Thorax (1965), **20**, 146.

Use of recirculating air conditioners to clean the air of small wards

J. McK. ELLISON

From the M.R.C. Air Pollution Research Unit, St. Bartholomew's Hospital Medical College, London E.C.1

Before 1945 air pollution, when it was considered at all, was regarded by the public mainly as an aesthetic affront or a filthy nuisance, but since then evidence to show that it can affect health has been accruing. The London fog of 1952 showed that prolonged exposure to high concentrations of pollution could be the final blow that overwhelmed patients with impaired lungs or hearts, and subsequently the work of Waller and Lawther (1955, 1957) demonstrated that even in less extreme circumstances sufferers from bronchitis may feel appreciably worse when the air is badly polluted. Although there is a surprising dearth of evidence that this association is causal, it seems reasonable to assume that patients may benefit from the removal of the principal pollutants, sulphur dioxide and smoke, from the air which they breathe.

Many hospitals in the United Kingdom are in towns which are likely to remain subject to serious air pollution for many years to come. Complete air conditioning of whole hospitals has hitherto been regarded as prohibitively expensive, and very few have even one large ward which is provided with filtered or purified air, but a number have installed room air conditioners in small side wards (Tuffley and Zorab, 1964). These room air conditioners draw room air either through filters, which remove particulate matter, or through some form of air purifier, which removes objectionable gases, or through both, and then pass the cleaned air back into the room. The intention is that during periods of high pollution the wards so equipped should be set aside for the use of patients with serious respiratory or cardiac embarrassment; some of the devices on the market are intended for fitting in the homes of individual sufferers.

The purpose of this paper is twofold: (1) to derive algebraic expressions from which may be calculated, in terms of the output of the air conditioner and its efficiency in removing pollutants from the air passing through it, the amount by which and the rate at which it reduces the concentration of any pollutant in the room; and (2) to use these expressions to formulate a specification of the minimum requirements of a useful device. For simplicity, the term 'filtration' will be used to describe any process which removes a pollutant from the air, but the arguments and discussion can be applied to the removal of gases as well as to the removal of particles.

REMOVAL OF A POLLUTANT FROM ROOM AIR

The air in a room is always being exchanged with that out of doors: were this not so, any filter, however small and inefficient, would eventually remove all the pollution present, but this does not happen because the incoming air brings more pollution with it, and all the time this is mixing with the air already in the room. The concentration of pollution must therefore vary from one point to another. For the moment let it be assumed, however, that the concentration of pollution is the same everywhere in the room, c_r, and that the rate at which air is being exchanged with the outside is constant, volume v_i being exchanged per hour.

If c_i is the concentration of the pollutant under consideration in the incoming air, then in time δt the net amount entering the room from outside is $v_i(c_i - c_r)\delta t$; likewise, if v_p is the volume of air passing through the purifier per hour and c_p the concentration of pollution in the air leaving it, the amount being removed in the same time is $v_p(c_r - c_p)\delta t$. Hence, if the volume of the room is V_r the change of concentration δc_r in time δt is given by

$$\{v_i(c_i - c_r) - v_p(c_r - c_p)\}\delta t = V_r \delta c_r \quad \text{...........(1)}$$

The filtering medium may behave in any of several different ways. The simplest assumption is that it removes from the air entering it a fixed proportion $1-k$ $(k<1)$ of each pollutant, so that $1-k$ may be regarded as the efficiency of the filter with respect to the pollutant concerned. The value of k will not be the same for all pollutants, nor for a given pollutant will it be the same under all operating conditions, and in particular k will be different for different gases and for particles of different sizes, but it seems reasonable to assume that it does not vary very much over relatively short periods of time and under fixed conditions. Then $c_p = kc_r$, and the rate at which c_r changes can be calculated from (1) to give

$$\frac{dc_r}{dt} = \{v_i(c_i - c_r) - v_p c_r(1-k)\} \times \frac{1}{V_r} \quad \text{..........(2)}$$

This can be simplified by putting $v_i/V_r = a_i$, the natural rate of ventilation of the room expressed in air changes per hour, and $v_p/V_r = a_p$, the output of the purifier expressed in the same units. Equation (2) then becomes

$$\frac{dc_r}{dt} = a_i(c_i - c_r) - a_p c_r(1-k) \quad \text{................(3)}$$

At equilibrium c_r is constant, say $c_{r,\infty}$, and therefore $dc_r/dt = 0$. Hence, if it is assumed that a_i, a_p, c_i, and k remain constant, it is possible to calculate $c_{r,\infty}$ since it must be the value of c_r when the right-hand side of equation (3) is put equal to zero. Solving for c_r this gives

$$c_{r,\infty} = \frac{a_i c_i}{a_i + a_p(1-k)} \quad \text{......................(4)}$$

c_r will never reach this value but will approach it asymptotically. In practice, however, conditions in an occupied room seldom stay the same for very long, and the rate at which equilibrium is approached is therefore of as much interest as the level finally reached. Since $c_{r,\infty}$ is a constant $\frac{dc_r}{dt} = \frac{d(c_r - c_{r,\infty})}{dt}$ and therefore we may rewrite equation (3) in the form

$$\frac{d}{dt}(c_r - c_{r,\infty}) = -\{a_i + (1-k)a_p\}(c_r - c_{r,\infty}) \quad \text{......(5)}$$

Hence

$$\log_e(c_r - c_{r,\infty}) = -\{a_i + (1-k)a_p\}t + \text{constant} \quad \text{..(6)}$$

If the value of c_r at $t=0$ is $c_{r,0}$ the value of the constant must be $\log_e(c_{r,0} - c_{r,\infty})$ and the variation of concentration with time may be expressed by the equation

$$\frac{c_r - c_{r,\infty}}{c_{r,0} - c_{r,\infty}} = e^{-[a_i + (1-k)a_p]t} \quad \text{.................(7)}$$

c_r therefore approaches $c_{r,\infty}$ exponentially, and $c_r - c_{r,\infty}$ will fall by a factor $e = 2{\cdot}72$ in a period $t_{2\cdot72}$ given by

$$t_{2\cdot72} = \frac{1}{a_i + (1-k)a_p} \text{ hours} \quad \text{.................(8)}$$

MINIMUM REQUIREMENTS OF A USEFUL AIR CONDITIONER

An occupied room cannot be kept shut for very long, and if an air conditioner is to be of much value to sufferers from chest disease it must be capable not only of reducing the concentration of pollution to a low level but also of making a substantial reduction in concentration within a relatively short time. These vague desiderata must however be translated into firm figures from which an engineer can calculate the output of clean air which is needed if the improvement of the air in a given room is to be worth while. Such figures are necessarily arbitrary, but it seems reasonable to stipulate that the device must be able to lower the concentration within the room to less than one quarter of that outside (*i.e.*, $c_{r,\infty} < \frac{1}{4}c_i$) and also that it must be capable of reducing $c_r - c_{r,\infty}$ by a factor e within less than a quarter of an hour. The first of these two conditions gives (from equation (4)) the inequality $a_i/[a_i + (1-k)a_p] < 1/4$ or $(1-k)a_p > 3a_i$ and the second (from equation (8)) gives $a_i + (1-k)a_p > 4$, so that the equations

$$(1-k)a_p = 3a_i \quad \text{.....................(9)}$$

and

$$a_i + (1-k)a_p = 4 \quad \text{.................(10)}$$

specify the minimum requirements which an adequate air conditioner must satisfy. The lines corresponding to equations (9) and (10) are shown in the Figure, and only if the point representing a given pair of values of a_i and $(1-k)a_p$ lies within the shaded area will both conditions be satisfied. In medium-sized rooms, such as those for which room air conditioners appear to be intended, the natural ventilation rate a_i will normally be less than 1·5 air changes per hour unless doors or windows are left open or unless open fires are used for heating (Bedford, 1964).

From the Figure it is seen that an air conditioner with an output $(1-k)a_p = 4{\cdot}5$ would just meet the requirements, but one with $(1-k)a_p = 5$ would leave a small margin of safety.

The efficiency of the removal of particles is very dependent on particle size, and the calculation of the output of an adequate conditioner has therefore been based on the removal of sulphur dioxide. If the efficiency of removal of SO_2 is 80%, then for a side ward of volume 50 m.³ (1,750 cu. ft.) the output required is

$$\frac{50 \times 5}{0{\cdot}8} = 312{\cdot}5 \text{ m.}^3 \text{ per hour}$$

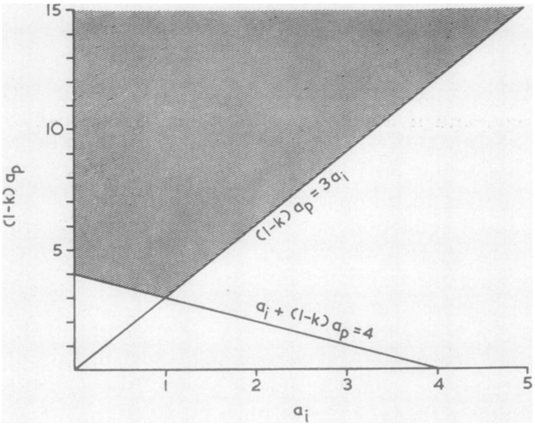

FIGURE. *Output of clean air needed in order to achieve substantial reduction of pollution. Any value of* $(1-k)a_p$ *lying in the shaded area will satisfy the conditions specified in the text.*

a_i *is the natural air change rate of the room,* $1-k$ *is the efficiency with which a given pollutant is removed, and* a_p *is the volume of air passing through the purifier per hour, expressed as an air change rate.*

or about 5m.[3] per minute (175 c.f.m.). Although most of the devices on the market appear to have a rather lower output than this, it should be possible to design a suitable machine. On the other hand, a conditioner able to achieve a standard of air purification appreciably higher than that quoted above, or to achieve even this standard in a room of ventilation rate markedly higher than 1·5 changes per hour (that of a room heated by an open fire usually exceeds three changes per hour), would probably be too bulky to be acceptable.

DISCUSSION AND CONCLUSIONS

It is implicit in the above argument that c_r is the same throughout the room, and at both intake and exhaust of the purifier, and clearly this is not strictly true. It is of course possible to make corrections for one or another assumed form of imperfect mixing, but it is highly questionable whether it is worth doing so: in a reasonably uncluttered room the air which a patient breathes should be reasonably well mixed because his warmth induces convection and mixing. In any case the argument above and the figures put into the formulae are so conjectural, and the situation in an occupied room is so fluctuating, that the output quoted should be taken as indicating little more than an order of magnitude. It is, of course, possible to start from more sophisticated assumptions, but it seems pointless to do so ; the formulae given above will give rough answers to problems which can only be roughly specified.

The need for a quantitative study of air conditioning of small wards was realized in discussion with Dr. Robin Tuffley: I am grateful to him for his very helpful comments on the resulting work. I am also grateful to the Director of this Unit, Dr. P. J. Lawther, and to my colleague, Mr. R. E. Waller, for their valuable criticism of the manuscript.

REFERENCES

Bedford, T. (1964). *Basic Principles of Ventilation and Heating*, 2nd ed. Lewis, London.
Tuffley, R. E., and Zorab, P. A. (1964). Portable air purifier. *Lancet*, **1**, 415.
Waller, R. E., and Lawther, P. J. (1955). Some observations on London fog. *Brit. med. J.*, **2**, 1356.
—— —— (1957). Further observations on London fog. *Ibid.*, **2**, 1473.