Practical Paper

Redesigning the ventilated improved pit latrine for use in built-up low-income settings

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ABSTRACT

The ventilated improved pit (VIP) latrine has the potential to address the challenge of access to improved sanitation in built-up low-income settings. However, its conventional technical design fails to address the needs and preferences of some users. The objective of this paper was to test the technical performance of modified engineering designs of the technology to respond to some preferences of toilet users. The entry of air from multiple windows in the superstructure and installation of insect screens in windows were tested in an experimental VIP latrine. The modified design achieved the recommended ventilation rate of 20 m^3/h when a vent pipe diameter of 150 mm was used. The study concludes that adopting a multidirectional airflow design leads to a lower ventilation rate as compared to the conventional design. However, when fitted with the recommended size of vent pipe, this modified design achieves more than twice the recommended ventilation rate with or without an insect screen installed in the windows. Nevertheless, the practice in which 100 mm diameter vent pipes are used with insect screens installed in windows is likely to lead to odour problems due to inadequate ventilation through the vent pipe.

Key words | dry sanitation technology, multidirectional VIP, ventilation rate, VIP latrine

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INTRODUCTION

The design and operational mechanism of the ventilated improved pit (VIP) latrine have been discussed in a significant number of publications such as Kalbermatten *et al.* (1980), Mara (1984), Cotton *et al.* (1995) and Harvey *et al.* (2002). The principal feature which distinguishes this technology from other dry sanitation systems is its odour control mechanism. In its conventional design (Figure 1), odour is controlled by the chimney effect by which air entering the superstructure reaches the pit via the squat hole and leaves via the vent pipe.

To enhance the chimney effect and to ensure an optimum rate of air movement through the vent pipe, a number of design guidelines are recommended in the above-cited literature. Most important among these is a requirement that either a window, or some other form of opening, is provided only in the windward side of the superstructure. It is argued that providing a window on other sides of the latrine leads to a significant drop in air pressure in the latrine room and, consequently, disrupts the pushing of cold air down the squat hole to displace hot, malodourous

doi: 10.2166/washdev.2019.098

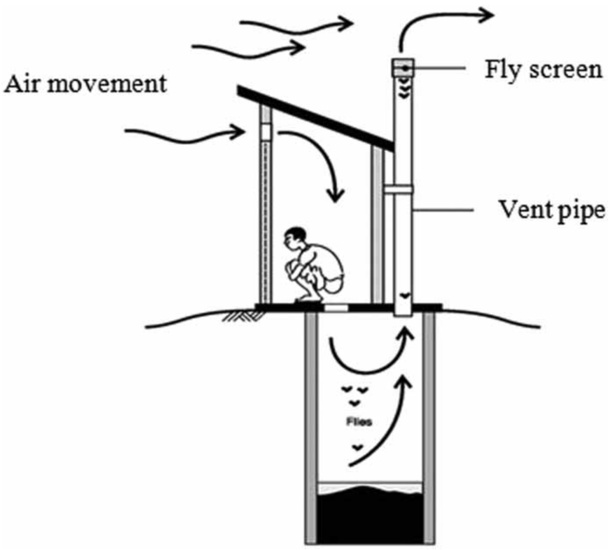

Figure 1 | The chimney effect in a VIP latrine (*Source:* Harvey *et al.* 2002).

air through the vent pipe (Mara 1984). Furthermore, it is recommended that no insect screens are attached to the window to prevent head loss across the screen which could also minimise the air pressure in the latrine room.

These technical requirements tend to place some limitations and complexities on the use of the technology, especially in built-up low-income peri-urban areas where some informal land development practices are known to constrain the provision of sanitation facilities (Schouten & Mathenge 2010; Katukiza *et al.* 2012). First, the windward direction at the location of the latrine should be established at the outset and assumed to remain unchanged after the latrine is built. However, in a built-up low-income area, uncontrolled physical development, especially extensions to existing houses (Hogrewe *et al.* 1993; Parkinson & Tayler 2003; Paterson *et al.* 2007), could alter the local air circulation. This could, therefore, disorient the latrine relative to the direction of wind and disrupt its odour control mechanism (Obeng *et al.* 2015). Secondly, the provision of screens in windows has been identified as a solution to the entry of rodents and reptiles into the latrine which has been reported as a barrier to the use of the latrine (Obeng *et al.* 2015).

Against this backdrop, it is necessary to explore the potential of innovations to respond to these limitations of the VIP latrine. There is the need to assess the extent to which innovations to allow the entry of air in multiple directions and prevention of entry of rodents could affect the ventilation rate through the vent pipe. Secondly, it is imperative to explore whether any losses in ventilation could be compensated for by adjustments to the size of the vent pipe. In general, since pioneering research in the 1970s and 1980s developed the existing VIP design guidelines, not much further work has been done to re-evaluate the relevance of these guidelines and introduce innovative modifications that would make the technology more responsive to emerging user needs and preferences. A search in the Web of Science database reveals no relevant current literature on the VIP latrine design concept. The aim of this study was to assess the ventilation rate in the modified design of the VIP latrine that allows the entry of air from multiple directions as well as attaching insect screens to prevent the entry of rodents and to assess whether any losses in the ventilation rate could be compensated for by adjustments to the vent pipe diameter.

MATERIALS AND METHODS

Study setting

This study was conducted in Prampram, a peri-urban community in Southern Ghana, located between 5°45′–6°05′N and 0°05′–0°20′W along the coast of the Gulf of Guinea. It is the administrative capital of the Ningo-Prampram District of Ghana's Greater Accra Region. Prampram has a population of 7,800 (DHRC 2012), which is growing rapidly, partly due to its proximity to Accra, the national capital. The occupation of the residents are mainly fishing, farming and trading.

Description of experimental VIP latrine set-up

The experimental set-up was designed to measure the ventilation rates in a conventional VIP latrine and various modifications based on observations of existing toilets in Prampram. The experimental VIP latrine had internal cubicle dimensions of 1.2 m × 1.5 m and was built on a pit of internal dimensions 1.2 × 2.5 × 3.0 m. The design modifications included the provision of windows in multiple sides of the superstructure and installation of insect screens in windows. To distinguish it from the standard VIP in which a window is provided only in the windward direction, the modified design in which a window was provided in each of the four sides of the superstructure to allow the entry of air in multiple directions is referred to in this paper as a *multidirectional* VIP.

This study was designed to assess whether the modifications, which are known to compromise the ventilation rate through the vent pipe (Mara 1984), would achieve the recommended ventilation rate of 20 m^3/h in a vent pipe of the recommended size (150 mm). However, the tests were repeated for a vent pipe of 100 mm diameter, which was the size used in all VIP latrines found in the study community, as well as a diameter of 200 mm to assess whether a bigger vent pipe could compensate for any negative effect of the design modifications.

The insect screens had an aperture of 1.2 mm × 1.2 mm, while the windows had a dimension of 0.2 m × 0.7 m. The dimensions of the window were chosen arbitrarily to ensure that the effective area was three times bigger than the cross-sectional area of the biggest pipe diameter (200 mm) to be tested (Ryan & Mara 1983a). When required, any of the windows was closed by covering with a piece of plywood. Only one of the three sizes of vent pipes was installed at a time to a height of 500 mm above the highest point of the roof (Ryan & Mara 1983a). Thus, 12 different set-ups shown in Table 1 were studied. Each set-up was monitored from 5 am to 5 pm for 2 days.

Table 1 | Experimental set-up combinations

Design set-up	Superstructure design	Vent pipe diameter (mm)	Screen installed?
STD100	Standard	100	No
STD150	Standard	150	No
STD200	Standard	200	No
MTD100	Multidirectional	100	No
MTD150	Multidirectional	150	No
MTD200	Multidirectional	200	No
SSW100	Standard	100	Yes
SSW150	Standard	150	Yes
SSW200	Standard	200	Yes
MSW100	Multidirectional	100	Yes
MSW150	Multidirectional	150	Yes
MSW200	Multidirectional	200	Yes

Measurement of ventilation rate and elements of weather

Ventilation rates and air temperature in vent pipes were measured with a hot wire anemometer, *Airflow Model TA430*, manufactured by TSI Incorporated. For each experimental set-up, data were logged at a minute interval for 10 continuous minutes. This was repeated at hourly intervals over the period of monitoring. For an overview of the weather conditions under which the study was conducted, elements of weather comprising the wind speed, temperature, humidity and atmospheric pressure were measured with the aid of the PCE-FWS 20 Weather Station, which was programmed to log data at 5-min intervals. Both devices were mounted following procedures prescribed by Ryan & Mara 1983b.

Data analysis

The data were analysed to assess whether the modified designs could achieve the recommended ventilation rate of 20 m^3/h (Ryan & Mara 1983a). Non-parametric statistics were used due to some observed violations of the requirements for parametric analysis in the data. The Wilcoxon signed-rank test was used to compare the difference of two means while comparison of three or more means was done using the Kruskal–Wallis test. Multiple comparisons of all design set-ups were done using the Bonferroni *post hoc* test.

RESULTS AND DISCUSSION

Weather conditions at the study site

The study site had tropical weather with an average temperature of 36 °C recorded over the period of monitoring. Summary statistics of key elements of weather that are relevant to ventilation studies are presented in Table 2.

Among the elements of weather, the wind speed is regarded as the most important factor to influence the performance of the VIP (Mara 1984).

Table 2 | Summary statistics of the elements of weather

Parameter	Minimum	Maximum	Average	Standard deviation
Ambient temperature (°C)	20.40	36.00	30.40	3.40
Humidity (%)	10.00	93.00	63.50	18.10
Wind speed (m/s)	0.00[a]	5.50	2.10	1.00
Atmospheric pressure (kPa)	100.69	101.83	101.16	0.21

[a]Below a detection limit of 0.1 m/s (*Source*: own field data).

Overview of ventilation rates

Table 3 provides an overview of the mean ventilation rates recorded in the various design set-ups. The result of the Kruskal–Wallis analysis of variance indicates that the ventilation rate was significantly affected by the design modifications, $H(11) = 128.11$, $p < 0.001$.

It is noted that the primary focus of this paper is to assess whether the individual design modifications may be adopted based on their respective ability to achieve the recommended ventilation rate of 20 m^3/h rather than how they compare with each other per se. Hence, the subsequent discussion emphasises the comparison of the ventilation rates for the individual set-ups with the recommended rate using the Wilcoxon signed-rank test. However, for the benefit of readers who may be interested in discovering which design modifications provide the best ventilation rates, the results of multiple comparisons of the ventilation rates for all design modifications and the recommended rate using the Bonferroni *post hoc* test can be found in Table 3 of the Supplementary Material (available with the online version of this paper).

The *post hoc* analysis using the Bonferroni test for 12 different comparisons reveals that increasing vent pipe diameter guarantees an increase in ventilation rates. It can also be seen that the ventilation rates in all set-ups involving the recommended vent pipe diameter of 150 mm or bigger were significantly higher than the recommended rate, implying that all such design modifications could be adopted without compromising the odour control function of the VIP latrine. The increase in ventilation rate with vent pipe diameter is explained by the relatively larger cross-sectional area over which the action of wind takes place as the vent pipe diameter increases (Ryan & Mara 1983a).

Ventilation rate in the multidirectional VIP with no insect screens

Table 4 shows a sample of the results of the test for difference between the ventilation rates in the individual set-ups and the recommended rate. For any vent pipe diameter, the multidirectional design led to lower ventilation rates as compared to the standard design (see Table 1 in the

Table 3 | Overview of ventilation rates with Kruskal–Wallis analysis of variance

	Ventilation rate (m^3/h)			
Design set-up	Mean	SD	*H*-statistic	*p*-value
STD100	33.49	6.33	128.11	0.000**
STD150	74.10	20.03		
STD200	139.41	32.35		
MTD100	26.23	3.76		
MTD150	47.84	8.37		
MTD200	74.69	12.69		
SSW100	33.93	8.07		
SSW150	60.41	15.94		
SSW200	61.82	22.04		
MSW100	17.63	1.80		
MSW150	45.05	8.21		
MSW200	43.74	7.43		

SD, standard deviation.
**Significant at 1% level (*Source*: own field data).

Table 4 | Comparison of ventilation rates in modified VIP designs with the recommended rate

	Ventilation rate (m^3/h)				
Design set-up	Mean	SD	Mean-*R*[a]	*z*-score[b]	Significance
STD100	33.49	6.33	13.49	−3.180	0.000**
MTD100	26.23	3.76	6.23	−3.041	0.000**
SSW100	33.93	8.07	13.93	−3.180	0.000**
MSW100	17.63	1.80	−2.37	−3.042[c]	0.000**
STD150	74.10	20.03	54.10	−3.181	0.000**
MTD150	47.84	8.37	27.84	−3.180	0.000**
SSW150	60.41	15.94	40.41	−3.181	0.000**
MSW150	45.05	8.21	25.05	−3.182	0.000**

[a]Recommended ventilation rate of 20 m^3/h.
[b]Based on the Wilcoxon signed-rank test, *T*; Mean-*R*.
[c]Based on positive ranks; all other *z*-scores based on negative ranks.
**Significant at 1% level, one-tailed (*Source*: own field data).

Supplementary Material, available online). However, it can be seen in Table 4 that, even for a vent pipe diameter of 100, the multidirectional design without insect screens (MTD100) produced a significantly higher ventilation rate (26.23 m^3/h) than the recommended rate, $z = -3.041$, $p < 0.001$. With the 150 mm vent pipe, the multidirectional design achieved more than twice the recommended rate (47.84 m^3/h, $z = -3.180$, $p < 0.001$).

This result confirms earlier findings that the provision of extra openings in other sides of the superstructure other than the windward sides leads to a drop in the ventilation rate (Mara 1984). This has been attributed to loss of air pressure in the latrine cubicle, which reduces its effectiveness in pushing cold air into the pit to displace warm air via the vent pipe. Notwithstanding, the proposition of this paper is that, adopting the multidirectional design, which may lead to a lower but adequate ventilation rate, is a better choice than a conventional design in which the only window provided may not necessarily be in the windward direction for a number of reasons such as changes in the local air circulation.

To verify the effect of a conventional VIP latrine having its window disoriented from the local wind direction, the experimental VIP latrine was set up with a 150 mm diameter vent pipe and all windows sealed except one which was at the leeward side of the superstructure. The results, shown in Table 5, indicate that the average ventilation rate dropped to nearly half of that recorded in the corresponding multidirectional VIP and less than one-third of the rate in the standard VIP with a window provided in the windward direction.

The findings of this study extend existing knowledge on VIP latrine design to the extent that having the window or openings of a standard design disoriented from the local wind direction could cause much greater reduction in the ventilation rate than having openings on all sides of the superstructure. Based on the findings of this study, it could be concluded that the multidirectional design could achieve the recommended ventilation rate expected in a VIP latrine under favourable weather conditions such as those encountered in Prampram.

Table 5 | Comparison of ventilation rates in a conventional, multidirectional and a disoriented VIP latrine

VIP description	Ventilation rate (m^3/h) Mean	SD	*H*-statistic	*p*-value
Standard VIP	74.10	20.03	30.919	0.000**
Multidirectional VIP	47.83	8.37		
Disoriented standard VIP	24.85	4.01		

SD, standard deviation.
**Significant at 1% level (*Source*: own field data).

Effect of installation of insect screens

Generally, the use of insect screens in latrine windows significantly reduced the ventilation rate due to loss of air pressure across the screen (Mara 1984). Nevertheless, it can be seen in Table 4 and in the *post hoc* analysis that using insect screens with the recommended vent pipe diameter of 150 mm achieved significantly higher ventilation rates than the recommended rate of 20 m^3/h. As seen in Table 4, the standard design with a screen (SSW150) had an average of 60.41 m^3/h, $z = -3.181$, $p < 0.001$, while the multidirectional design (MSW150) achieved 45.05 m^3/h, $z = -3.182$, $p < 0.001$.

It can, however, be seen from Table 4 that the installation of insect screens in the multidirectional design when a 100 mm vent pipe is used fails to achieve the recommended ventilation rate, with the average being 17.63 m^3/h ($z = -3.042$, $p < 0.001$). Thus, VIP users who wish to adopt the multidirectional design to enhance air circulation in the cubicle and install insect screens in windows to prevent the entry of rodents can only be guaranteed adequate ventilation through the vent pipe when they use the recommended diameter of 150 mm or higher.

CONCLUSIONS

The findings of this study confirm that providing a window or an opening only in the windward side of the VIP latrine, as recommended in the conventional design, achieves a higher ventilation rate than the multidirectional design in which windows are provided on all sides of the superstructure to allow the entry of air from multiple directions. Nevertheless, the multidirectional design achieved the recommended ventilation rate when the minimum recommended vent pipe diameter of 150 mm was used. Furthermore, the ventilation rate in the multidirectional VIP was found to be significantly higher than the rate in a conventional VIP in which the only window does not face the windward direction. Regarding the use of insect screens in windows, this study found that although it has a negative effect on the ventilation rate, the recommended ventilation rate can be maintained when a vent pipe of 150 mm diameter or bigger is used. However, the practice in which 100 mm diameter vent pipes are used with insect screens attached to the windows is likely to lead to odour problems in the latrine due to inadequate ventilation through the vent pipe.

ACKNOWLEDGEMENT

The authors wish to acknowledge the Danish International Development Agency for funding their work under the Sustainable Sanitation (SUSA) Ghana research project. The agency played no direct role in the conduct of the research and the views expressed in this paper do not necessarily reflect its views.

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First received 17 June 2018; accepted in revised form 14 January 2019. Available online 25 February 2019