7435

International Conference on

Fan Design & Applications

Guildford, England: September 7-9, 1982

PAPER D2

PUBLIC TRANSPORT GARAGE (PARKING AREA) VENTILATION

I. J. Cockram and J. F. Bearman

London Transport Executive, U. K.

Summary

After numerous tests and experiments on the best way to overcome the problems associated with Bus Garage Ventilation, a simple solution was arrived at - being the most effective and economic.

Organised and sponsored by
BHRA Fluid Engineering, Cranfield, Bedford MK43 0AJ, England.

0263 - 421X/82/01 00 - 0001 $5.00
The entire volume can be purchased from
BHRA Fluid Engineering for $82.00

Introduction

London Transport has, at this time, 64 operational bus garages with bus allocations ranging from 30 to 170. Some are hole-in-the-wall establishments, while others are barn-like structures. The only thing most have in common is that they are cramped or awkward shapes, being developed from extensions of Horse Bus Stables, Re-constructions of Tram Sheds - either directly or via a Trolley-Bus Conversion, or built on land left over from something else. The parking diagram ..... Figure 1 gives an idea of what is expected, although admittedly it is theory rather than practice; anyway, it is a far cry from some other European transport installations which have a place-for-every-bus and every-bus-has-its-place.

Most of the ex.Tram Sheds had continuous louvres along the roof ridges, but surprisingly the Old Bus Garages had nothing more than an occasional louvred vent and no other ventilation. Limited natural vents were incorporated into the garages built in the late 1920s and early 30s, such as Upton Park, whilst the last new garage built before the war, Gillingham Street Victoria, had mechanical ventilation. This was restricted to the basement parking area and comprised openings in the wall 1m off the floor, with special emphasis on the 'climbing ramp'. The premises involved in the 1936-40 Tram to Trolley Bus conversion retained the louvred roof vents.

The post-war Tram Conversion commenced in 1949 and extended to 1952. The programme included the reconstruction of 7 Tram Depots, 6 Bus Garages, all on the existing sites and 5 Bus Garages on new sites; the last being probably the most spacious and best arranged of all the premises housing the bus fleet. The design of the Parking Area at all these garages was purposely designed to give the longest unsupported spans possible on the site and some approach 61m. By this time Garage Ventilation was considered right from the inception of the design of each garage. Where possible and to keep the Building Services (Mechanical) installations as simple and uncomplicated as practicable - still a fundamental rule; the Garage Configuration was designed so that the entrance arrangements, as well as complying with operational requirements, gave a generous natural airflow through the Parking Area. Where this was not possible,and this applies to nearly all the re-constructions because of site restrictions, ventilating shafts were incorporated. These comprised a structural shaft, with a diaphragm supporting axial flow fan(s), in a position for easy maintenance, picking up just above floor level and discharging above the roof and clear of surrounding premises. The fans were sized to give, in combination, an air movement of $0.28\ ms^{-1}$ through the garage i.e. vertical cross-sectional area x air movement = volume, location being in the back walls at the opposite end to the entrances - which functioned as the main air inlets, occasionally supplemented by wall or roof vents. The object as stated, was to promote a positive air movement in the single direction from the front to the back of the garage - so that as buses nearest the doors left the garage, the atmosphere was cleared progressively towards the rear and the crews of each new bus rank were able to work in 'nearly agreeable' conditions. There was one major exception to this basic formula which will be discussed later. It may be said that after nearly 30 years these arrangements, both natural and fan-assisted versions, worked effectively and there is no record of any dis-enchantment during the whole of this period.

The Trolley Bus Depots converted to diesel buses in the 1959-62 Programme were all generously provided with un-powered roof vents before the conversion and needed no mechanical provision. Bus Garages modernised during the 1960s were also laid out in such a way that it was not considered necessary to provide additional ventilation in the general parking area, although in 3 cases, special arrangements had to be made to ventilate the areas where buses were 'stacked', to wait their turn to be re-fuelled at the 'run-in'.

Environmental Conditions

The early 1970s brought an increasing awareness of the health & safety (small initials at that time) aspects of the work. Following a staff complaint to a Factory Inspector at Sutton Bus Garage, some correspondence ensued, referring to Section 63 of the Factory Act 1961, which culminated in a joint visit (December 1971), during the early morning 'run-out' by the London Transport Executive's Medical Officer, Scientific Adviser, Rolling Stock Department, Building Services and the Factory Inspectorate, who also brought along a H M Chemical Inspector and a mobile laboratory. The result of this was that we were informed that the 'concentrations of the common toxic exhaust constituents, identified and determined were individually below the threshold limit values, when averaged over a 40 hour working week and the total exposure time for the permanent garage staff amounted to only 10-12 hours per week. Measurements were not made of Acrolein or Aldehydes, which were identified as being present in the fumes'.

The Factory Inspector's report stated that it was generally agreed that the 'fumes generated' were offensive, whilst hinting that although they could not strictly be proved to be actionable, it might be a gesture to do something and offered a suggestion as to what that 'something' might be ..... Figure 2 refers.

A similar complaint to the Factory Inspector arose shortly after, at Tottenham Bus Garage and again it was demonstrated that the fumes so generated could not be regarded as having a concentration of toxic constituents, beyond the threshold value.

A new Garage Modernisation Programme was being considered soon after this and in view of the increasing attention being given to Health & Safety (now with capitals), it was decided to install Mechanical Ventilation as a standard provision of Parking Areas, when premises were dealt with.

Defining The Problem

In order that the policy should be implemented in the most effective and economic way, one of the team was asked to approach the problem, which he defined as 'the Build-Up of Toxic Exhaust from Buses, particularly during run-up periods (early morning and afternoon)' from first principles.

It is not proposed to detail his work here, but only to 'summarise' it in Question & Answer form:-

Two questions were asked of the Engineer responsible for the design of power units (i) During the early morning visits, it had been noticed that Buses were stationary for periods of 15 minutes or more (before run-out time) and with their engines running. Was this necessary? or could it be shortened by more disciplined operation? The reply stated that it was necessary, both for engine warming and for replenishing the vehicle air reservoir. (ii) What were the engine speeds? and what was the volume of exhaust gases discharged? We were advised that the engine speeds were 2 minutes at 33.3 revs. s^{-1} and 13 minutes at 6.6 revs. s^{-1}, with an engine swept volume of 12 litres. The mean volume of exhaust gas for each engine was calculated to be 0.061 $m^3 s^{-1}$ for the 15 minute period.

$$\text{i.e.} \left[2 \left[12 \times \frac{33.3}{2} \right] + 13 \left[12 \times \frac{6.6}{2} \right] \right] \div 15 \times 10^3$$

These figures would obviously differ for other capacity engines.

The Scientific Adviser was asked to give the constituents of exhaust gas and the Senior Medical Officer (Environmental) to give the threshold values of these constituents. The combined answers being as set out in the following Table:-

Constituent	ppm. in Undiluted Exhaust	ppm. Dilution required	Dilution Volume m^3s^{-1}
CO	1000	100	0.613
CO_2	90000	5000	1.1
Aldehydes	20	5	0.245
Formaldehydes	11	5	0.134
Oxides of N_2	400	5	4.9
SO_2	200	10	1.23
Water Vapour	remainder	-	-

Oxides of Nitrogen and the Aldehydes are the Constituents which cause smoke and irritation.

Acrolein - forms part of the Aldehydes (it is stated to be the simplest of the unsaturated Aldehydes). It is a colourless liquid having a boiling point of 52.4°C, with a disagreeable 'tear exciting' odour. Tail pipe gas temperature 32-38°C.

From the above it can be seen that a replacement volume of 4.9 m^3s^{-1} i.e. $(0.061 \times \frac{400}{5})$ per engine, will prevent any of the toxic elements in the exhaust, reaching a threshold value. This figure was then applied to the 'run-out' requirements in each case.

To determine the dilution volume for a particular garage, the maximum hourly scheduled 'run-out' is obtained from the Bus Operating Department; this figure is then divided by 4 so as to give the maximum number of vehicles, which will be standing with their engines running at any given moment. The result multiplied by 4.9 will then give the optimum dilution rate and therefore the required fan capacity in m^3s^{-1}.

It will be noted that neither the physical size nor indeed the bus capacity of the garage is of any consequence, since there is just as likely to be a more intense 'run-out' from a small garage as from a large one - this is where the calculation differs from the usually accepted air change procedure.

Having now arrived at a dilution rate, how is it achieved and what are the ways and means?

In association with the calculations, some experiments were conducted to see what happens to 'exhaust' after it leaves the bus tail pipe ..... Figures 3 & 4 refer. Observations were made at a number of garages - it was considered essential that to get the 'feel' of the operation, the Design Engineer should attend before the start of the 'run-out' and observe the whole procedure.

From the experiments it was deduced that the chief force affecting the gases was 'buoyancy', which takes effect as the tail pipe velocity decays. By installing a fan in an inspection pit and forming an 'adjustable-slot' at garage floor level, attempts were made to determine if there was a 'practicable pick-up velocity', to capture the fumes in underfloor ducts - thus avoiding them passing through the 'breathing zone'. Inlet velocities of up to 10.16 ms^{-1} were tried, but in each case the bulk of the discharge escaped collection.

To assess the suitability of natural roof ventilators, two louvres were installed at Hounslow Bus Garage in northlight glazing. As in earlier experiments, 'smoke' was introduced into the exhaust gas in order to observe and photographically record the movements. Vehicles were positioned in locations which allowed for the 'throw' of the exhaust into the ventilated bays. Despite a number of tests with varying combinations of one and two engines running, engines idling or accelerated and with increasing volumes of 'smoke', at no time was 'smoke' issuing from the vents in sufficient quantity to enable photographs to be taken; visually it was just possible to discern a faint 'whisp' from the upper part of the ventilators. A limited amount of extraction took place, but unfortunately the lower part acted as a fresh air inlet and effectively cooled the rising exhaust gases, thereby depressing same.

The tests were carried out in late June 1973, in warm weather - 21/24^{o}C, with a fresh breeze blowing across the face of the ventilators. It is unlikely that there would have been an improvement in cooler weather and with adverse wind conditions no extraction at all could have been expected. It was therefore concluded that natural ventilators alone as such, were unsuitable for diesel fume extraction - but used in conjunction with mechanical units and judiciously located, could be employed as fresh air inlets.

From the results of this work, it was decided that the basic design of Parking Area Ventilation should be by 'roof extraction' to boost the 'buoyancy' effect and the volume related to the dilution rate required by the bus 'run-out' intensity. There should be air inlets - carefully placed to avoid short circuiting and to get an air movement into 'dead' corners or areas.

Installation

The first installation to be carried out using these principles was at Peckham Bus Garage .....Figure 5 refers and this has been the prototype for subsequent installations.

Peckham was a new garage built on an existing site during the 1950/51 period, having an allocation of 140 vehicles; major inspections and overhauls being undertaken additionally. It has a single span roof of concrete barrel vault construction with 47 circular ventilators incorporated. The bus 'run-out' was a maximum of 48 per hour, or 12 with engines running for the 15 minute warm up. The fan extraction to give dilution was 61.5 $m^3 s^{-1}$. Twelve 0.914 m diameter propeller fans, each of 5.19 $m^3 s^{-1}$ in glass fibre reinforced polyester housings were selected and these ran at 9.5 revs.s^{-1} with a sound level of 66 dBA.

The fans are controlled from a panel located in the Night Foreman's Office and are started in 'groups' to avoid overloading the electrical supply and at predetermined times - being switched off automatically. Whilst there is provision for manual selection and for operation out of the 'set' time periods, this is only for emergency use by the operation of a keyed switch. The automatic starting and running sequence is we find important, as it frees the supervisory staff from an additional responsibility, it also covers the change in 'shift' which occurs at the morning 'run-out' period.

The installation went into service in August 1973 and the series of photographs ..... Figures 6 & 7 refer, show the effectiveness, during a morning 'run-out' - in early 1974. The results were generally satisfactory.

As the full effect of the Health & Safety At Work legislation has resulted in a demand for better working conditions all round, a 3-year programme to provide Parking Area Ventilation was authorised on a similar basis for all garages. The 63rd installation (totalling 922 fans) has recently been completed.

The number of fans, their positions, rating and sound levels is specified in each case. Where applicable, consideration is given to the location and effect of the smoke partitioning - which is required to give a maximum of 3700 m^3 of unsegregated roof space. Equally, if the fans can be incorporated in the smoke ventilation schemes now being demanded, then this is done if there is no prejudice to the fume exhaust function, otherwise smoke actuated vents are installed.

The number of stages in the fan starting sequence is selected so that the maximum current does not exceed 100 amps., thus saving installation costs and cable sizes.

This is usually achieved by pre-set pneumatic switches, but one series of panels has the motor driven 'cam' type. Operationally there is little difference, although for a larger number of stages, the motor driven units can be accommodated in a smaller space - with the corresponding reduction in cubicle size.

A number of fan manufacturers were considered having regard to performance, weight, sound levsls, cost and their inclination to undertake the installation work. The fans installed are of two main types produced by three manufacturers - 55% being of the aluminium vertical discharge type and 45% of the glass fibre cowl type. The most desirable size being 710 mm running at 14.3 revs.s^{-1} with an extract rate of 3.8 m^3s^{-1} at Free Air and 63 dBA at 3 m. All are fitted with safety cages beneath and designed for maintenance from inside (due in the main to roof conditions); the vertical discharge models have weathering flaps. Noise limits have generally been restricted to a maximum of 66 dBA at 3 m. However, where residential buildings are close to the site, this limit is reduced to 61 dBA so as to avoid 'arousing' the neighbours too early in the morning!

The three years of experience we have had with this type of installation, has highlighted the difficulties. These are mainly related to those fans fitted with non-return flaps, in that the flaps jam with packed snow and the flap bearings ice-up during winter. Additionally, the flaps generally jam with dirt. Fans of all types have suffered from the safety cages clogging with dirt - this can obviously only be overcome by regular cleaning.

A New Look At Underfloor Extraction

Sometime after the tests described earlier, proposals for Bus Stations were being considered, especially a new garage in the basement of a development, which has a bus station and a bus terminal working within it as a combined unit. Consideration was again given to the use of underground extract points, or even the use of low 'bollards' opposite bus stands.

The one exception to the 1949/52 Bus Garage Programme mentioned at the beginning, was Loughton - this is at the extreme north-eastern corner of the Executive's area of operations, on the edge of Epping Forest. It was built on a new sloping site, so that the Parking Area floor is a 'raft' raised on stilts, allowing the economic installation of a large underfloor horizontal airway, with grilles in the floor of the garage along the rear wall. A single centrifugal fan rated at 26.5 m^3s^{-1} extracts from this airway. Because development in the area has not been as vigorous as was originally envisaged, the garage capacity was found to be excessive. Part of the covered Parking Area has therefore been let - with the result that half the underfloor duct is sealed-off and 5 grilles serve the operational area. Tests showed that the total volume extracted through the grilles is 16.08 m^3s^{-1} at a face velocity of 5.08 ms^{-1} ..... Figures 8 & 9 refer, (which is approximately one eighth of the exhaust pipe terminal velocity).

The diagram ..... Figure 10 refers, shows the results of tests, carried out with a bus at varying distances from a grille. It will be noted that the overall 'extraction' is reasonably good, due to the grille being adjacent to the end wall and any fumes missing 'direct pick-up' at the grille are ultimately extracted through a general air movement - the photographs illustrate this quite well. It is considered that if the grilles were in the centre of the Parking Area, the fumes would pass through the 'breathing zone' twice - this effect is obviously worse than the high level extraction position, where only one 'pass' is made.

The installation is only effective very close to the grilles because of the very high volumes passing through them, giving a correspondingly high pick-up velocity. Volumes on this scale could not be provided at the required 'pitch' in a garage without introducing prohibitively high quantities of fresh air and the use of excessive fan power, as well as the adoption of fixed parking positions for buses.

It was considered that the results of an installation of this arrangement would not justify the high capital and running costs involved. We have however, still not given up and are seriously considering the use of low profile 'powered bollards' in Bus Stations, where the bus standing position is fixed by the queue pens.

Summary

Generally the recommendations are:-

1. Study the way the garage is operated at first hand, or if a new site, study similar premises already in operation.

2. Decide what effect can be achieved by locating the entrances & openings, in relation to the prevailing winds etc.

3. Determine the chemical, medical and engineering criteria.

4. Design for simplicity.

The fume exhaust extraction systems described, apply to the Executive's standard unheated parking areas. A heated parking area would present a different problem bearing in mind the need for energy conservation.

Having said all this, let us take another look at the Factory Inspector's proposal for Sutton ..... Figure 2 refers. Should buses discharge their exhaust at ground level? Perhaps this is another legacy from the horse buses! Although there are problems associated with the extension of the exhaust pipe to discharge at roof level, insulation, access, height clearance and the possibility of bodywork/window 'streaking', the difficulties are not insuperable. Our Bus Engineers have not therefore entirely rejected the suggestion for the next generation vehicle.

Acknowledgements

The authors wish to thank the London Transport Executive for permission to publish this paper.

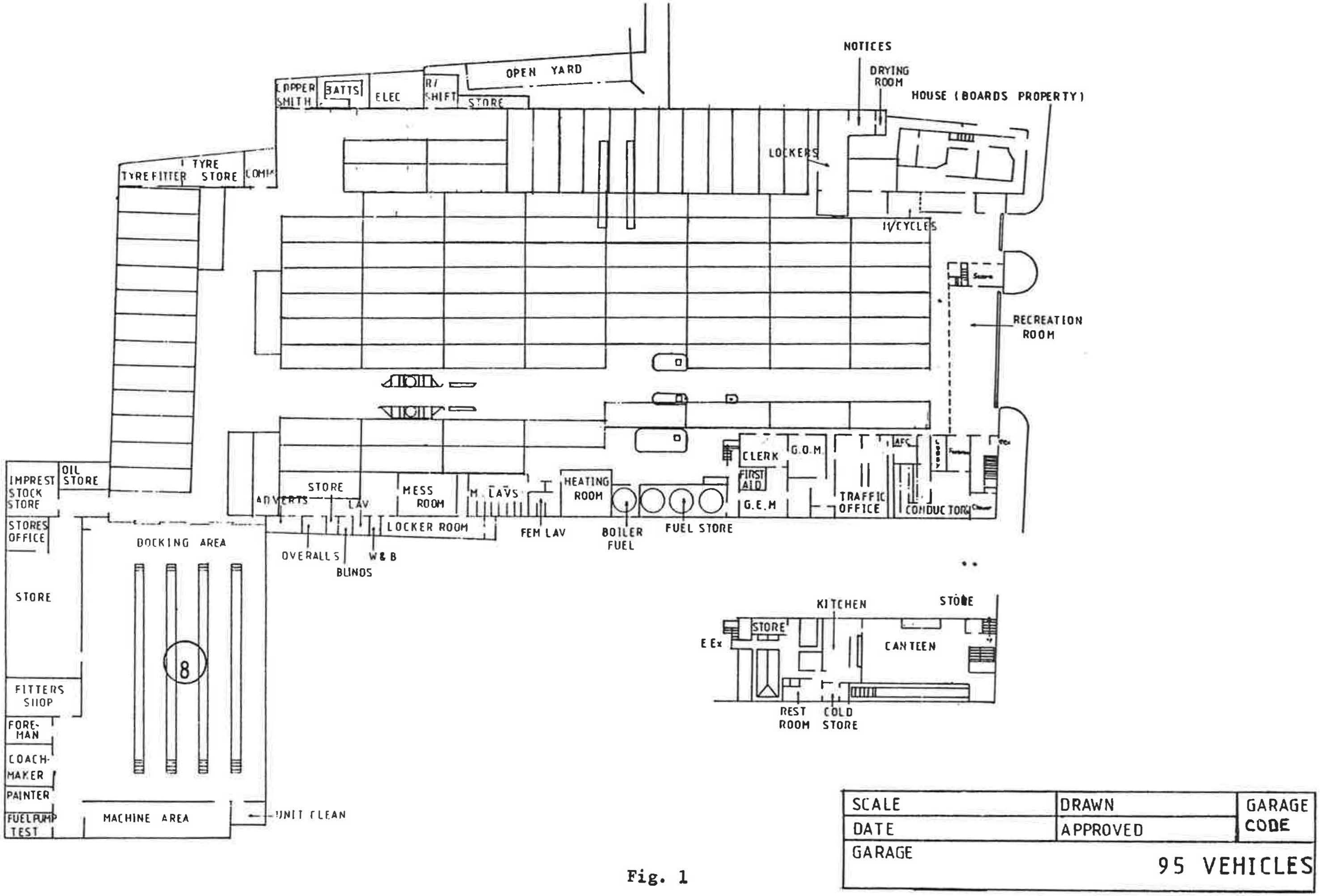
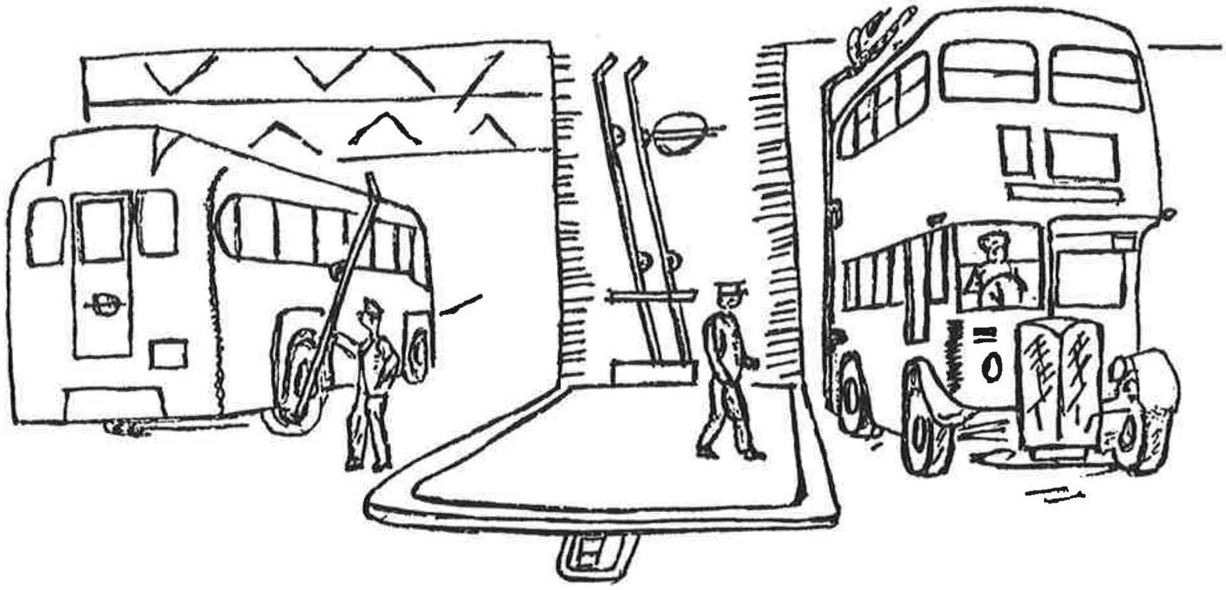

OPEN YARD
NOTICES
DRYING ROOM
HOUSE (BOARDS PROPERTY)
COPPER SMITH
BATTS
ELEC
R/ SHIFT
STORE
LOCKERS
TYRE FITTER
TYRE STORE
COMM
I/CYCLES
RECREATION ROOM
OIL STORE
IMPREST STOCK STORE
STORES OFFICE
STORE
FITTERS SHOP
FORE-MAN
COACH-MAKER
PAINTER
FUEL PUMP TEST
DOCKING AREA
8
MACHINE AREA
UNIT CLEAN
ADVERTS
STORE
LAV
MESS ROOM
M. LAVS
LOCKER ROOM
OVERALLS
BLINDS
W & B
HEATING ROOM
FEM LAV
BOILER FUEL
FUEL STORE
CLERK
G.O.M.
FIRST AID
G.E.M
TRAFFIC OFFICE
CONDUCTORS
KITCHEN
STORE
E Ex
STORE
CANTEEN
REST ROOM
COLD STORE
SCALE
DRAWN
GARAGE CODE
DATE
APPROVED
GARAGE
95 VEHICLES

Fig. 1



1. Detachable exhaust extensions attached on entry to garage with suction pads or magnets.

2. Roof bay partitioned to act as collection hoods.

3. Roof fans.

Fig. 2

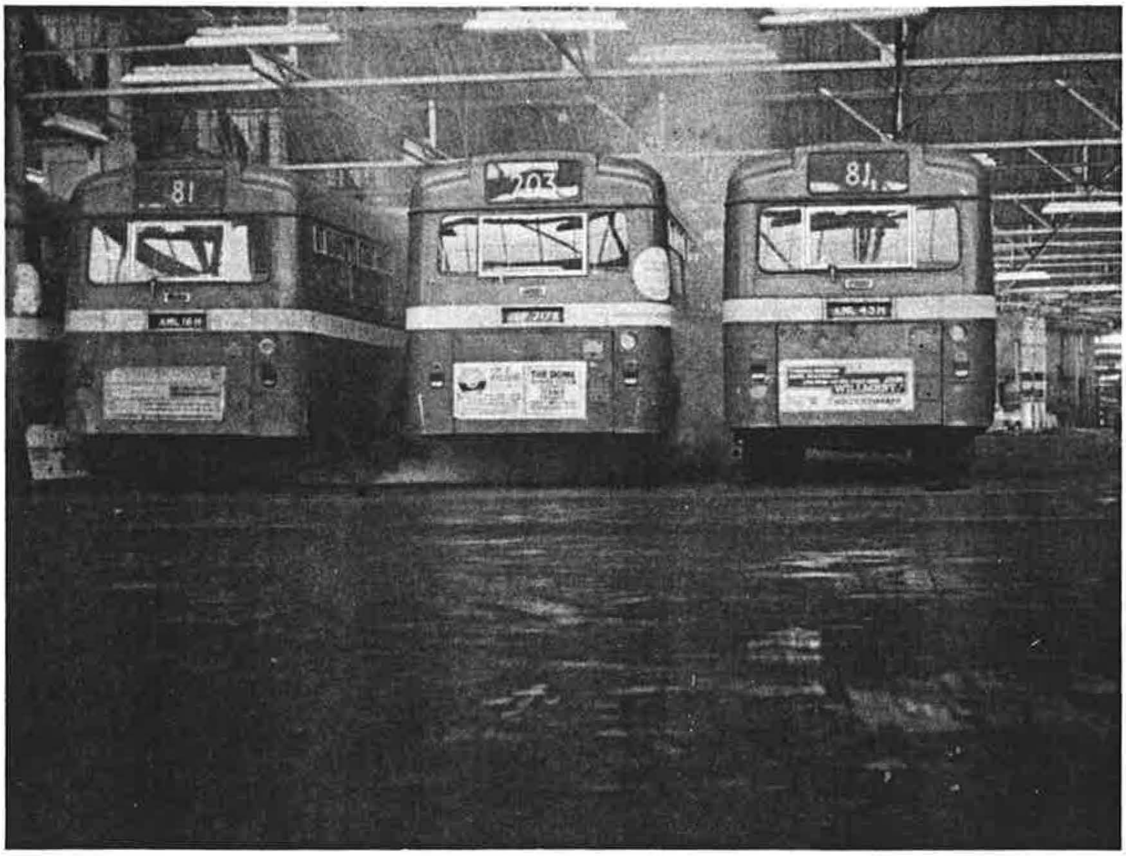


Fig. 3 Hounslow - chimney effect

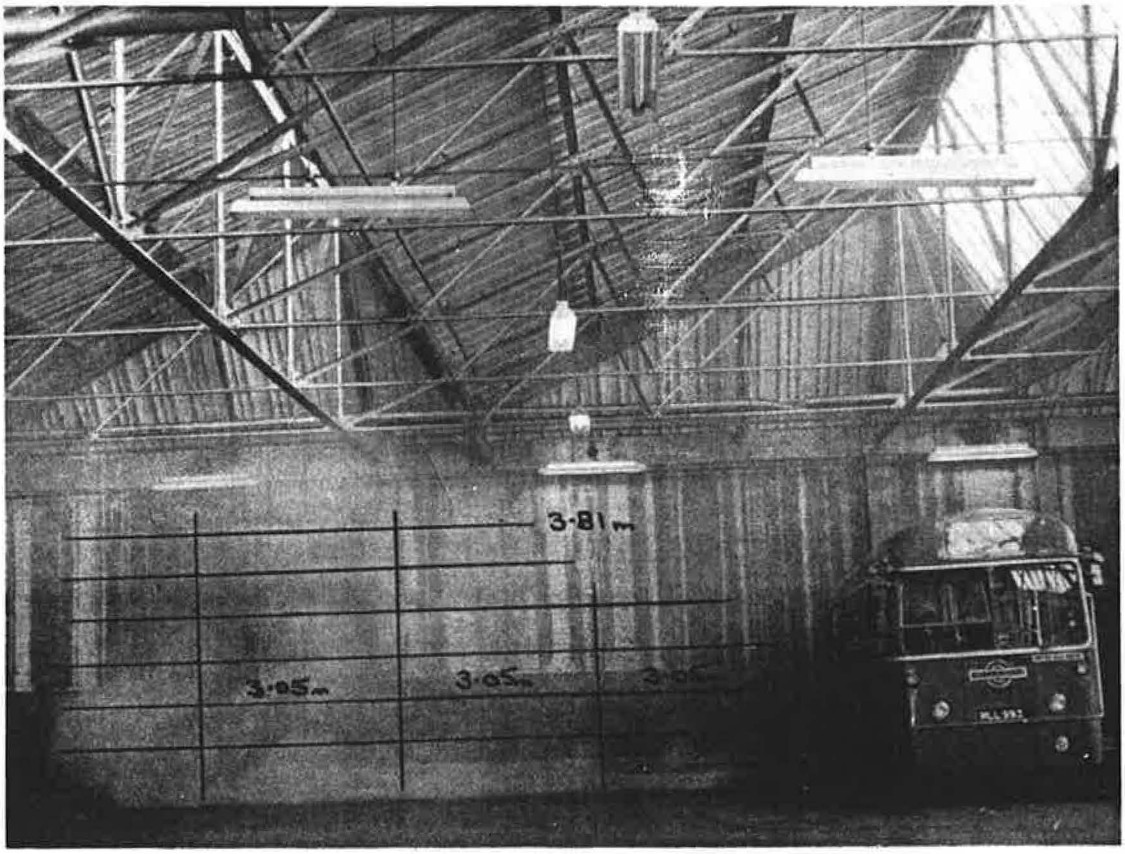


Fig. 4 Hounslow

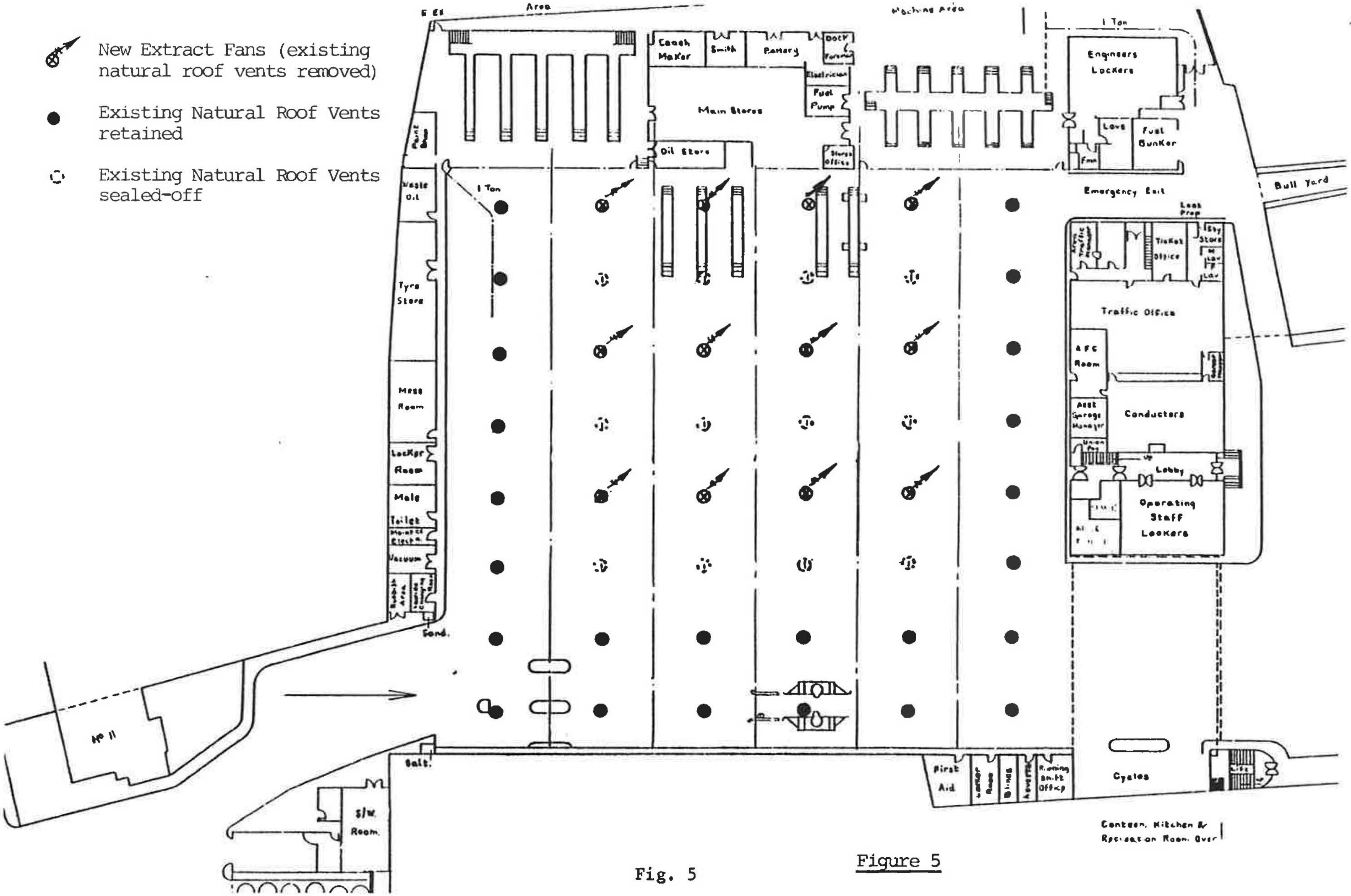


Fig. 5

Figure 5

Fig. 6 Peckham garage - parking area - new ventilation scheme

Fig. 7

Fig. 8 Loughton
All grilles open
Bus at 20ft (6m)
Running: tickover
Grille vel. 1200ft/min

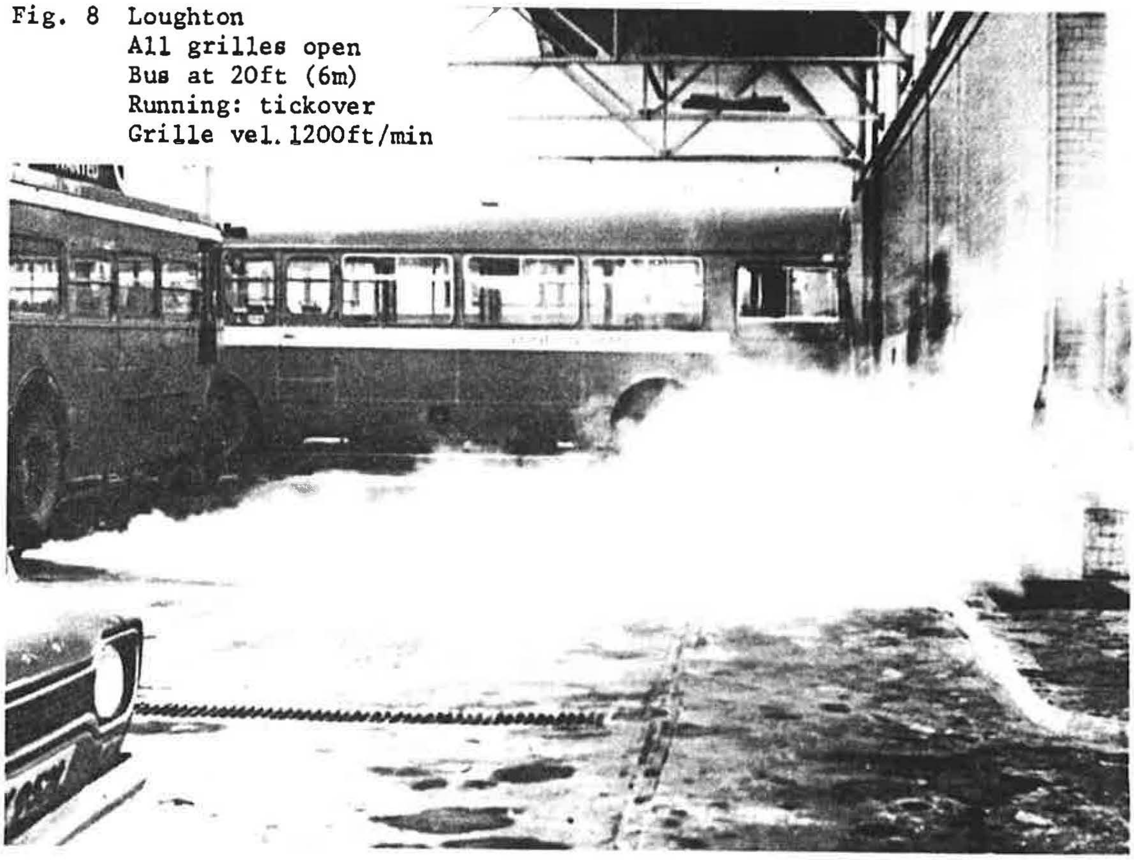
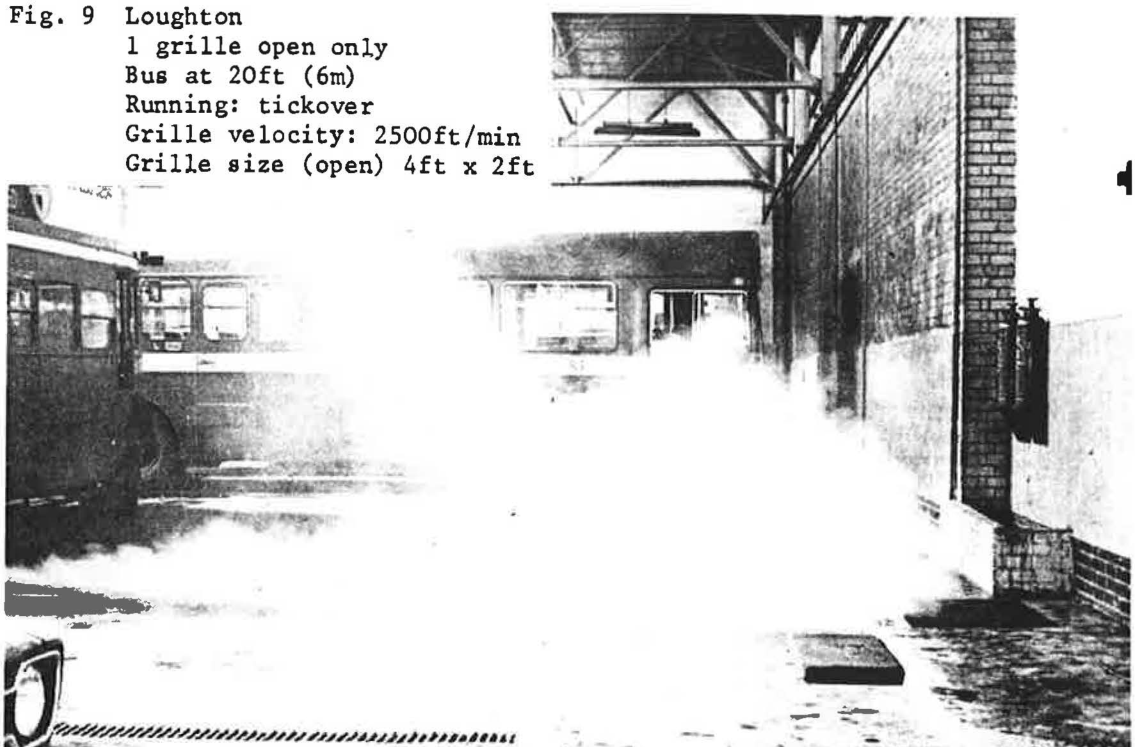
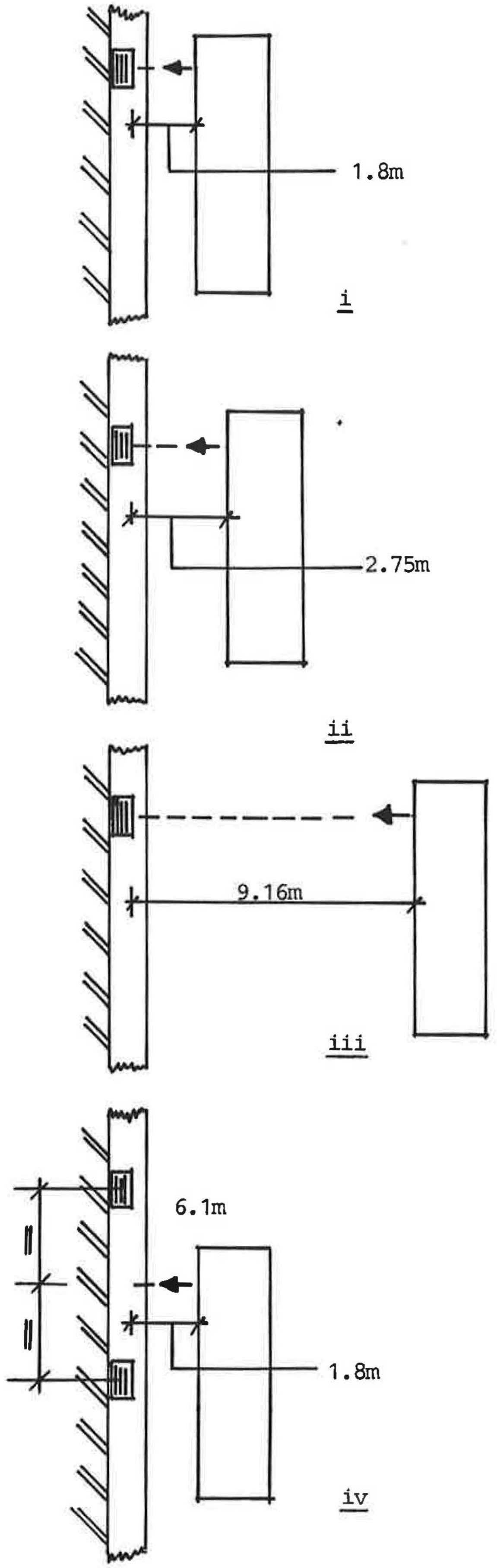
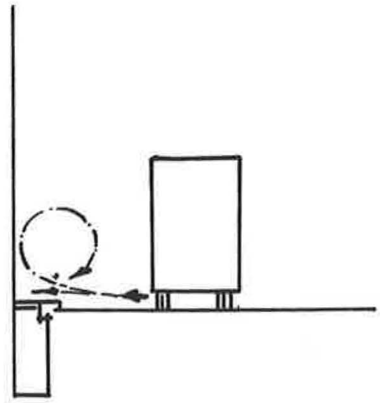


Fig. 9 Loughton
1 grille open only
Bus at 20ft (6m)
Running: tickover
Grille velocity: 2500ft/min
Grille size (open) 4ft x 2ft







Typical Cross-Section

Reference	Effective Pick-up %
i	100
ii	60-75
iii	10
iv	0

Fig. 10 Underfloor parking area ventilation - test positions of buses