–4 times higher in the treatment room than in the ward area and the time between patients' dressings very short. Using these large quantities of air a balanced system, although the least efficient of the three methods, would ensure almost absolute protection against the movement of bacteria across the door, provided the temperature differences were small. With such a balanced system it should not be necessary to provide an air lock in a mechanically ventilated ward. It is felt that it would still be advisable to dress the clean wounds first.

In isolation rooms, where the air will be supplied all the time, the choice of a ventilation scheme suitable for most purposes is complicated by the fact that between 250 and 500 ft.^{3}/min. of air would probably be regarded as an economical amount of air. With an air supply of less than 400 ft.^{3}/min. a balanced system would not give as full protection as a negative or positive system. The situation is further complicated by the variable use to which isolation rooms may be put. The decision as to what type of ventilation scheme should be used must ultimately depend on the type of patient to be nursed and the type of facility which may be economically provided. The lower the resistance of a patient to infection the greater the degree of protection which must be given. For the extremely critical situation a laminar flow system could be used (Michaelson, Vesley & Halbert, 1967).

Whatever ventilation scheme is chosen, the degree of elaboration built into the experimental systems we investigated would not be necessary, or indeed desirable, in the normal hospital. Their general complexity meant that in the treatment room the nurse had the option of five different ventilation schemes. A simple system which can be easily understood and seen to work would be much better.

SUMMARY

The degree of protection provided by various air movement control systems, as applied to isolation and treatment rooms, has been assessed. The main factors influencing the efficiency of isolation were the air supply rate to the room and the time the door was left open. The effect of some other possible factors, such as temperature differences and method of air distribution, are discussed.

The type of facilities provided must depend on the type of patient and economics,

but prediction equations, which allow the assessment of positive, negative and balanced ventilation systems, are presented. The ventilation requirements for isolation rooms should be assessed individually, but for a treatment room a balanced system of ventilation with between 500 and 1000 ft.^{3}/min. should be very effective. Precautions should be taken to ensure the air quantities are balanced and temperature differences are minimized. An air lock should not be necessary for balanced systems provided these rooms are in a mechanically ventilated ward.

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Requests for reprints, or a fuller description of the ward unit and test results, should be addressed to George Baird, Building Services Research Unit, 3 Lilybank Gardens, Glasgow, W.2.

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