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USE OF MECHANICAL VENTILATION TO REDUCE EXPLOSION HAZARDS IN HIGH FLATS

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SUMMARY

The use of mechanical ventilation to protect high flats against explosions involving flammable gases or liquids is discussed in general terms. The relevant properties of the gases and vapours are considered, the extraction ventilation requirements are suggested, and application is made to a specific example (Flat 90, Ronan Point).

The advantages of mechanical ventilation are that it would control the time for which a dangerous explosive volume of gas or vapour would be present, reduce the size of the volume, prevent an escape of gas from spreading to other rooms, and would prevent a slow leak from accumulating.

The proposed mechanical ventilation should not cause discomfort to the occupants and should give good protection against explosions caused by leakage of town gas, likely leakage of L.P. gas, and moderate spillages (a few pints) of flammable liquids such as petrol. Some discussion is made of the problem of large spillages.

The desirability of full scale tests on actual structures is stressed, particularly as regards the extent of mixing of flammable gas or vapour with air and the probability of forming a hazardous pocket in ventilated rooms. Also the extraction rates of unmixed layers and the mixing effect of heating systems should be investigated.

KEY WORDS: Explosion, Flats, Ventilation, Building multi-storey.

MINISTRY OF TECHNOLOGY AND FIRE OFFICES' COMMITTEE
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1. INTRODUCTION

The presence in dwellings of flammable gases and liquids, such as Town gas, L.P. gas, aerosols, petrol or solvents is now common and to be expected. If the gas, or vapour from a liquid, were mixed with air and ignited it would burn rapidly and produce an explosion. The severity of the explosion would depend upon the volume of mixture and its composition, but it could be sufficient to cause structural damage to a room or rooms in the dwelling. The more violent explosions could be so severe that major structural damage to the premises would occur, unless specific measures were taken to mitigate the effect. One such measure is explosion relief venting, the action of which is to open during the early stage of the explosion and allow gases to be rapidly discharged to atmosphere. The rise in pressure within the structure is thereby controlled and may be kept to a low value. That part of the structure acting as a relief vent should be of lightweight construction and weaker than the surrounding walls and load-bearing members. In practice there would be a lower limit to the pressure at which the vent is designed to open, because it should not be opened by wind pressures acting on the building, and this limit would also apply to the use of a window as a vent. If the vent is opened by the blowing out of a panel, its inertia will also affect the maximum pressure attained in an explosion.

The maximum explosion pressure that the structure can safely withstand is limited, and if additional strength has to be provided, the cost may be high. The possible use of mechanical ventilation to ease the problem is discussed here, but it is not a complete substitute for the provision of explosion relief. Increase of the structural strength and provision of explosion relief may, however, be modified if mechanical ventilation is installed, and this procedure may have economic advantages.

The following sections consider mechanical ventilation in some detail and are based on available technical information. Confirmatory tests would be advisable, and their need is stressed in several specific instances.

2. PRINCIPLE OF VENTILATION

To reduce the risk of explosion arising from flammable gas or vapour the air should be extracted from each of the principal rooms within the dwelling, by mechanical means, and ultimately discharged to atmosphere; special provision may be necessary for the supply of fresh air to the rooms to replace that extracted. Mechanical ventilation could be arranged to have the following effects:

(a) Control of the time for which an explosive volume of gas or vapour would be present, and which would be sufficient to cause serious structural damage if it became ignited.

(b) Reduction of the size of such an explosive volume, as compared with unventilated conditions, and the maximum explosion pressure that could develop.

(c) Prevention of an escape of gas or vapour in one room from entering and accumulating in an adjoining room.

(d) Prevention of an escape of gas or vapour from a slow leak accumulating sufficient volume to cause a serious explosion hazard to the structure. Some control would therefore be provided during the night, or when the dwelling was unoccupied.

3. APPLICATION OF THE PRINCIPLE

Mechanical ventilation can be provided in high flats, and was installed in the bathroom/toilets in the Ronan Point flats. Five main ducts for this purpose ran the full height of the building, there were five flats to each floor, and each main duct connected to one flat per floor. In the case of Ronan Point the ventilation system could be extended within each flat.

For high flats with no existing mechanical ventilation a new installation would be necessary, and individual systems connecting directly to the external air could be considered. With either individual or common duct systems it would be essential that the mechanical ventilation should run continuously.

In the following sections, the suggested ventilation requirements are listed, for the general case, and the application to a specific example (Flat 90 Ronan Point) is described. In other applications, modification of the procedure may be needed to meet local conditions.

4. FLAMMABLE GASES AND VAPOURS

Some properties of common liquids and gases likely to be found in domestic premises are listed in Table 1. The densities are noticeably different from that of air, Town gas and North Sea gas being about half the density whereas the gas or vapour from L.P. gas or petrol are 2 to 3 times the density of air. All the material will have a tendency to stratify in a room, at ceiling level for the low density gases and at floor level for the others. This property can be made use of in the design of the ventilation system.

Table 1

Common flammable gases and vapours

Flammable material	Relative density of gas or vapour (Air = 1)	Flammable concentration range in air per cent by volume	Supply
Town gas	0.5	5.3 - 32	Unlimited
North Sea gas	0.5	5.3 - 14	Unlimited
Petrol	3	1.2 - 7.5	Limited
L.P. gas (butane)	2	1.9 - 8.5	Limited
Acetone (typical solvent)	2	3.0 - 11	Limited

The low density gases have a wider range of flammable concentrations when mixed with air than do the gases and vapours denser than air (Table 1), and this implies that it is easier with them to form a flammable mixture with air by chance. The light gases have a potentially unlimited supply, until a valve is turned off, whereas with the others the supply would be limited by the quantity initially present in the container. Although the supply is limited the rate of production of vapour could be faster than the rate of escape of, for instance, Town gas. If 2 gallons of petrol were spilled onto a non-absorbent floor, it could spread over an area of about 100 ft^2 and the rate of production of vapour over this area would be about 250 ft^3 per hour. Two gallons of petrol would produce in all about 66 ft^3 of vapour, so that the duration of the evaporation period would be about 0.26 hours (about 16 minutes). For comparison the discharge rate from an open $\frac{3}{4}$ in. gas pipe, as in Flat 90, Ronan Point, was approximately

120 ft^3/h but the supply would be unlimited until turned off. Because of differencies in air requirements (Table 1) a cubic foot of petrol vapour would produce about four times as much explosive mixture as a cubic foot of Town gas.

Common solvents such as acetone, would evaporate at about the same rate as petrol or more slowly. The L.P. gas butane is much more widely used for camping and other domestic purposes than is propane; the contents of a 10 lb bottle may be regarded as a likely maximum quantity to be present in a single container, and many L.P. gas containers in fact contain only 1 lb or less. The chance of accidental fracture of an L.P. gas bottle is negligible, the greatest risk is if the valve were left fully open. A 10 lb bottle would release about 1.5 lb butane in 8 minutes (about 12 ft^3) after which the flow would be a trickle due to cooling of the liquid butane. With solvents and with L.P. gas the total quantity of vapour produced would be limited.

5. With Town gas and North Sea gas the likely positions of leaks can usually be foreseen. These are at an appliance, and at pipe joints, flanges etc. The extraction ventilation can therefore be concentrated at these positions, and this simplifies the protective installation.

5. MOVEMENT OF ESCAPED GAS AND VAPOURS

After escape the gas or vapour will tend to move either to the ceiling or the floor, depending on density. The extent of mixing with air, may be considered in three categories.

1. No mixing. Favoured by the production of heavy vapours at floor level, e.g. spillage of petrol, by light gases at ceiling level, or by slow leaks from pipe joints or valves.
2. Rapid and complete mixing. Favoured by vigorous stirring of the air in the room by mechanical means, e.g. a powerful fan.
3. Partial mixing. Likely to arise if escaping gas or vapour is mixed locally with air so that part of the room contains a gas/air mixture and other parts contain air, and also possibly unmixed gas. Favoured by local stirring, e.g. discharge of gas from a jet. A sufficiently large pocket might then be produced which could cause structural damage on ignition, and this is one of the situations for which the explosion relief venting would be considered.

The explosion hazard arising from each of the above categories of movement needs consideration. With no mixing with air ignition would be followed by relatively slow burning and only minor pressure effects would be expected. Fire spread would, however, be likely within the room. The no mixing condition would be favoured by large density differences between the gas or vapour and air, but typical mixing patterns would need to be established by test.

The flow of flammable gas or vapour without mixing is a simple situation for mechanical ventilation to deal with and it is likely to be an effective means of removing explosion risks.

Rapid stirring of the air in the room , leading to effective mixing of the flammable gas or vapour with air, is the opposite extreme case to no mixing. In a ventilated room the concentration of gas or vapour varies with time as follows

$$c = 100 \frac{m}{v} \left(1 - e^{-tv/V}\right) \qquad \text{........(i)}$$

where v is the rate of ventilation (ft^3/hour)

V is room volume (ft^3)

m is the rate of escape of flammable gas or vapour (ft^3/hour)

c is percentage of flammable gas mixed with unit volume of air at time t (hours).

If the supply of flammable gas or liquid is unlimited, as with Town gas, after a long time (say 1 hour)

$$c = 100 \frac{m}{v} \text{ approximately}$$

For safety c should not exceed 5 per cent for Town gas and if $m = 120\ ft^3/h$ then $v = 2400\ ft^3/h$ and is likely to be in the range 2-5 air changes per hour depending upon the volume of the room.

For petrol, and other materials in limited supply, after all the liquid has evaporated the vapour concentration is given by

$$c = c_{max}\, e^{-tv/V} \qquad \text{.........(ii)}$$

where c_{max} is percentage concentration of flammable vapour or gas when vaporization was just completed

t is time elapsed after vaporization completed (hours)

At a ventilation rate of 2 changes per hour the vapour concentration would drop to about one-seventh of its maximum value when another hour had elapsed. A similar dilution would be obtained after turning off gas flowing from an unlimited supply.

The effects of partial mixing of flammable gas and air are more difficult to specify. The most severe case is where a sizeable pocket of the most flammable mixture of gas or vapour with air is formed. This would be the result of some mechanical stirring action; if the action were continuous it could be expected to further change the composition of the atmosphere in the room away from the most flammable composition. In addition, with mechanical ventilation, there would be a continuous air change within the room. If the mixing process should cease, with two air changes per hour, substantial alleviation of the explosion risk would be obtained within $\frac{1}{2}$ hour. With no mechanical ventilation, the most flammable mixture might persist for many hours.

Stirring of the atmosphere in a room could be obtained by opening a window, in this case the stirring action would be accompanied by dilution of the flammable mixture with clean air and should be regarded as beneficial.

Another likely cause of stirring of the atmosphere in the room is the heating system. Under-floor heating, as at Ronan Point, produces very little air movement and is conducive to the formation of stable layers of gas at ceiling or floor level. Hot water radiators have a more vigorous stirring effect, and the extent to which they could break up ceiling or floor level layers would need to be established by direct tests. Warm air central heating, powered mechanically, would be an effective stirring agent, although the air stream is not usually directed to the floor and consequently the stirring action at floor level might be much less than in the centre of the room. Direct tests would again be necessary.

All the gases and vapours listed in Table 1 have noticeable odours; if mixed with air suddenly in an occupied room, their presence is likely to be detected rapidly.

6. EXTRACTION RATES

If mechanical ventilation is used to draw off flammable gases and vapours clearly the higher the extraction rate the greater the leakage or spillage which can be dealt with safely. On the other hand, too many air changes per hour make a room uncomfortable to live in. For living rooms and bedrooms, the usual natural ventilation rate is 1-1$\frac{1}{2}$ air changes per hour. For the removal of flammable gas or vapour by mechanical ventilation, a maximum of 2 air changes per hour is proposed as an acceptable compromise. It is shown below that complete protection is not thereby obtained for large spillages or leaks, but that for moderate and small spillages good protection is obtained. For bathrooms and toilets at least 6 air changes per hour are customary; for kitchens a compromise maximum of 4 changes per hour is proposed.

If it is decided that protection by mechanical ventilation is only necessary for Town gas, and that explosions in other gases and vapours can be dealt with by relief venting alone, the ventilation need only be installed in those rooms etc. with gas connected.

The above air change values should be regarded as the recommended design rates, and an excess capacity of about 20 per cent may be necessary to ensure that the recommended values can be obtained.

The extraction should be divided between floor level and ceiling level grilles, depending upon the gas or vapour likely to be involved. For living rooms and bedrooms, where no supply of Town gas has been installed, floor level grilles only would be required. These would deal with the heavier than air materials, such as petrol, L.P. gas, aerosols, solvents etc. For kitchens where both Town gas and liquids may be involved, 2 air changes per hour should be extracted at floor level and the remainder at ceiling level or by a reasonable alternative; for Town gas only, two changes per hour would usually be adequate (see below).

A reasonable alternative, where there is a gas stove or gas refrigerator in a kitchen would be to erect an extraction hood over the stove etc. connected to the mechanical ventilation system. The hood should cover a floor area from the wall forward across the full extent of the appliance. Particular attention should be given to the point of attachment of the appliance to the gas pipe and it is most important that any leak of gas should be directed upwards into the hood. Normally the back of the appliance would assist in this, and if necessary side panels should be attached from the hood downwards to deflect any horizontal jet of gas from the gas pipe and fitting. The hood would also deal with any small leakage, e.g. escape from an unlit burner. The extraction rate from the hood should preferably be at least 20 times the maximum possible escape rate of gas. If this condition is too arduous the extraction rate may be reduced, but not below 10 times the maximum escape rate. Under the latter conditions the concentration of gas in the extraction ducting could be up to 10 per cent by volume, this is within the flammable range (Table 1) but is only half the concentration for maximum explosive effect. The duct length should preferably be straight, although one right-angled bend could be permitted, and within a distance of 30 diameters should be joined by ducting from another extraction point carrying at least the same throughput of air.

Any explosion within the ducting from the extraction hood would then be minor and would not lead to major structural damage of the dwelling.

As regards halls, large store cupboards etc. some relaxation of the proposed requirements may be permitted depending on local conditions. Good protection could be obtained with extraction rates of 2 air changes per hour, divided equally betweem ceiling and floor level grilles, where both light and heavy gases or vapours may be involved. In the absence of light gases, e.g. if no gas meter in hall or cupboards, 1 change per hour at floor level only would be proposed. If the necessary air changes can be supplied easily and reliably by natural ventilation, then mechanical ventilation would not be essential.

Special attention should be given to enclosures containing gas-fired appliances, such as central heating units. If the design of the enclosures and appliance is such that the atmosphere within the enclosure is static, i.e. not used as a source of combustion air, or not used as part of the warm air flow, then mechanical ventilation of the enclosure should be installed. The extraction rate should be preferably 20 times the maximum possible escape rate of gas and in any case at least 10 times the maximum possible escape rate.

7. POSITION OF EXTRACT GRILLES

One aim of the mechanical ventilation is to draw off the flammable gas or vapour as a layer with the minimum of mixing with the air in the room. The grilles should be as close as possible to the ceiling or floor; the distance between the edge of the grille and the ceiling or floor should not exceed 6 inches and if possible should be about 1 inch. The grille should be elongated horizontally so as to facilitate the extraction of layers of gas; slot ventilators could be used. The position of the grille within the room will depend on the layout, particularly also the position of any inlet grille. Floor level grilles should be sited so that likely onstruction by heavy furniture, such as sideboards, wardrobes, is minimized. The area of ventilator may be calculated in the usual way, e.g. for a room of volume 1000 ft^3, 2 air changes per hour, and for a pressure drop across the ventilator of 0.1 in water gauge, the area of the grille would be about 9 in^2.

The ventilation system within the dwelling must be balanced so that the required volumes are drawn from the appropriate rooms. The main duct work to the fan, external to the individual dwelling in high flats, should be within an enclosure having the appropriate fire resistance.

8. POSITION OF AIR INLETS

If air is mechanically withdrawn from a room at several changes per hour, it may be necessary to provide inlet ventilators to replace the air. The inlet ventilators should be sited at high level for floor level extract grilles, and at low level for ceiling grilles. The inlet should preferably be on the opposite side of the room to the outlet, although this is not essential, and slot ventilators giving a difuse spread of the incoming air are advisable. Where extract grilles are provided at both ceiling and floor levels in a room, high and low level inlets would also be desirable.

To prevent the spread of flammable gas or vapour from outside the room where it is released, it is desirable that the extraction rate from the room should be greater than the inlet rate from the ventilators. The suggested difference is about 25 per cent of the extraction rate. The desired effect should be present for the majority of the time, but under adverse external wind pressure conditions, some escape from the room might still occur. The use of self-closing doors would be advisable.

9. APPLICATION TO SPECIFIC EXAMPLE (Flat 90 Ronan Point)

9.1. Living room.

Floor area was 213 ft^2, volume was 1600 ft^3. No gas supply connected, this should be continued in future. Flammable vapours would thus be heavier than air; ventilation extraction rate 2 air changes per hour at floor level.

Consider a spillage of 2 gallons of petrol extending over a floor area of 100 ft^2. The volume of vapour formed would be 66 ft^3 over a period of 0.26 hours (Section 4), which is a mean vaporization rate of 250 ft^3 per hour per 100 ft^2. The density of the vapour is three times that of air (Table 1), and there would be a strong tendency for a layer of vapour to form at floor level. The extract grille would remove 3200 ft^3 per hour from floor level during and after the vaporization period. For the case where there is no mixing of the atmosphere in the room, the accumulation of vapour at floor level is unlikely to cause a major explosion hazard. Substantial clearance of the vapour would be expected within the period of 0.5 hours (30 min) from the initial spillage, and may be even more rapid, but this ought to be checked by a direct test. (With no ventilation a vapour/air layer about 1.5 ft thick would form over the whole floor area, which would then gradually mix with the overlying air in the room).

The generation of a uniform concentration of vapour in air throughout the room is unlikely because of the density difference and the requirements that mixing should be rapid. If the situation did occur, the variation of vapour concentration with time is shown in Fig.1 which is based on equations (i) and (ii). With rapid mixing the maximum volume of petrol that could be spilled, without a flammable mixture being formed, would be about 0.6 gallons (with no ventilation a concentration of 4.1 per cent would be obtained after 0.26 hours, the concentration would then remain at this value indefinitely).

With partial mixing a sufficiently large pocket of vapour/air/might be produced which could cause structural explosion damage. Hence there may be a need for explosion venting. Substantial clearance of such a pocket could be expected within the time scale for clearance in Fig.1, i.e. within 0.8 hour of the initial spillage. The probability of the formation of a hazardous pocket would need to be estimated by direct test.

Other flammable liquids, such as solvents, should not present any greater hazard than petrol. With L.P. gas and aerosols, released by rapid leakage of the valve the mixing with air may be more efficient than with the evaporation of petrol in still air, but the rate of leakage is less than with petrol and the total quantity of gas is not likely to exceed 1.5 lb (12 ft^3), see Section 4. If rapid mixing with the air in the room takes place the maximum weight of L.P. gas that could be discharged into a room without a flammable mixture being obtained would be about 5 lb for rapid release, and larger amounts for slow release. The time required to clear the L.P. gas after release has finished would be similar to that for the same weight of petrol.

9.2. Bedroom

Floor area was 135 ft^2, volume was approximately 1000 ft^3. The procedure for ventilation is the same as that for the living room. Because of the smaller volume of the bedroom, the maximum spillage that could occur without generating flammable mixtures in a rapidly mixed room would be reduced proportionately. In the same way, the maximum concentration developed on spilling 2 gallons of petrol would be increased proportionately.

9.3. Kitchen

Floor area was 96 ft^2, volume was approximately 750 ft^3. As both light and heavy gases and vapours are involved, the ventilation should be at two levels. A floor level extract grille to take two air changes per hour to remove heavy vapours, and either a ceiling level grille to take two air changes per hour or, alternatively, an extraction hood over the gas cooker. For a gas leakage rate of 120 ft^3 per hour, the extraction rate should ideally be 2400 ft^3 per hour. If this rate would cause discomfort it could be reduced to 1200 ft^3 per hour (see Section 6) which would give a total extraction rate from the kitchen of under four air changes per hour. With an efficient extraction hood little gas should fail to be collected by it even if the atmosphere in the room is rapidly stirred. The risk of a Town gas explosion in the kitchen, sufficient to cause serious structural damage, would be negligible. For vapours and gases heavier than air the procedure is similar to that for the living room and bedroom. The volume of the kitchen is smaller than these rooms but the extraction rates are higher. The spillage of two gallons of petrol would give a maximum vapour concentration of about 5.6 per cent after 0.26 hours, see Fig.1, but the subsequent rate of clearance would be faster than in the larger rooms, for rapid stirring conditions. (With no ventilation a Town gas concentration of 16 per cent would be obtained after 1 hour, rising steadily. Two gallons of petrol would form a 9 per cent concentration approximately).

9.4. Hall

Floor area was approximately 46 ft^2, room volume approximately 300 ft^3. The possible sources of flammable gas are a leak of Town gas from the gas meter cupboard and leakage of heavy vapours from the store cupboard. Any Town gas leak is likely to be small, e.g. a pipe joint, and hence a ceiling level grille extracting one change per hour should be adequate. For heavy vapours the extraction of one air change per hour at floor level within the store cupboard would be reasonable if the front door is an explosion vent*

Consideration should be given to dividing the hot water/gas meter cupboard so that two parts do not communicate. At present any gas leak would tend to be retained within the upper part of the cupboard, which contains an immersion heater which could spark when the thermostat operated. A better arrangement would be for the meter cupboard to be separate from the hot water tank cupboard.

9.5. Bathroom/toilet

This room was generously ventilated, about six air changes per hour and the release of flammable vapours in it would be unlikely. No change would be necessary.

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*If not, 2 changes (600 ft^3) per hour at floor level may be advisable, possibly from store cupboard with airbrick connecting to hall.

10. COMMENTS ON THE ABOVE

10.1. Provision of mechanical extract ventilation in the principal rooms of high flats could give substantial protection against a formation of explosive gas or vapour mixture able to cause severe structural damage. Careful design of the extract ventilation could ensure that the risk of a serious Town gas explosion would be minimal, even for a leak of the size which cause the severe damage at Ronan Point. With other gases, and with flammable liquids such as petrol, several pounds would need to be discharged rapidly before a serious risk to the structure developed. The chances of this occurring with domestic L.P. gas containers would be small.

10.2. Slow leaks, such as at pipe joints or gas bottle and aerosol valves, evaporation of liquids in open cans, would not be able over long periods to accumulate flammable volumes which could endanger the structure of the buildings. Slow leaks are particularly hazardous during the night time, and when buildings are unoccupied.

10.3. Mechanical ventilation could be arranged so that escape of gas or vapour in one room did not flow into another room. Flammable mixtures in two rooms are liable to give violent explosions if ignited.

10.4. Under the worst conditions with a large spillage of flammable liquid an explosion could occur. Explosion relief venting would then be needed to prevent damage to the structure. The likelihood of the hazardous conditions arising cannot be predicted accurately, and some tests on gas flow patterns in rooms would be useful.

10.5. Alternatively, some limitation might be considered on the volume of flammable liquid that should be permitted in a single container in a high flat.

10.6. The proposed mechanical ventilation should not cause discomfort to the occupants of a flat.

10.7. In the case of Ronan Point, the mechanical ventilation would need to be increased to about five times its present value and distributed between the principle rooms as indicated.

10.8. The levels of ventilation proposed are sufficient to ensure that if flammable gas or vapour is drawn off by one ventilator it would have been safely diluted with air before entering the common duct.

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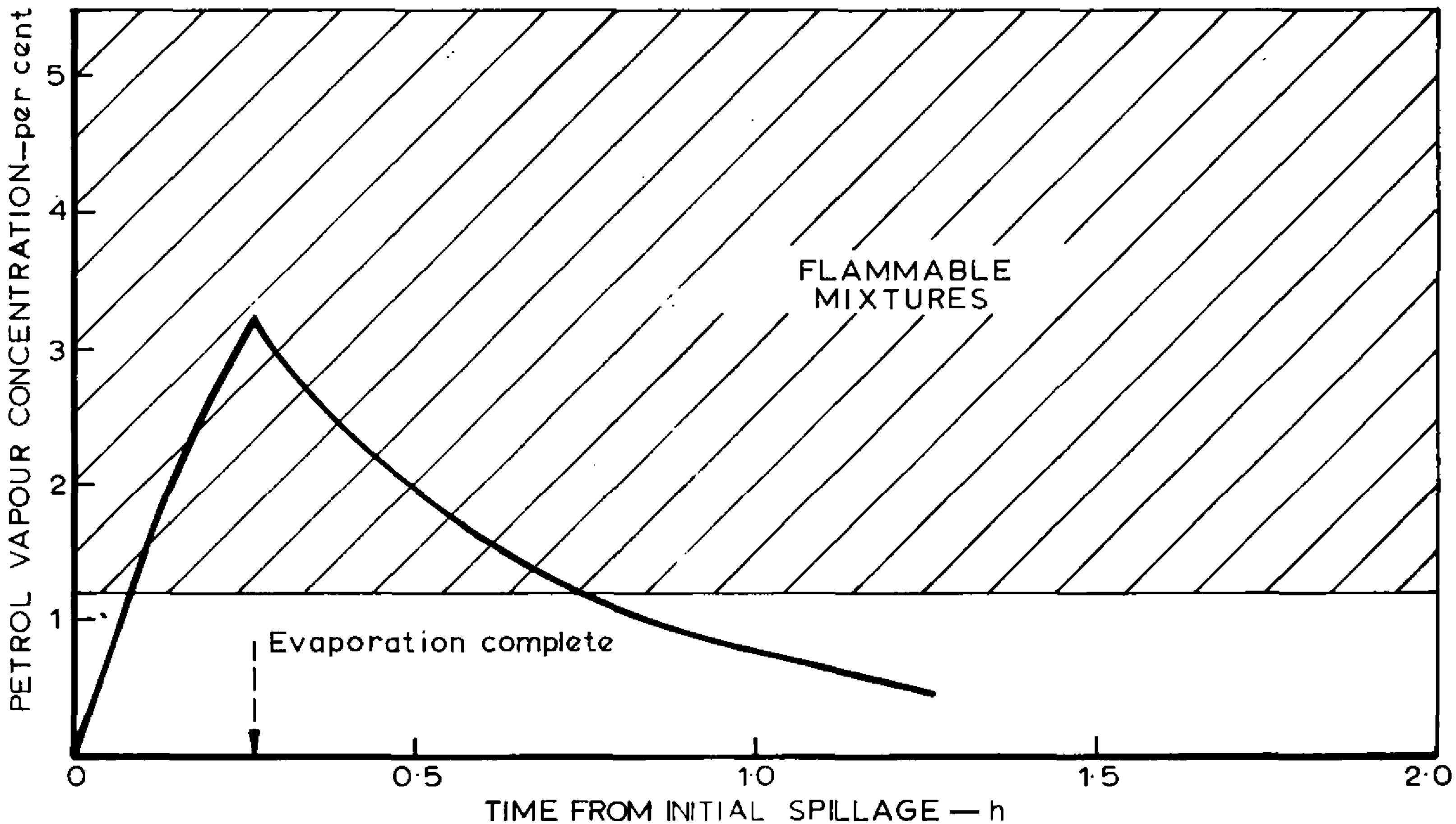

Room volume 1600 ft^3

2 air changes per hour

Complete mixing of atmosphere

FIG. 1. SPILLAGE OF 2 GALLONS OF PETROL IN MECHANICALLY VENTILATED ROOM