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Ventilated Pit Latrines: Vent Pipe Design Guidelines

by Beverley Ryan and D. Duncan Mara

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United Nations Development Programme
Interregional Project INT/81/047
Executing Agency: World Bank

Ventilated Improved Pit Latrines: Vent Pipe Design Guidelines

by Beverley A. Ryan (Consultant), and
D. Duncan Mara,
Technology Advisory Group (TAG)



A joint United Nations Development Programme
and World Bank Contribution to the International
Drinking Water Supply and Sanitation Decade

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PREFACE

This Technical Note by Beverley A. Ryan, and D. Duncan Mara sets out preliminary guidelines for the design of vent pipes for ventilated improved pit (VIP) latrines. These guidelines are based on extensive fieldwork, done in Botswana and Zimbabwe in 1981/2, which showed that the local wind speed and direction were the major factors responsible for inducing updraught in the vent pipe; thermally induced updraught was found to be of only minor importance.

The paper is one of a series of informal Technical Notes prepared by TAG^{1/} on various aspects of water supply and sanitation programs in developing countries. The papers were originally prepared as internal discussion documents; their wider distribution does not imply endorsement by the sector agencies, government, or donor agencies concerned with the programs, not by the World Bank or the United Nations Development programme. Comments and suggestions on the papers should be addressed to the Project Manager, UNDP Project INT/81/047, Water Supply and Urban Department, the World Bank, 1818 H Street, NW, Washington, DC, 20433.

Richard N. Middleton
Project Manager

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^{1/} TAG: Technology Advisory Group established under the United Nations Development Programme Global Project GLO/78/006 (renumbered on January 1, 1982; now UNDP Interregional Project INT/81/047), executed by the World Bank.

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SUMMARY

These guidelines are based on extensive fieldwork, done in Botswana and Zimbabwe in 1981/82, which showed that the local wind speed and direction were the major factors responsible for inducing updraught in the vent pipe; thermally induced updraught was found to be of only minor importance.

These studies suggest that satisfactory odor control is achieved with a ventilation rate of 10 m³/h; minimum vent pipe sizes to achieve this are 100 mm diameter for AC or PVC pipes, 200 mm diameter for rural vent pipes made from cement-rendered reeds, bamboos or similar materials, and 180 mm square for brickwork. For permanent installations, especially in congested urban areas where latrines may need to be placed very close to living quarters, or in areas where mean wind speeds may fall below 0.5 m/s, and where minimizing cost is not an overriding consideration, adoption of a ventilation rate of 20 m³/h will provide a greater factor of safety; corresponding vent pipe sizes will be 150 mm for AC or PVC pipes, 200 mm for rural vent pipes, and 230 mm square for brickwork. In all cases the vent pipe should extend 500 mm above the highest part of the roof (or, in the case of conically shaped thatched roofs, to the level of the roof apex); expanded sections at the top of the vent pipe are unnecessary. Openings in the latrine superstructure (e.g., doors) should face into the direction of the prevailing wind in order to maximize ventilation rates. The fly-screen at the top of the vent pipe should have apertures no greater than 1.2 mm x 1.5 mm in order to prevent the ingress and egress of insects.

Recommendations are given for methods of fixing (a) the vent pipe to the superstructure and cover slab; and (b) the fly screen to the vent pipe, and for squat-hole and pedestal seat covers (which do not impede the air flow) and mosquito traps.

INTRODUCTION

1. Research by the World Bank^{1/} has shown that ventilated improved pit (VIP) latrines can provide most of the health and convenience benefits of conventional waterborne sewerage but at a fraction of its costs. There are various designs of VIP latrines (Figures 1-3) but they all differ from traditional pit latrines in having a vertical vent pipe which has a fly screen at its top and which leads directly from the pit beneath. The vent pipe generates a strong updraft and so maintains a flow of air down through the squatting plate. The effect of this air flow is to minimize odors in the superstructure and to discourage breeding of insects (flies and mosquitoes) in the pit. Most flies approaching a latrine will be attracted to the top of the vent pipe by the fecal odors being discharged there, but the fly screen prevents them entering the pit. Moreover, provided the superstructure is kept reasonably dark, any flies that hatch in the pit are attracted to the daylight at the top of the vent pipe but are prevented from leaving by the fly screen; they eventually fall back into the pit and die.

2. Systematic application of the principles of VIP latrines has so far been limited to a few countries, notably Zimbabwe, Botswana, Ghana, Tanzania and Lesotho. However, it is clear the VIP latrine (and its variant with alternating twin pits) is one of the most appropriate sanitation technologies for a wide variety of conditions in low-income rural and urban communities in many developing countries.

Ventilation mechanisms

3. Proper design of the vent pipe is essential for the correct functioning of VIP latrines. Underdesign will normally cause problems in odor and insect control, and overdesign will increase costs unnecessarily. The purpose of this Technical Note is to give preliminary design guidelines for VIP latrine vent pipes, based on the field experience of members of the Technology Advisory Group (TAG) operating under the United Nations Development Programme Interregional Project INT/81/047 executed by the World Bank. This field experience has included an extensive program of monitoring the ventilation performance of different types of VIP latrines in Zimbabwe and Botswana.^{2/}

1/ J.M. Kalbermatten, D.S. Julius and C.G. Gunnerson, "Appropriate Sanitation Alternatives: A Technical and Economic Appraisal," World Bank Studies in Water Supply and Sanitation, The Johns Hopkins University Press (1982).

2/ B.A. Ryan, D.D. Mara and J.A. Fox, "Ventilation Mechanisms in Ventilated Improved Pit Latrines," Research Report Series, Department of Civil Engineering, University of Leeds, England (forthcoming). The work in Botswana was funded by the United Kingdom Science and Engineering Research Council, and that in Zimbabwe by TAG.

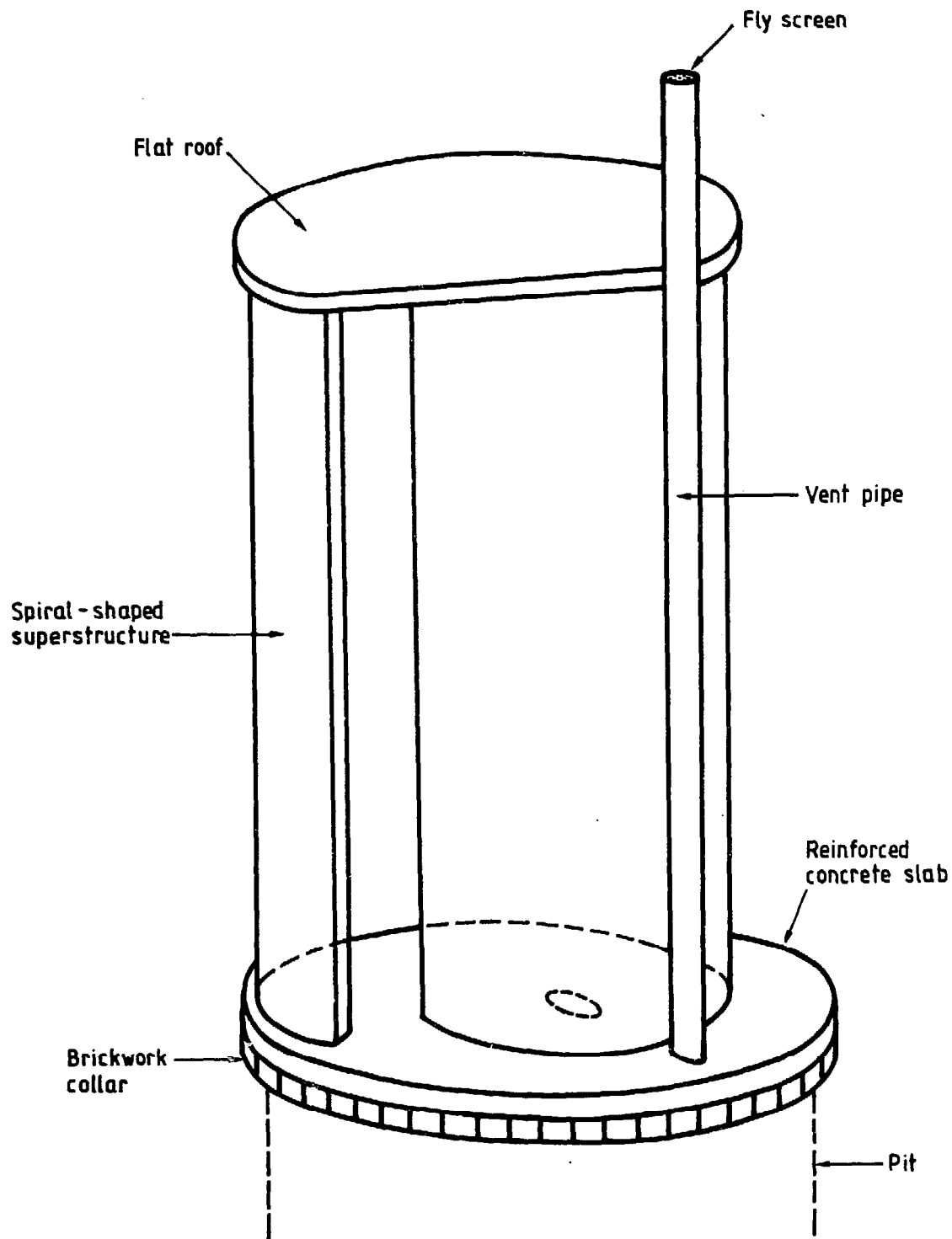


Figure 1. Zimbabwean spiral VIP latrine.

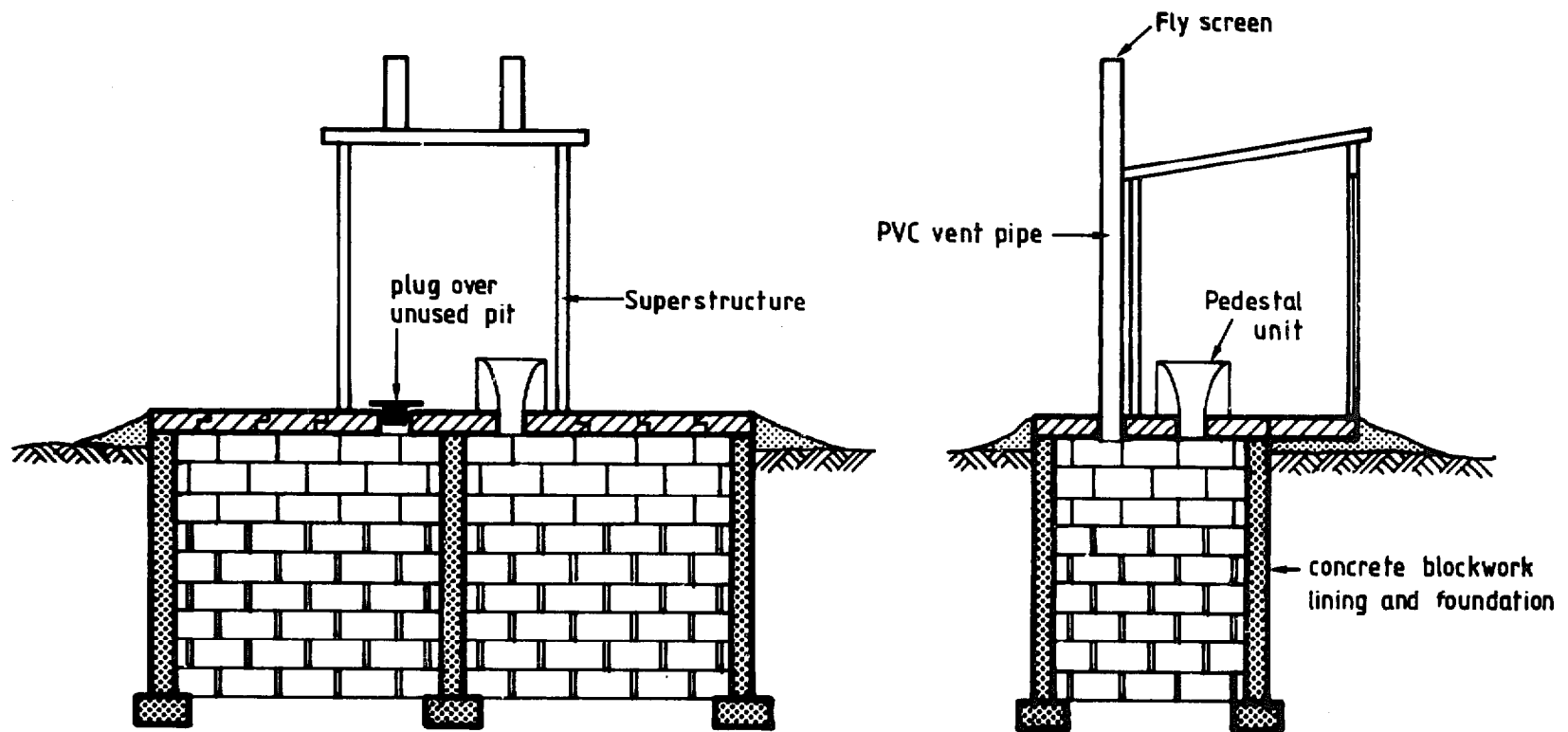
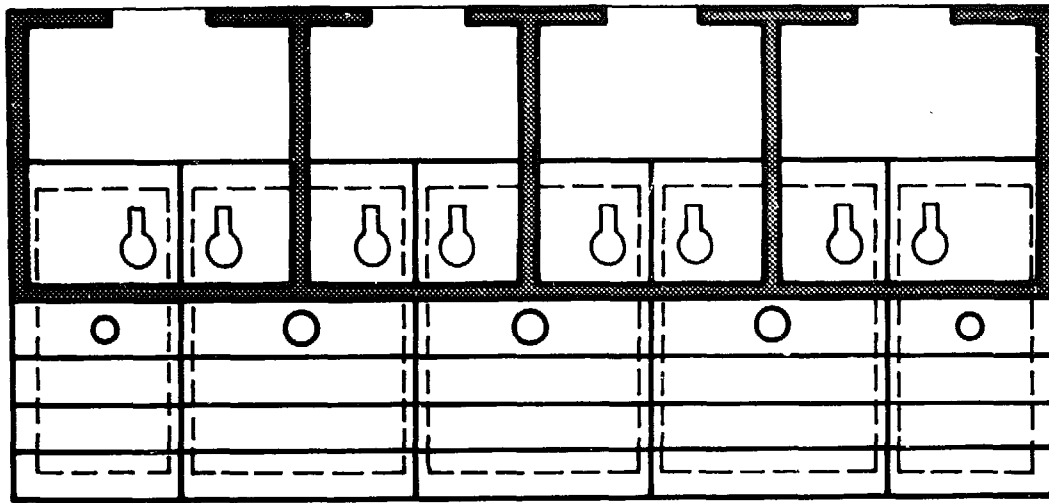
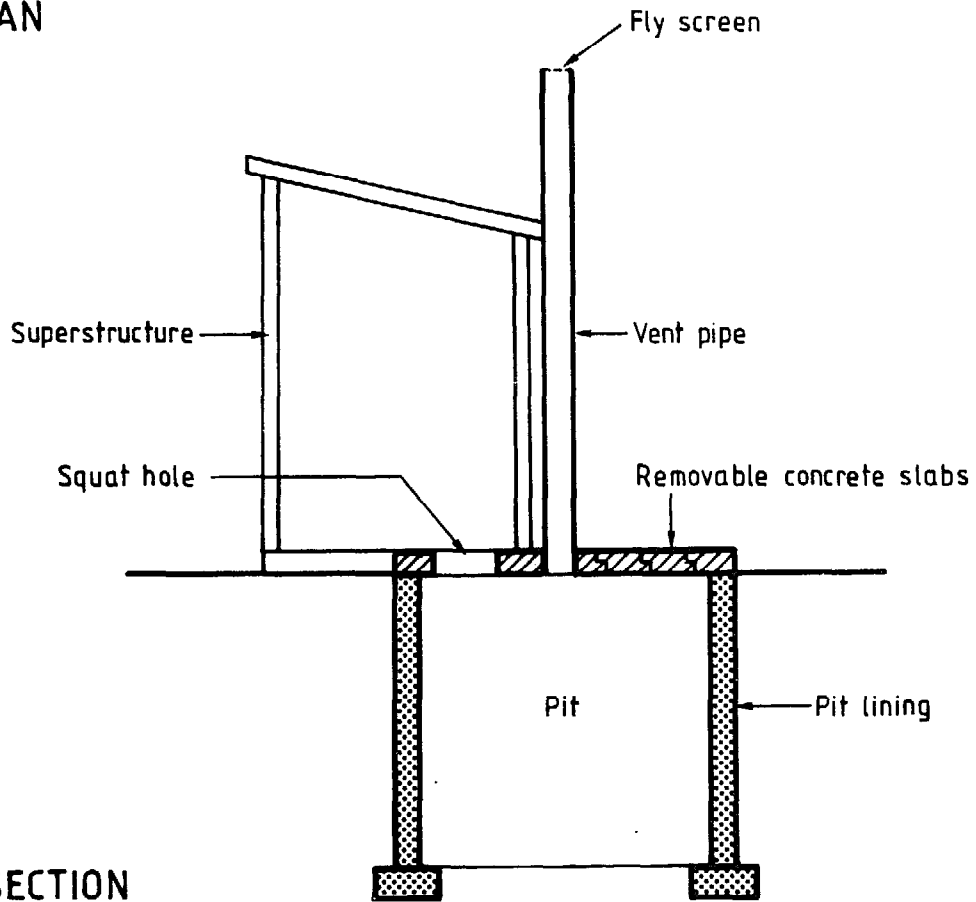


Figure 2. Botswanan alternating twin-pit VIP latrine.



PLAN



SECTION

Figure 3. Ghanaian alternating multiple-pit VIP latrine for communal or institutional use.

4. As a result of this VIP latrine ventilation monitoring program (the methodology of which is described in a separate Note in this series^{3/}), it is now clear that the two most important factors governing the ventilation rate in VIP latrines are the local wind speed and its direction; thermally induced updraught caused by the absorption of solar radiation by the external surface of the vent pipe was found to be of relatively minor importance. The action of the wind as it passes over the top of the vent pipe is to create a suction pressure within the vent pipe; wind speeds of 2 m/s and above, which are not uncommon in developing countries, were found to induce air velocities within the vent pipe ("venting velocities") of at least 0.7 m/s. Venting velocities were found to increase substantially when the latrine superstructure opening faced into the wind: the wind is channelled into the latrine through the openings on the windward side, down through the squat hole and up the vent pipe; venting velocities of 1.2 m/s or more were commonly observed.

VENT PIPE DESIGN

Ventilation rate

5. The vent pipe must be designed so that it can induce sufficient air flow through the latrine to leave the superstructure odor-free. All of the latrines studied in Botswana or Zimbabwe were completely free of fecal odors, although a few of them had a slight odor of ammonia from urine splashed on to the squatting plate. Odorless conditions were associated with vent pipe air flow rates of 10 m³/h and above; this corresponded to approximately 6 changes per hour of the superstructure air volume. This ventilation rate appears, on the basis of the information currently available, to be a reasonable minimum requirement in cases where costs must be kept as low as possible (such as in most rural latrine programs). However, the field studies also show that a flow rate of 20 m³/h, which would provide a good factor of safety for odor control, can be relatively easily achieved, and this higher rate would be a desirable design standard in, for example, urban programs providing permanent (emptiable) latrines located close to living quarters.^{4/}

Pipe materials

A wide variety of different materials has been successfully used to form vent pipes: for example, asbestos cement (AC), polyvinyl chloride (PVC), unplasticized PVC (uPVC), bricks, blockwork, cement-rendered reeds, cement-rendered hessian supported on steel mesh, and even anthill soil; bamboo with the cell dividers removed can also be used. (Methods for the construction of cement rendered reed and hessian pipes and other essentially

^{3/} Beverley A. Ryan and D. Duncan Mara, "Pit Latrine Ventilation: Field Investigation Methodology," Technical Note TAG/TN/04.

^{4/} A ventilation rate of 20 m³/h is also recommended for WC rooms in the United Kingdom ("Ventilation of Internal Bathrooms and WCs in Dwellings", Technical Digest No. 170, Building Research Establishment, Watford, England, 1981).

rural vent pipes are described in Annex I). Whatever material is used, its durability (in particular corrosion resistance), availability, cost and ease of fixing in place are important factors. Thus, vent pipes made, for example, from thin galvanized steel sheet are not recommended as they are prone to corrosion, especially in humid areas. PVC pipes become brittle when exposed to high sunlight intensities, and thus it is better to use PVC pipe made with a special stabilizer to prevent damage by ultra-violet radiation; however, this grade of PVC may not be generally available. Cost is particularly important in rural VIP latrines; for example, the use of a PVC pipe, rather than a cement-rendered reed pipe, more than doubles the cost of a mud and wattle latrine in rural Zimbabwe.^{5/}

External surface preparation

7. In areas where the mean wind speed is less than 0.5 m/s^{6/}, the external surface of the vent pipe should be painted black in order to increase the absorption of solar radiation and thus the magnitude of the thermally-induced venting velocity. In areas where the mean wind speed is above 0.5 m/s the color of the vent pipe is not important.

Vent Pipe Length

8. The vent pipe should be sufficiently long so that the roof does not interfere with the action of the wind across the top of the vent pipe. With flat roofs, the top of the vent pipe should be at least 500 mm higher than the roof, and in the case of sloping roofs the vent pipe should be 500 mm above the highest point of the roof. When the roof is made from thatch and shaped conically, as is common in rural Zimbabwe and Botswana, the vent pipe (which is generally the cement-rendered reed type) should be at least as high as the apex of the roof.

9. It is very important to ensure that the vent pipe is straight and vertical in order to allow as much light as possible to shine down the pipe into the pit and so attract any newly emergent flies up the vent pipe. (Galvanized steel sheet vent pipes with a 90° bend were installed in a humid coastal area in Africa; not only did this effectively prevent fly control, but it also induced severe corrosion at the bend due to moisture accumulation there.)

Vent Pipe Diameter

10. The internal diameter of the vent pipe depends on the required venting velocity necessary to achieve the desired ventilation rate, and this in turn depends on such factors as the internal surface roughness of the pipe and its length (which determine the friction losses), the head loss through

^{5/} P.R. Morgan and D.D. Mara, Ventilated Improved Pit Latrines: Recent Developments in Zimbabwe, World Bank Technical Paper No. 3, Technology Advisory Group, The World Bank, Washington, DC (1982).

^{6/} Wind speed data can be obtained from local meteorological stations (or often from the nearest airstrip).

the fly-screen and squat-hole mosquito trap^{7/}, and the wind direction. Thus cement-rendered reed vent pipes, for example, need to have a much larger diameter than AC or PVC pipes since their internal roughness is considerably greater; brick vent pipes, which have a square cross-section, also need to be larger not only because the roughness is greater but also because a square cross-section is inherently less efficient than a circular one in inducing updraft.^{8/}

11. In Zimbabwe vent pipes have been constructed with an expanded top section, with the intention of compensating in part for the large head loss across the fly screen. However, during the field studies it was found that this feature did not significantly increase venting velocities, and it is therefore not recommended.

12. From the results of the latrine ventilation monitoring program in Zimbabwe and Botswana (Table 1), it is clear that:

- (a) the ventilation rate increases as the internal diameter of the vent pipe increases;
- (b) PVC and AC pipes of the same diameter and length perform equally well; and
- (c) the performance of cement-rendered reed and other rural vent pipes is equal to that achieved by AC or PVC pipes of approximately half the diameter.

Design Recommendations

13. On the basis of these field studies, the following minimum vent pipe sizes are recommended for various applications (see Table 2). These sizes are probably slightly conservative (that is, result in slight over-design) and should ensure satisfactory latrine operation under normal conditions and with normal maintenance by the householder (keeping the flyscreen clear of debris and ensuring that any cover used does not impede the air flow down through the seat or squat hole).

^{7/} Squat-hole mosquito traps have been recommended to prevent the escape of mosquitoes breeding in pits that extend below the water table (C.F. Curtis, "Insect traps for pit latrines", Mosquito News, 40, 626-628, 1980). Annex II gives construction details for these traps.

^{8/} D.R. Wills, E.W.G. Dance and G.T. Blench, "The Design and Performance of Natural Flue Terminations," Gas Council Research Communication No. GC61, Institute of Gas Engineers, London (1959).

Table 1. Measured ventilation rates in VIP latrines in Botswana and Zimbabwe

Vent pipe details		Super-structure volume (m ³)	Ventilation rate (m ³ /h)	Superstructure air volume changes per hour
Material	Internal diameter (mm)			
(a) Botswanan alternating twin-pit VIP latrines				
PVC	110	2.5	18	7
PVC	160	2.5	36	14
PVC	200	2.5	49	20
FVC	100	2.5	18	7
(b) Zimbabwean single-pit VIP latrines				
PVC	100	1.8	11	6
PVC	150	1.8	18 - 47	10 - 26 <u>a/</u>
AC	150	1.8	18	10 <u>b/</u>
Reed/cement	280	1.8	32	18
Pole/soil	280	1.8	32	18
Hessian/wire mesh/cement	250	1.8	43	24
Brick	230 square	1.8	36	20

a/ The differences are due to differing wind directions.

b/ The test was carried out under adverse wind conditions.

Table 2. Vent pipe material and (mm) recommended minimum internal size for various pipe materials

	<u>AC or PVC</u>	<u>Brick</u>	<u>Cement-rendered reed or hessian</u>
Permanent installations, mean wind speed below 3 m/s (design venting velocity 20 m ³ /h)	150 mm dia	230 mm square	250 mm dia
Permanent installations, mean wind speed above 3 m/s (design venting velocity 20 m ³ /h)	100 mm dia	180 mm square	200 mm dia
Rural installations, minimum-cost urban installations	100 mm dia	190 mm square	200 mm dia

Location

14. The latrines should be located away from overhanging branches and anything else that might impede the action of the wind across the top of the vent pipe. The vent pipe itself should be located on the windward side^{9/} of the superstructure, as also should any openings (doorways, windows, gaps between roof and the walls). If, however, it is impossible to have both the vent pipe and any openings on the windward side, at least one of them must be (and this should preferably be the openings). Minimum opening requirements are discussed in paragraph 20 below.

15. In general the vent pipe should be located on the outside of the superstructure, since it is difficult and expensive to ensure a rain-proof and wind-tight seal if the vent pipe passes through the roof. Moreover, in very sheltered areas, thermally-induced ventilation may be more important than that due to the wind and thus the vent pipe must be placed outside the superstructure. In urban areas especially, external vent pipes could be subject to damage by vandals, although no reports of this occurring have yet been made.

16. The vent pipe must be rigidly fixed to the superstructure and the cover slab; design details are discussed in Annex II.

^{9/} The direction of prevailing wind may be ascertained from the local wind rose which is normally available from meteorological stations.

Fly screen specification

17. The purpose of the flyscreen is to prevent the passage of flies and mosquitoes; in order to achieve this, the mesh aperture must not be larger than 1.2 mm x 1.5 mm (smaller apertures will result in greater reduction in air flow, due to frictional losses, and so a mesh with apertures as close to 1.2 mm x 1.5 mm as possible should be used). The screen must be made of material that is corrosion-resistant, since it must withstand strong sunlight, high temperatures, intense rainfall, and the corrosive environment of the vented gases. Experience from Zimbabwe suggests that PVC-coated glass fiber screens are effective for at least five years; the material is relatively cheap (approximately US\$2 per m²), and is suitable where a latrine will be abandoned within five years or where there are good assurances that the screens will be renewed as necessary. For more permanent installations, where cost is not of such great importance, it would normally be better to instal stainless steel screens, although this may cost five times as much as the cheaper PVC-coated glass fiber alternative. Other materials, in particular synthetic fibers such as nylon and polyester, appear to offer attractive alternatives to PVC-coated glass fiber, but there are no field records on their use and so they cannot, at this stage, be recommended with confidence.

18. It is important to ensure that the fly screen is tightly fixed to the top of the vent pipe in order to prevent access by insects. With AC and PVC pipe the fly screen can be simply glued with epoxy resin to the pipe end (which should be filed to remove any sharp edges which might damage the fly screen); alternative fixing details and those for rural vent pipes are given in Annex II.

19. When the fly screen is in place there should be no obstruction to the wind flow across the top of the vent pipe. In order to obtain maximum wind shear and hence updraught, it is important that the fly screen presents a clear, flat face to the wind. Fixing cowls, which reduce wind shear by inducing turbulence, should not be used.

SUPERSTRUCTURE DESIGN

20. Openings (doorways, etc.) in the superstructure should be located on only one side of it, preferably the windward side. It is extremely important to avoid openings on opposite sides, as this would significantly reduce the pressure difference causing updraught in the vent pipe. In latrines designed with doors the minimum size of ventilation opening(s) should be at least three times the cross-sectional area of the vent pipe (to allow for head losses in the superstructure).

21. Squat-hole cover plates are unnecessary if the superstructure is kept reasonably dark inside, as it is the case in the spiral latrines used in Zimbabwe. If, however, the superstructure is not dark it becomes necessary to shade the squat-hole so the emergent flies are attracted up the vent pipe rather than to the squat-hole. A suitable cover can be readily made from plywood and so shaped as to fit between the footrests; strips of wood of 25 mm square cross-section must be screwed to the underside of the longitudinal edges of the cover in order to permit the free passage of air.

If a seat cover is used with pedestal seats, a small block of wood, 25 mm thick, should be screwed to its underside at the front for the same reason. In high groundwater table areas where mosquito breeding in pit latrines occurs, the use of squat-hole mosquito trap has been proposed by some researchers (details are given in Annex II); however, there are few field data yet on the willingness of householders to use these traps, nor their effect on reducing the ventilation rate.

ALTERNATING TWIN-PIT VIP LATRINES

22. Twin-pit VIP latrines should be designed with a vent pipe for each pit and there should be no interconnection between the two pits. The cover over the squat hole of the pit not in use must provide an effective seal which prevents air entering the pit. If these precautions are not followed, the ventilation performance will be severely curtailed due to cross-flows occurring between the two pits.

MULTIPLE-PIT VIP LATRINES

23. With multiple-pit VIP latrines, which are used as communal or institutional sanitation facilities, it is very important that the precautions given in paragraph 22 are followed. If the multiple-pit latrine is designed as a series of alternating twin-pit latrines, with each pit (other than the two end pits) serving two cubicles (Figure 3), the vent pipe must be large enough to provide adequate ventilation of both cubicles; experience in Ghana suggests that a 200 mm internal diameter pipe is necessary.

FURTHER DATA ON FIELD EXPERIENCES

24. The feature which distinguishes the VIP from older unsatisfactory designs of pit latrines is the large diameter vent pipe fitted with an insect screen. This addition makes the latrine hygienic and readily acceptable, but does add significantly to the cost or effort involved in construction, especially in the case of rural latrines. It is therefore important to refine the design recommendations in this Technical Note in the light of further field experience. A companion Technical Note (TAG/TN/04) sets out procedures for formal monitoring of ventilation performance, but TAG would also be most interested in receiving formal or informal reports on VIP programs. Data either on actual ventilation performance (expressed in air flow or changes of air per hour) or on satisfactory insect and odor control (as determined by the users) should be related to factors such as the location of the latrines relative to other buildings, trees, etc.; their orientation and design; the arrangement, diameter and construction material of the vent pipe; daily or seasonal variations in wind patterns; and user behavior (such as keeping the flyscreen clear of leaves and cobwebs or replacing mosquito traps). This Technical Note and others in the series will be updated periodically to ensure that the most recent field data is incorporated.

FABRICATION OF RURAL VENT PIPES**(a) Cement-rendered reed vent pipes**

Local reeds, approximately 1 cm diameter, are tied together with wire or string to form a mat measuring 2.5 m by 1 m. The mat is then rolled around four or five rings of green saplings to form a tube of some 300 mm external diameter. The fly screen is then fixed to one end (Annex II). Cement mortar (1 part cement, 3 parts sand) is applied to the tube along its entire length but only around half its circumference; when this had hardened, the vent pipe is fixed in position (Annex II) and the other (outer) side then plastered with cement mortar. Thin poles or bamboo sticks may be used instead of reeds. Larger bamboo sticks, split longitudinally into 10-20 mm wide strips, may also be used.

(b) Cement-rendered hessian wire mesh vent pipes

Spot-welded mild steel mesh (4 mm bars at 100 mm centres), 2.5 m long and 0.8 m wide, is rolled into a tube to give an internal diameter of approximately 250 mm. Hessian or jute fabric is then tightly stitched around the outside of the tube, and the fly screen fixed to one end by stitching with string or thin galvanized wire. Cement mortar (1 part cement, 2 parts sand) is then applied by brush to the hessian surface in thin layers, to a final thickness of at least 10 mm. The vent pipe is then fixed in place (Annex II).

(c) Anthill soil vent pipes

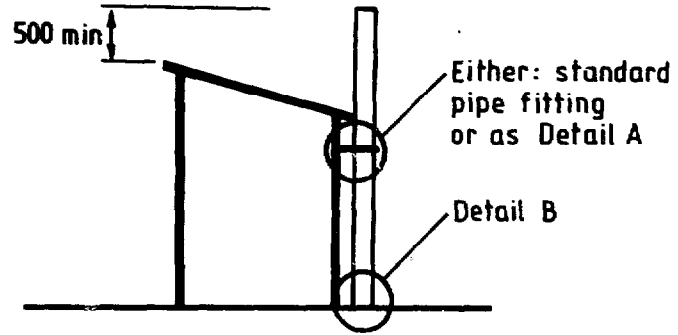
Well-kneaded anthill soil is rolled into "sausages," approximately 100 mm in diameter and 900 mm long, which are made into circles of approximately 280 mm internal diameter. The vent pipe is constructed *in situ* from these circles; vertical reinforcement with short lengths of reed or thin bamboo (or other suitable material) can be driven in between adjacent circles as construction proceeds. When the vent pipe has been built to a height of 2.5 m, its external surface is smoothed off by adding more soil; the fly screen is attached to the upper end (Annex II) and then a thin coat of cement mortar (1 part cement, 6 parts sand) applied.

CONSTRUCTION DETAILS

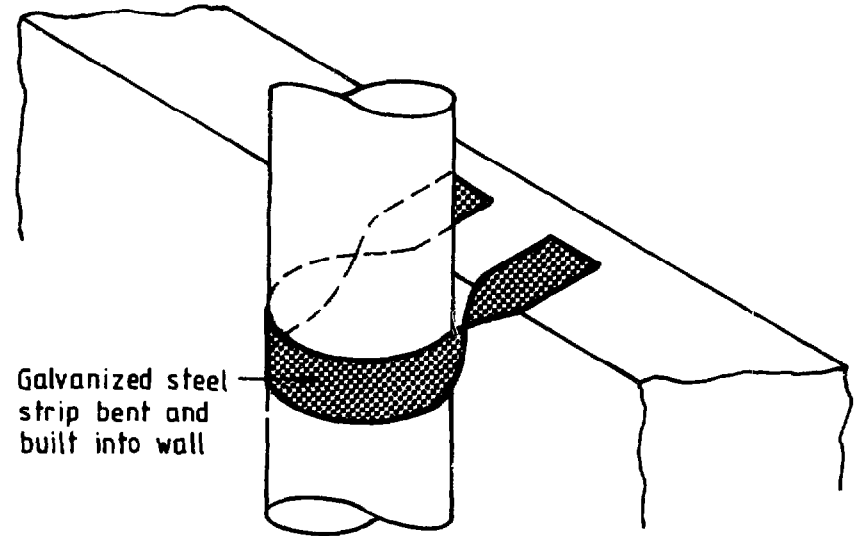
This Annex gives construction details for:

- (a) fixing the vent pipe to the superstructure and cover slab (Drawing No. VP/01);
- (b) fixing the fly screen to the top of the vent pipe (Drawing No. VP/02); and
- (c) squat-hole mosquito traps (Drawing No. VP/03).1/

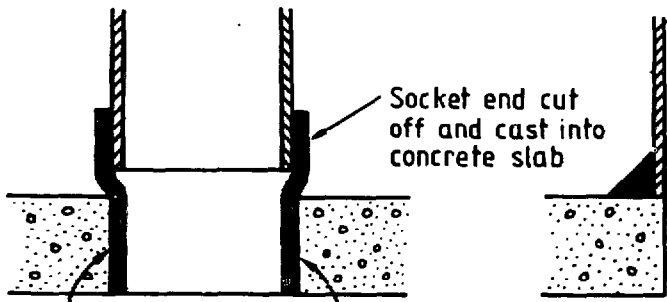
1/ The mosquito trap design is based on that given by C.F. Curtis and P.M. Hawkins, "Entomological studies of on-site sanitation systems in Botswana and Tanzania", Transactions of the Royal Society of Tropical Medicine and Hygiene, 76 (1), 99-108, 1982.



General arrangement

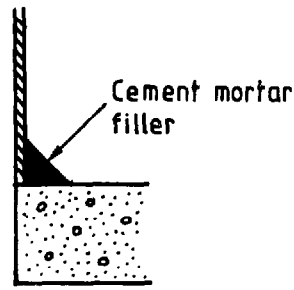


Detail A
Method of fixing vent pipe to superstructure

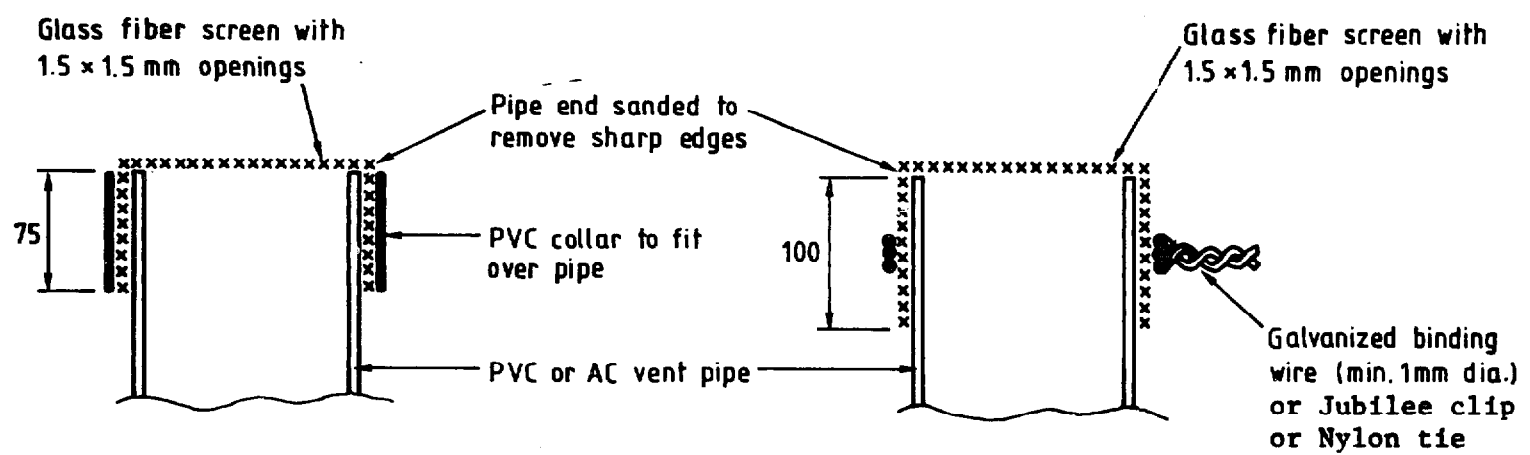


PVC pipe roughened with solvent cement and sand

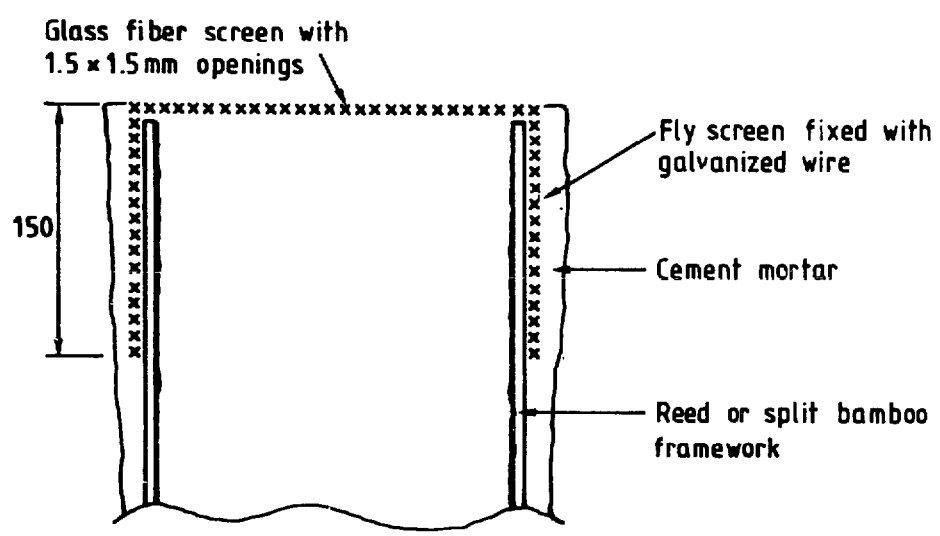
Detail B
Alternative methods of fixing vent pipe to slab



UNDP Interregional Project INT/81/047	
VIP VENT PIPE DESIGN	
Vent pipe fixing details	
Dimensions in mm	Drg.No. VP / 01

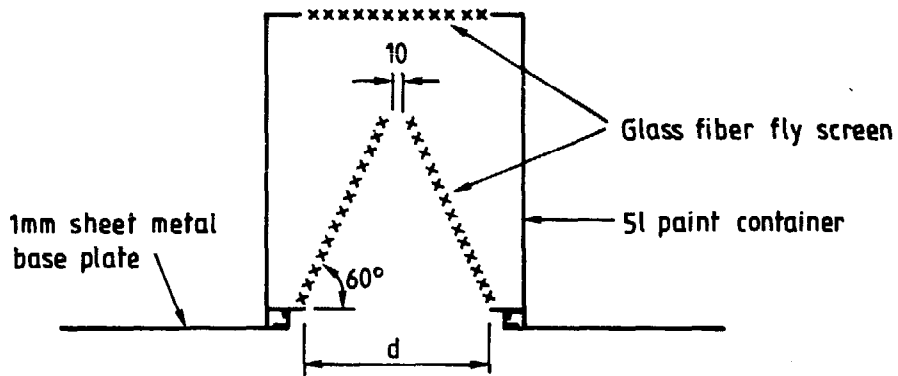


Alternative methods of fixing fly screen to AC and PVC vent pipes

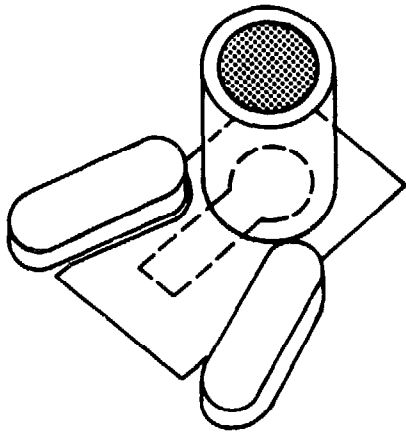


Method of fixing fly screen to a 'rural' vent pipe

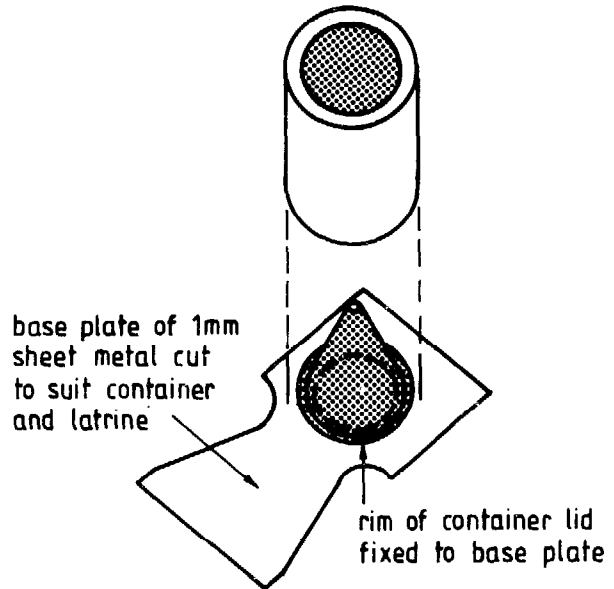
UNDP Interregional Project INT/81/047	
VIP VENT PIPE DESIGN	
Fly screen fixing details	
Dimensions in mm	Drg. No. VP/02



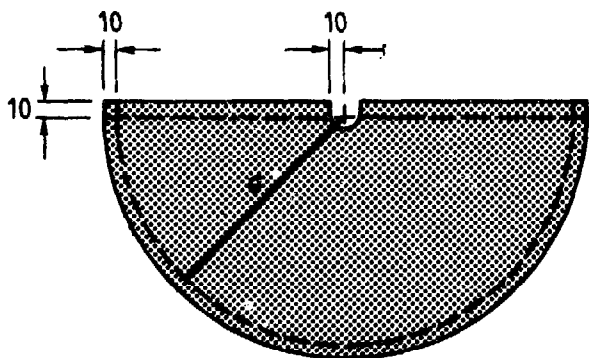
Section through mosquito trap



Mosquito trap in position over squat-hole



Mosquito trap with container removed for emptying



Pattern for cutting fly-screen material

UNDP Interregional Project INT/81/047	
VIP VENT PIPE DESIGN	
Squat-hole mosquito trap	
Dimensions in mm	Drg.No. VP/03