USAGE BARRIERS AND IMPROVEMENT OF THE VENTILATED IMPROVED PIT LATRINE FOR USE IN PERI-URBAN SETTINGS OF GHANA

By

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Certification

I hereby declare that this submission is my own work towards the award of PhD and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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Abstract

The overall aim of this research was to improve the ventilated improved pit (VIP) latrine to make it more suitable for use in peri-urban settings in Ghana. The specific objectives were to assess the barriers associated with the use of existing latrines, identify the factors which influence the level of odour in latrines and to evaluate improvements in modified designs of the VIP latrine. The research was conducted in Prampram, Ghana, using focus group discussions, questionnaire surveys and field measurements in an experimental and existing latrines. A linear regression model was used to assess the relative effect of the various design modifications and the elements of weather on the ventilation rate in the experimental VIP latrine. It was found that private latrines shared by multiple households were as highly patronised by the intended users as those used by single households but communal latrines were avoided by most expected users (75%) in favour of open defecation. The main technical barrier to use of existing facilities was intense odour (23%) while long walking distances (28%) and the charging of a user fee (21%) were the major nontechnical barriers. The concentrations of hydrogen sulphide and ammonia in latrine cubicles, used as potential surrogates of odour, generally reflected the level of odour as perceived by the latrine users but hydrogen sulphide was found to be a more reliable surrogate of the level of odour. On the average, a hydrogen sulphide concentration of 0.04 ppm was perceived by latrine users as being tolerable. The level of odour was significantly influenced by the type of latrine technology. For VIP latrines, the level of odour was influenced significantly by the ventilation rate through the vent pipe and the cleanliness of the latrine. With windows provided in all sides of the superstructure of the experimental VIP latrine and insect screens installed to serve various purposes in the peri-urban setting, the 100 mm diameter vent pipe commonly used in Ghana achieved a lower ventilation rate (17.6 m^3/h) than the recommended rate of 20 m^3/h but a 150 mm vent pipe exceeded the recommended rate with an average of 45 m^3/h. Generally, reduction in the ventilation rate due to the provision of windows in all sides of the superstructure (32%) and the installation of insect screens (7%) could be compensated for by increasing the vent pipe diameter by 50 mm. A regression model of the ventilation rate developed in this study could be used to predict the ventilation rate based on a set of design criteria and meteorological data.

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List of Abbreviations

AC	Asbestos Cement
ASTM	American Society for Testing and Materials
ASW	Autodesk Sustainability Workshop
CP	Composite Perception
DFID	Department for International Development
DHRC	Dodowa Health Research Centre
FDG	Focus Group Discussion
GSS	Ghana Statistical Service
JMP	Joint Monitoring Programme
KNUST	Kwame Nkrumah University of Science and Technology
KVIP	Kumasi Ventilated Improved Pit
MDG(s)	Millennium Development Goal(s)
MLGRD	Ministry of Local Government and Rural Development
MWRWH	Ministry of Water Resources Works and Housing
NPDA	Ningo-Prampram District Assembly
PPM	Parts Per Million

PVC	Polyvinyl Chloride
SUSA	Sustainable Sanitation
UNHR	United Nations Human Rights
UNICEF	United Nations Children's Fund
VIP	Ventilated Improved Pit
WC	Water Closet
WHO	World Health Organisation

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1 INTRODUCTION

CHAPTER 1: INTRODUCTION

1.1 Background Information

The availability and usage of improved sanitation facilities at the household and community levels is indispensable to the maintenance of public health. It is also an important requirement for achieving several targets of the Millennium Development Goals (MDGs) such as access to potable water, reduction of child mortality and improvement in maternal health (Tornqvist et al, 2008; UNDESA, 2007; UN Millennium Project, 2005 and Scott et al, 2003). In spite of the critical role effective human excreta management and, for that matter, sustainable environmental sanitation play in human development, the MDG on basic sanitation was one that was widely believed to be unachievable. It is estimated that over 2.5 billion people in the developing world, representing about half of the population, do not have access to basic sanitation (WHO/UNICEF, 2014). Consequently, environmental factors account for nearly a quarter (24%) of the global burden of disease and 23% of all deaths (Pruss-Ustun and Corvalan, 2006).

The region of Sub-Saharan Africa has made a very slow progress towards the sanitation MDG. The region had a sanitation coverage of 26% in 1990 and is pursuing a target of 64% by the year 2015. However, the 2014 progress report (WHO/UNICEF, 2014) indicated that only 30% of the region's population – based on 2012 data – had access to improved sanitation. Though Southern Asia had the lowest sanitation coverage of 24% in 1990, it has currently overtaken Sub-Saharan Africa, albeit, with an equally unimpressive coverage of 42% in 2012, as against a subregional target of 63%.

In Ghana, only 14% of the population have access to improved sanitation technologies (WHO/UNICEF, 2014). A key factor accounting for the nation's poor rank is the extensive use of shared latrines, either private or public, which do not meet international criteria for improved sanitation. Globally, Ghana has the highest proportion (59%) of population using shared latrines (WHO/UNICEF, 2014). The Ghana Living Standards Survey Round Five (GLSS 5) (GSS, 2008) estimated that 10% of households use flush toilets while 32% and 12% respectively use pit latrines and the Kumasi Ventilated Improved Pit (KVIP) latrines; pan or bucket latrines are used by 1.3% of households. Between the urban-rural divide, more urban households (39%) rely on public toilets as compared to rural households (14%). Some 44% and 58% of rural coastal and rural inland households respectively use pit latrines, while 30% of all rural households have no toilet facility as compared to an urban average of 5.3%. In rural savannah areas, 69% of households have no toilet facility at all. The pit latrine is the most popular technology – used by about 32% of all households. Sewerage coverage is estimated at 3% (GSS, 2013) while less than 15% of excreta generated in Accra and Kumasi, the two largest cities, is effectively treated (MLGRD, 2010a).

Although access to sanitation in low-income countries like Ghana is generally low and lags behind the MDG target, peri-urban areas of those countries have been recognised as facing unique socio-economic and developmental challenges which have direct or indirect consequences on the uptake of sanitation (Hogrewe et al, 1993). Consequently, the state of sanitation in low-income peri-urban areas has been identified as potentially worse than national averages and *"represents a major* *challenge for the 21st century"* (Paterson et al, 2007; p. 902). The developmental challenges in peri-urban areas which negatively affect sanitation uptake in those areas have been widely reported and include the following: (Hogrewe et al., 1993; Parkinson and Tayler, 2003; MWRWH, 2007; MLGRD, 2010b):

- high population densities and, hence, high demand for rental accommodation, with some landlords changing toilets to living rooms;
- poor physical planning and haphazard development that leave no space for siting sanitation facilities;
- unreliable water supply, which limits the use of some sanitation technologies, and
- low income levels, which make acquisition of household toilets and public toilet user fees unaffordable to many households.

These challenges and their effects on the uptake and regular usage of sanitation technologies have been elaborated in Chapter Two of this thesis.

1.2 Statement of the Problem

In Ghana, not much is known about how the physical and socio-economic characteristics of peri-urban settings affect the potential of existing technologies to address the needs and preferences of latrine users. Failure to meet what latrine users require in their latrines create barriers to consistent use of facilities (Garfi and FerrerMarti 2011; Olschewski 2013) and lead to open defecation, which is recognised as the riskiest sanitation practice (WHO, 2013a). In other words, knowledge of user preferences and barriers to latrine usage is essential to guide the selection of appropriate technologies and modification of conventional designs to match the determinants of latrine usage in the peri-urban setting.

In the low-income peri-urban setting, only a limited range of technologies may be technically feasible. For instance, irregular water supply and poor physical planning make the introduction of sewerage systems technically unfeasible (Hogrewe et al, 1993; Parkinson and Taylor, 2003; Paterson et al, 2007). Similarly, wet on-site systems like the water closet which require regular water supply for efficient operation are less popular and often unaffordable to several households. Thus, dry on-site sanitation technologies such as the simple pit and the ventilated improved pit latrines often become the technically appropriate choice for most households. As stated earlier, nearly half (44%) of Ghanaian households depend on the simple pit (32%) and the ventilated improved pit (12%) latrines (GSS, 2008).

The ventilated improved pit latrine is designed as an improvement over the simple pit latrine in the control of odour and fly nuisances. If properly constructed and maintained, the technology could afford the user most of the health benefits and conveniences of conventional sewerage at a relatively lower cost (Kalbermatten et al., 1980; Ryan and Mara, 1983a). Nevertheless, the latrine is required to be designed and constructed in accordance with a set of stringent design codes and guidelines such as those contained in Ryan and Mara (1983a) and Mara (1984) in order to be efficient in the reduction of odour. Adherence to such design codes and guidelines is deemed to be necessary to maintain an optimum rate of ventilation through the vent pipe, which is emphasised as the key to odour reduction.

Nonetheless, the complexity and haphazard development of the peri-urban environment tend to create conditions that make it difficult to always ensure that the latrine is constructed and operated in compliance with the relevant codes and guidelines. For instance, it is required that a VIP latrine is constructed with openings or a window provided only in the windward direction as a prerequisite for achieving the optimum rate of ventilation in the vent pipe (Ryan and Mara, 1983a; Mara, 1984). However, multiple attachments and extensions to existing buildings in the peri-urban setting in response to high demand for residential accommodation may lead to changes in the original pattern of air flow in a neighbourhood which could alter the direction of wind relative to the orientation of previously existing toilets. This increases the occurrence of intense odour in VIP latrines and make some prospective users resort to open defecation. This makes it imperative to explore design modifications which could make the efficiency of the VIP latrine less dependent on the direction of wind. However, a review of existing literature reveals that since pioneering research in the late 20th Century developed the existing VIP design codes and guidelines, not much further work has been done to re-evaluate the relevance of these guidelines in specific geophysical contexts and to test potential modifications that may be introduced to make the application of the VIP more flexible. The existing guidelines have been criticised as being overzealous (Jenkins and Sudgen, 2006).

A further challenge lies in the methodology for assessing the improvement resulting from design modifications, especially, in the removal of odour which is the key strength of the VIP over other dry on-site sanitation technologies. In attempting to adapt the VIP to any locality or functional purpose, it is crucial to ensure that any modification in the conventional design does not compromise the technology's potential to minimise odour, which is frequently cited as a barrier to regular usage. This raises the question of how to objectively assess the impact of design modifications on the control of odour in the latrine. Earlier works like Ryan and Mara (1983a) recommended the use of the latrine users' perception of the odour level. However, this approach is subjective and likely to generate data of questionable reliability or reproducibility. On the other hand, the advent of portable gas detectors offers the opportunity for adopting the concentrations of odourproducing volatile constituents of excreta such as hydrogen sulphide and ammonia as surrogates for the level of odour. However, this approach is also criticised as measuring mere concentrations of a compound rather than the human experience of odour sensation (Powers, 2004; Sironi et al, 2007). To overcome this, there is the need to verify whether such concentrations correlate with the odour perception of the latrine users and to benchmark the concentrations with user perception in order to make it possible to interpret the concentrations of the surrogate compounds in terms of how humans would perceive the level of odour.

1.3 Research Objectives

The overall aim of this research was to improve the VIP latrine to make it more suitable for use in peri-urban settings in Ghana. The specific objectives of the study were to:

1. assess the barriers associated with the use of on-site sanitation technologies in the low-income peri-urban setting in Ghana;
2. identify the factors that influence the level of odour in latrines; and
3. evaluate improvements in modified designs of the VIP latrine.

1.4 Scope of Work

This research was limited to the capture and storage components of the sanitation chain. Thus, the term 'sanitation technologies' is used to refer to the different types of structures and fittings used for the capture and on-site storage of excreta, including those appurtenances provided to ensure easy emptying. The study covered both private and public sanitation facilities. Though public toilets are shared facilities according to the Joint Monitoring Programme (JMP)'s definition (WHO/UNICEF, 2006), the term ‘shared’ is used to exclusively refer to home-based or privately owned facilities that are shared by two or more households. Geographically, the study was conducted in Prampram, a peri-urban community and the administrative capital of the Ningo-Prampram District in the Greater Accra Region of Ghana.

1.5 Significance of the Study

The study provides an analysis of latrine usage in the low-income peri-urban context. It establishes the pattern of latrine usage and the factors which influence the users' choice of latrines. It also reveals existing technical and non-technical barriers to regular use of facilities and potential interventions to address them. The study, therefore, provides a useful guide to practising engineers in the identification of technological innovations aimed at removing technology-related barriers that hinder the consistent use of sanitation facilities in low-income peri-urban areas.

With odour control emerging from the contextual analysis as a key factor affecting the regular use of latrines, this study sought to identify the factors that influence the level of odour in latrines. This was done after testing a methodology for objectively assessing the level of odour in a latrine which could serve as a key indicator for identifying the factors influencing odour levels and for evaluating the impact of technological innovations. This simple methodology can be adopted by scientist involved in latrine improvement research in low-income countries.

This study also tested some modifications of the seemingly rigid guidelines for the design and construction of the VIP latrine and established some opportunities and conditions for relaxing some of the existing guidelines to suit the geophysical conditions of the low-income peri-urban settings without necessarily compromising the odour removal function of the technology. Such innovations in the VIP are expected to contribute to increased latrine usage in the peri-urban setting as shown in Figure 1-1.

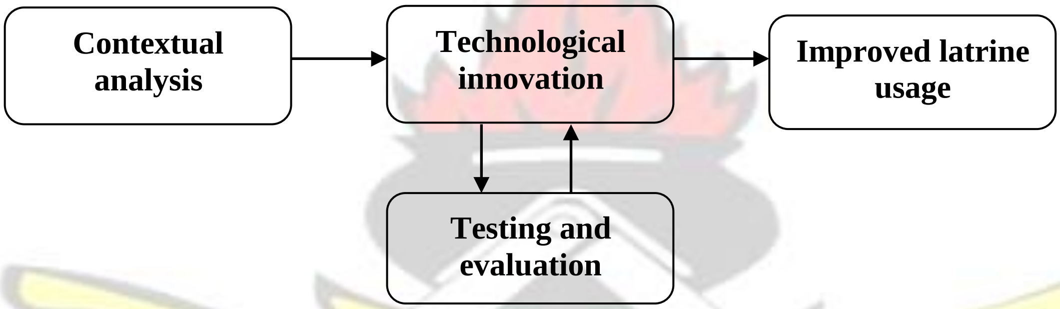


Figure 1-1: Conceptual framework

1.6 Thesis Structure

This thesis has been divided into seven chapters. This introductory chapter gives a background to the research including the statement of the research problem, the study objectives and the significance of the findings.

Chapter 2 provides a review of the relevant literature relating to the subject of the thesis. This includes the challenges associated with the provision of sanitation facilities in low-income peri-urban settings, the theory of sanitation and an overview of the functional design of the VIP latrine. The relevant technical issues for the design and usage of the VIP latrine are also reviewed in this chapter with emphasis on odour control.

Chapter 3 describes the study community and the materials and methods used to pursue the objectives of the study. Data collection and analysis techniques are detailed in this chapter.

Chapters 4—6 respectively present the results on the three specific objectives. Each of these chapters has a brief introductory section preceding the presentation and discussion of results, and end with a summary of the key findings. Chapter 4 reports the specific study conducted on specific objective 1, i.e., the usage and barriers to the use of latrines in the study community, Prampram. In Chapter 5, the study on the factors influencing the odour levels in latrines is presented. Chapter 6 presents the study on the modifications of the conventional VIP design to make it more suitable to the peri-urban setting.

In the Chapter 7, the findings of the various studies are summarised. The Chapter also makes recommendations for practice, policy formulation and future research.

2 LITERATURE REVIEWCHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This Chapter presents a review of literature relevant to the subject of the research. The review provides a general overview of the theory of sanitation and related concepts. It then defines the socio-economic and technical context within which sanitation is provided in low-income peri-urban areas and the associated barriers to latrine usage. The Chapter also reviews salient technical issues associated with dry sanitation systems, with emphasis on the ventilated improved pit latrine and its odour control mechanism. It also reviews human and non-human dependent techniques for odour measurement.

2.2 The Theory of Sanitation and Related Concepts

2.2.1 Sanitation as a barrier to disease transmission

The term 'sanitation' is often used in everyday life with reference to the physical facilities and activities involved in the collection and disposal of excreta and other types of wastes. However, sanitation is more than a device; it is a concept (UNICEF, 1997). It refers to the broader process of people initiating action to maintain a hygienic and healthy environment through the raising of premeditated or engineered barriers to prevent the transmission of pathogenic agents (Mara et al, 2010; UNICEF, 1997; Wagna and Lanoix, 1958). Figure 2-1 illustrates the role of sanitation in breaking the routes of faecal-oral disease transmission. Of all types of human excreta, faeces pose the greatest risk to health (Mara, 2010).

It is estimated that one gram of fresh infected faeces can contain 10^6 – 10^8 bacterial pathogens, 10^4 protozoan cysts or oocysts, 10^6 viral pathogens and 10 – 10^4 helminth eggs (Feachem et al, 1983). When infected faeces is indiscriminately disposed of, pathogens may be deposited in the soil, washed by water or carried by flies; it may also come into contact with human hands.

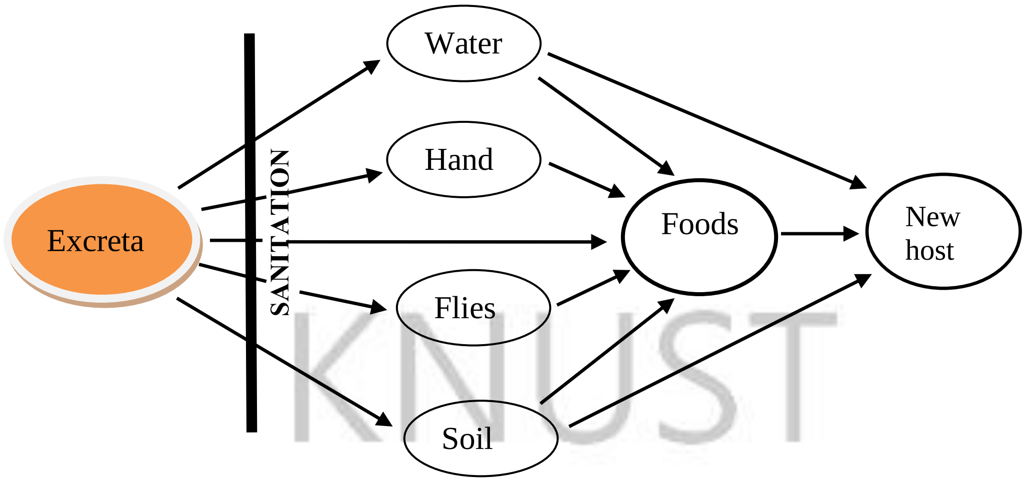


Figure 2-1: Sanitation as a barrier to faecal-oral disease transmission

Source: Adapted from Wagner and Lanoix (1958) and Mara et al (2010)

Through any of these routes, pathogens may be transferred to food and ultimately into the body of a new host. A person may also directly contract pathogens through contact with contaminated soil or drinking of polluted water. The result could be death or morbidity. Consequently, diarrhoeal diseases are the second cause of death in children under five years old, killing an estimated 760,000 of them yearly (WHO, 2013b).

Sanitation is a proven effective barrier to the transmission of gastro-intestinal diseases. Mara et al (2010) accredits the first scientific notice of the relationship between disease transmission and the lack of sanitation to Chadwick's *'Report on an inquiry into the sanitary condition of the labouring population of Great Britain'* (Chadwick, 1842). Since then, further scientific evidence has confirmed that gastrointestinal diseases can be prevented or efficiently controlled through effective sanitation or its combination with water supply and hygiene. For instance, improved sanitation has been found to reduce the rate of diarrhoeal diseases by 32% – 37% (Waddington and Snilstveit, 2009; Fewtrell et al, 2005; Esrey et al, 1998). Significantly, the impact of improved sanitation has been found to be even higher where baseline conditions were extremely poor. Examples of such cases were reported by Barreto et al (2007).

2.2.2 Definition and components of sanitation

Inspired by views expressed by the 2002 World Summit on Sustainable Development (WSSD), the UN Millennium Project Task Force on Water and Sanitation (TFWS) defined ***basic sanitation*** as:

> *"the lowest-cost option for securing sustainable access to safe, hygienic and convenient facilities and services for excreta and sullage disposal that provides privacy and dignity while ensuring a clean and healthful living environment both at home and in the neighbourhood of users"* (UN Millennium Project, 2005; p. 30; emphasis added)

Although experts agree on the conceptual soundness of this definition, there arose a concern at the onset of the MDGs about the feasibility of measuring and monitoring progress according to such a definition (WHO, 2010). For this reason, the WHO and UNICEF's JMP adopted as a proxy for basic sanitation, which it calls *'improved sanitation'*, and defines as:

> *"a sanitation system in which excreta are disposed of in such a way that they reduce the risk of faecal-oral transmission to its users and the environment"* (UN Millennium Project, 2005; p. 29).

Much as this definition practically serves the JMP's purpose, it has inadvertently created the tendency of reducing sanitation to an excreta disposal facility that can be physically enumerated as a measure of progress towards the sanitation MDG. In addition, it creates the temptation for Governments in poor countries seeking to demonstrate their commitment towards the MDG on sanitation to concentrate on those interventions which directly deliver the physical parameter that would be assessed, i.e.

the building of latrines. However, such an approach may only succeed in delivering the proxy without necessarily achieving the values which the proxy represents.

On the contrary, it can be deduced from the Sanitation Task Force's definition that sanitation, in its broadest sense, is not limited to excreta management. Rather, it includes other components like sullage and storm water drainage, hygienic living and solid waste management etc, which are required to ensure *"a clean and healthful living environment both at home and in the neighbourhood"* (Lenton and Wright, 2005). Further, sanitation should be recognised as comprising both

'hardware' and 'software' components, the latter referring to non-technology aspects such as health and hygiene education, community mobilisation and institutional development. Hérbert-Simpson and Wood (1998) and DFID (1998) identify the failure to pay adequate attention to these software issues as a major weakness in efforts to improve global sanitation towards the end of the 19th Century. Nevertheless, this research focused on the hardware component of excreta management.

2.2.3 The sanitation chain

An effective excreta management system can be conceptualised as a chain of functional stages consisting of capture, storage, transportation, treatment, disposal and/or reuse (see Figure 2.2). Each component in the chain plays a crucial role to ensure that *"excreta are disposed of in such a way that they reduce the risk of fecaloral transmission to its users and the environment"*, as expected of an improved sanitation (UN Millennium Project, 2005; p. 29).

Figure 2-2: The sanitation chain

The roles of these components towards the attainment of the purpose of an improved sanitation system are briefly stated as follows:

Capture: This is the first stage of any sanitation (excreta management) system and comprises the provision of user interface or toilet facilities for the direct and hygienic collection of excreta from the human body.

Storage: This is the retention of excreta in receptacles that allow in-situ treatment or easy emptying for transportation. During storage, strong emphasis is laid on the prevention of groundwater pollution by seepage of excreta from the storage receptacle.

Transportation: Transportation of excreta is associated with all forms of off-site sanitation systems where excreta are conveyed to a remote destination for treatment and disposal. In conventional sewerage, it is done via sewers under the influence of gravity or powered by a pump. In other off-site sanitation systems, cesspit emptiers are the major means of transporting excreta to a treatment plant or final disposal point.

Treatment: This is the breakdown or conversion of excreta into other harmless or less harmful substances which may be discharged into the environment or put to some productive use such as fertiliser or biogas.

Disposal/reuse: This is the final stage in the sanitation chain where the final effluent is either discharged into the environment or reused as fertiliser, biogas or for some other purposes.

While focusing on the hardware component of excreta management, this research was further restricted to the capture and storage stages of the sanitation chain.

2.2.4 Common classifications of sanitation technologies

a. Pro-poor or advanced

In developing countries, cost and simplicity are key factors that are considered in the comparison of sanitation technology options (Murphy et al., 2009). On this basis, excreta capture and disposal systems are classified as either pro-poor or advanced (Herron, 2007; Paterson et al., 2007). Pro-poor or affordable sanitation technologies are often described by various terms such as low-cost technologies, appropriate technologies, sustainable technologies etc. (Brikke & Bredero, 2003). Common examples include the pit latrines, the pour-flush toilet, the aqua privy and the septic tank system (Franceys et al, 2002; Herron, 2007). On the other hand, conventional sewerage is recognised as advanced or anti-poor (Paterson et al, 2007). The most important features of pro-poor sanitation technologies are that they are simple and inexpensive to construct, operate and maintain (Brikke & Bredero, 2003; Franceys et al., 1992). It is important, however, that their simplicity and low cost do not compromise their ability to perform the main sanitation function expected of an improved sanitation facility, i.e., the prevention of faecal-oral disease transmission (UN Millennium Project, 2005).

b. On-site or off-site

Sanitation technologies may also be classified as on-site or off-site, depending on whether the sanitation chain begins and ends within the premises of the excreta generating entity or some stages of the chain are completed at a remote destination (Torondel, 2010). Pit latrines, the aqua privy, the composting toilet and the septic tank system are all on-site technologies because they retain excreta in the vicinity of the toilet in a pit, tank or vault, whereas conventional sewerage and simplified sewerage, which remove excreta from the vicinity of the toilet for treatment and/or disposal elsewhere are off-site sanitation systems (Mara, 2006; Parkinson et al, 2008). The small-bore or settled sewerage system uses a septic tank to retain solids within the vicinity of the toilet while liquids join a sewer network for off-site disposal resulting in a 'hybrid system' (Parkinson et al, 2008). Nevertheless, an onsite sanitation system normally requires periodic removal of faecal sludge from the holding tank, pit or vault. Because some cost is saved by eliminating the need to transport excreta to a remote destination for completion of the sanitation chain, most pro-poor sanitation technologies are on-site rather than off-site. However, it has been argued that simplified sewerage relaxes the conservative design codes used in conventional sewerage and can be cheaper than on-site sanitation in peri-urban areas where high population densities create economies of scale (Paterson et al, 2007).

Notwithstanding, this review is restricted to on-site sanitation technology options.

c. <u>Dry or water-dependent</u>

Depending on the requirement of water for the operation of a sanitation technology, it may be classified as dry or wet. Dry sanitation technologies such as the pit latrine, VIP and compost toilet etc. do not require the use of water in their operation other than the washing of the user's hands and general cleaning purposes (Herron, 2007; Parkinson et al, 2008). On the other hand, the water closet with septic tank, the pourflush and aqua privy toilets are examples of wet systems because they require water for flushing or some other operational requirement (ibid).

2.3 Barriers to Sanitation Access in Peri-Urban Settings

There is no universal definition for the term peri-urban (Iaquinta and Drescher, 2000, Hogrewe et al, 1993) but it is generally associated with the *"meeting place between the urban and rural context"* (Tornqvist et al, 2008; p. 563) or *"settlements that are* *marginal to the physical and regulatory boundaries of the formal city"* (Hogrewe et al, 1993; p. 9). The term is used in this thesis to reflect these adopted definitions. Such communities in low-income countries are faced with a number of interrelated developmental challenges which affect sanitation provision. Some of these factors are discussed below:

High population density: Peri-urban areas serve as 'dormitory communities' for would-be urban dwellers who are unable to afford the high costs of living within the cities. This has implications on sanitation in the sense that continued investments in expanding sanitation facilities will have to be very significant just to maintain the existing coverage. On the contrary, there are reports of landlords turning toilet rooms into rental accommodation to get more money (MLGRD, 2010b). High population density also places restrictions on locating on-site collection and treatment systems. Additionally, it increases the number of users per facility, which leads to queuing to access latrines. The ultimate result is rampant open defecation.

Poor physical planning: With the scramble for space in peri-urban areas, local community members and informal estate developers take undue advantage of the weak regulatory capacity of government agencies to engage in unapproved land development (Parkinson and Tayler, 2003). Because formal settlement planning and land development processes are ignored, there are often no spaces left for future use as sanitary sites (Hogrewe et al, 1993). This practice is common in peri-urban areas of developing countries and eventually leads to poorly planned communities with narrow streets and irregular layouts which make it extremely difficult to install and operate sanitation facilities (Paterson et al, 2007; Hogrewe et al, 1993).

Unreliable water supply: Though regular water supply in low-income cities is a notable challenge (Sigel et al, 2011), peri-urban areas receive a disproportionally inadequate share, just as they do with other infrastructural services (Paterson et al, 2007; Parkinson and Tayler, 2003). According to Ghana's National Water Policy (MWRWH, 2007), only 55% of urban residents are served with piped water; worse still, *"peri-urban areas and the densely populated poor urban areas' customers receive supplies once a week or none at all"* (p. 29). In such areas, a wide range of technical options are ruled out.

Low income levels: Living in a peri-urban area could render people poor as a result of loss of livelihood to urbanisation when farmlands are demarcated for residential and other land uses (Allen, 2003). High unemployment rates have therefore become more closely linked with peri-urban dwellers than rural and urban dwellers (Sigel et al, 2011; Hogrewe et al, 1993). Poverty in peri-urban areas affects ability to pay for services or invest in household latrines. Even where public latrines are provided by donors or the government, the collection of user fees to break even on operation and maintenance compels some residents to resort to open defecation as observed in Prampram, Ghana (Hua et al, 2011).

2.4 Technical Issues with Dry Sanitation Systems

2.4.1 Introduction

Dry sanitation systems are popular in low-income settings, in general, due to their requirement of no or very little water for regular operation other than cleaning and hand washing purposes. Although the composting latrine is also a dry sanitation system, it is not as popular in Ghana as the simple pit and ventilated improved pit latrines, which are the most widely used technologies by Ghanaian households. Even though the simple pit latrine represents the cheapest form of sanitation possible (Franceys et al., 1992), it generates offensive odours and is associated with the breeding of insects especially house flies, mosquitoes and cockroaches. At their worst, their level of sanitary hygiene is only a little better than open defecation (Cotton et al., 1995). Consequently, their use in urban slums and high density periurban areas is limited. To address the limitations of the simple pit latrine, the ventilated improved pit (VIP) latrine is designed with a venting system that controls odour and fly nuisances and has a high potential of meeting the sanitation needs of peri-urban households. This section explains the design concept of the VIP latrine, especially its odour control mechanism and other issues related to the functioning of the technology.

2.4.2 The ventilated improved pit latrine concept

The main difference between the VIP and the simple pit latrine is that the pit cover slab of the former is fitted with a vent pipe that is covered at the top with a fly screen to control odour and fly nuisance. Odour control is achieved through the chimney effect that allows the circulation of air from the superstructure into the pit via the squat hole and out via the vent pipe as shown in Figure 2-3.

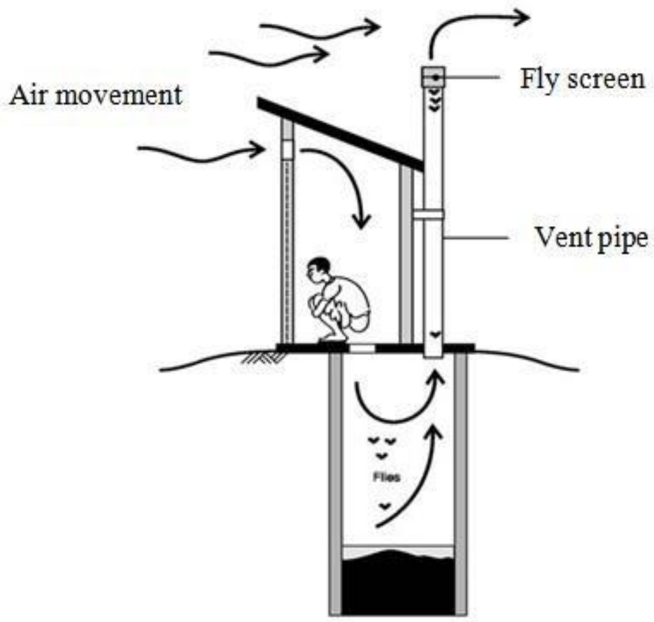


Figure 2-3: The ventilation mechanism in a VIP latrine

Source: Harvey et al., 2002

The vent pipe is also responsible for directing flies produced in the pit to the external bright light at the top of the pipe. Flies are prevented from escaping through the vent pipe by the fly screen and die of dehydration (Brikke and Bredero, 2003) or fall back into the pit to die eventually. External flies attracted to the odour emitted from the top of the vent pipe are also denied entry by the fly screen.

2.4.3 Enhancing odour control in VIP latrines

The problem of intense odour with the simple pit latrine is addressed in the ventilated improved pit (VIP) latrine with structural modifications that enhance the exchange of air between the pit and the external environment via the superstructure and vent pipe. The VIP is estimated to achieve odourless conditions when airflow rate through the vent pipe reaches 10 m^3/h but 20 m^3/h is recommended to ensure adequate factor of safety (Ryan and Mara, 1983a). The scientific principles underlying the rate of ventilation in the vent pipe are explained in Box 2-1.

Based on the scientific principles in Box 2-1, specific technical guidelines have been developed to guide the design of the VIP latrine in a manner that enhances the rate of ventilation through the vent pipe. The salient design guidelines are summarised in Box 2-2. Most notable among the guidelines is the size of vent pipes required. Table 2-2 summarises the sizes of vent pipes recommended to achieve the above levels of ventilation.

Box 2-1: The science of ventilation in vent pipes

Ventilation through the vent pipe of a VIP latrine is controlled by similar scientific principles as those which govern airflow through chimneys. The major factor which determines the rate of ventilation or airflow in a vent pipe is the difference in pressure between the ends of the pipe (ASW, 2011), i.e. the difference between the pressure of air in the pit of the latrine and the external air at the top of the pipe. This pressure difference has been attributed to two main phenomena, namely: the stack effect and Bernoulli's principle (Awbi, 1994).

The stack effect, which is also referred to as natural draft, is the phenomenon in which a mass of hot air rises or is displaced by a colder air mass due to the relatively lower density of the hot air (Wong and Heryanto, 2004). For this reason, ventilation caused by the stack effect is sometimes referred to as buoyancy ventilation (Wong and Heryanto, 2004). This phenomenon occurs in the VIP latrine as cold external air enters the pit through the superstructure and displaces hot air in the pit through the vent pipe. This effect is enhanced by the heating effect of the sun on the vent pipe which increases the temperature of the column of air in the pipe (Ryan and Mara, 1983a). Enhancement of stack ventilation is the reason why it is sometimes recommended that vent pipes should be painted black in order to absorb and retain the sun's heat energy (Mara, 1984).

On the other hand, the pressure gradient between the ends of the vent pipe is established by the faster movement of air across the top of the pipe which reduces the pressure at the top of the pipe in accordance with Bernoulli's principle (ASW, 2011). According to Bernoulli's principle, in the absence of energy (head) losses, the sum of the pressure energy, kinetic energy and potential energy possessed by a fluid remains constant (Darby, 2001). Thus, with potential energy remaining constant at a constant height, increase in kinetic energy or wind speed leads to a drop in air pressure at the top of the vent pipe. Since external air farther from the ground is less obstructed and moves faster, the reduction in pressure is enhanced if the height of the vent pipe is increased. The suction effect of wind is also enhanced by installing a pipe of a bigger diameter which provides a relatively larger cross-sectional area over which the action of wind takes place (Ryan and Mara, 1983a).

Generally, the suction effect of wind at the top of the vent pipe has been found to be more important than the stack effect (Ryan and Mara, 1983a). However, stack ventilation is highly relevant if the local wind speed is less than 0.5 m/s. In such cases, painting the vent pipe black is highly recommended (Ryan and Mara, 1983a). It is generally recommended to design the superstructure in such a way that air enters only through the windward direction and prevented from leaving the superstructure through openings in other directions in order to increase the pressure of air in the pit of the latrine (Mara, 1984). However, it is not clear as to what extent this design criterion can affect the ventilation rate through the vent pipe as compared to the speed of the wind on top of the vent pipe.

Based on the considerations of the stack effect and Bernoulli's principle in the design of the VIP latrine, Ryan and Mara (1983a) identifies a number of parameters that may be necessary to monitor in VIP performance studies. These include the:

- temperature of the ambient air and the air inside the vent pipe;
- external wind speed measured at a point near and at the same height as the top of the vent pipe;
- air velocity within the vent pipe;
- average atmospheric pressure; and relative humidity

Table 2-1: Minimum sizes of vent pipes

Type of vent pipe	Minimum size for 10 m^3/h ventilation rate	Minimum size for 20 m^3/h ventilation rate
Asbestos cement (AC) or polyvinyl chloride (PVC) pipe	100 mm diameter	150 mm diameter
Cement-rendered, bamboo or other rural vent pipes	200 mm diameter	230 diameter
Brickwork	180 mm square	230 mm square

Sources: Ryan and Mara, 1983a; Mara, 1984

Box 2-2: Guidelines for odour control in VIP latrines

a. The vent pipe should be installed to a minimum height of 500 mm above a flat roof or the highest point of a sloping roof; for conical roofs, the vent pipe should be at least as high as the apex of the roof.
b. Where local wind speeds exceed 3 m/s, the diameter of asbestos cement (AC) and polyvinyl chloride (PVC) vent pipes may be reduced to 100 mm while those of other types may be reduced to 200 mm instead of the dimensions stated in Table 2-1 for a 20 m^3/h ventilation rate.
c. For vent pipes serving two adjacent pits as in double-pit VIPs, the dimensions stated in Table 2-1 for 20 m^3/h ventilation should be maintained irrespective of the local wind speed.
d. For multiple alternating pits such as those used as communal latrines, a minimum of 200 mm diameter AC or PVC vent pipe should be provided
e. Where local wind speeds are less than 0.5 m/s, the vent pipe should be painted black to enhance thermally induced ventilation.
f. The vent pipe should be located on the windward side of the superstructure.
g. Openings of a total area not less than 3 times the cross-sectional area of the vent pipe should be provided on the windward side of the superstructure; if both openings and vent pipe cannot be located on the windward size, preference should be given to openings on the windward side.
h. Openings in the opposite side to the windward direction should be avoided to avoid a drastic reduction in the pressure difference required to cause up-draught in the vent pipe.
i. The squat hole or toilet seat should not be covered to allow air flow through the superstructure into the pit.

(Cotton et al., 1995; Feacham et al., 1983; Franceys et al., 1992; Mara, 1984; Ryan and Mara, 1983a)

Although adherence to these technical recommendations in Table 2-1 and Box 2-2 has been found to effectively control odour (Feacham et al., 1983; Franceys et al., 1992), their level of complexity may be above the capacity of many households in low-income peri-urban areas. The double-pit VIP developed with these guidelines in Ghana where it is locally known as the Kumasi Ventilated Improved Pit (KVIP) latrine has been particularly noted as being too complex and expensive (Jenkins and Sudgen, 2006). Such level of complexity may lead to poorly constructed latrines as households may lack knowledge of all relevant guidelines or seek to minimise cost. Poorly constructed latrines that fail to adequately control odour would discourage regular patronage by the prospective users and adoption by other households. To address these concerns, it would be necessary to assist households with technical support services through the local government system or use of community structures to train local artisans in latrine construction.

The above guidelines were found to achieve good odour control, mostly based on the feedback of users of the latrines studied in Africa. However, no studies have reported the use of modern gas detectors to quantify the actual levels of various odorous gases that can be maintained in latrines constructed in accordance with these guidelines. This could make research on odour control less subjective and contribute to the development of permissible levels for public health regulation, especially in the monitoring of public toilets in low-income countries.

2.4.4 Other odour control measures

a. Use of a water seal

Technologies such as the pour-flush, aqua privies and septic tanks make use of a water seal to prevent odorous gases from reaching the superstructure. For effective odour prevention, the following recommendations have been made:

a. The depth of the water seal, in a pour-flush latrine should be 20—30 mm in a 50—70 mm diameter water trap as shown in Figure 2-4 (Harvey et al., 2002; Roy et al., 1984)
b. The chute of an aqua privy latrine should extend to 50—75 mm below the water surface in the tank to effectively seal off odours (Brikke and Bredero, 2003; Franceys et al., 1992; Harvey et al., 2002). This requires that the water level above the sludge should be at least 75mm (Brikke and Bredero, 2003).

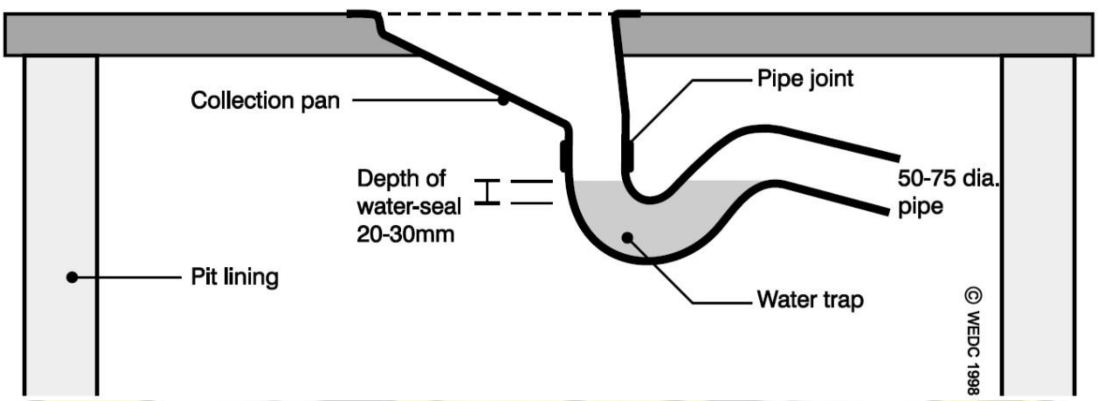


Figure 2-4: Cross-section of a typical pour-flush pan with a water-trap

Source: Harvey et al., 2002

b. Addition of substances

Various substances have been reported as being added to excreta by latrine owners in low-income countries to reduce odour. Substances that have been recognised by experts as inhibiting odours and commonly recommended for use, especially in composting latrines, are mostly absorbents such as sawdust, wood ash, dry grass, husks, peat moss, etc. (Brikke and Bredero, 2003; Fraceys et al., 1992; Kalbermatten et al., 1980). Most of these substances were thought to be readily available at an affordable price or at no cost in the peri-urban environment where latrine owners may keep gardens (Kalbermatten et al., 1980). However, recent sharp rises in population densities in peri-urban areas (Barrios et al., 2006; Paterson et al., 2007) make this claim contestable.

No guidelines were found on the optimum quantities of the various substances required to achieve an acceptable level of odour control for any given excreta loading rate. Such data would be useful to help households achieve a good level of odour control with minimal material doses. Given the bulky nature of some of these materials, applying optimum quantities is absolutely necessary to avoid compromising the excreta storage capacity of latrines.

2.4.5 Techniques for odour measurement

a. <u>Human-dependent techniques</u>

Various methods and techniques exist for measuring the concentration or intensity of odour which make use of a human agent. These include the olfactometric method of *dilution-to-threshold* which measures the total effect of odour as detected by humans (Gostelow and Parson, 2001). Essentially, the method expresses odour intensity in terms of the number of dilutions with odourless air required to reduce the odour concentration to the threshold detectable by the human nose (Capelli et al, 2013). Commonly referred to as dynamic olfactometry, this method has been adopted in standard practices such as the European Union's *Air Quality – Determination of Odour Concentration by Dynamic Olfactometry* (EN 13725, 2003) and the United States' *Determination of Odor and Taste Threshold by a Forced-Choice Ascending Concentration Series Method of Limits* (ASTM E679, 2011).

Another olfactometric method is the *referencing method* in which a series of concentrations of n-butanol is used as a standard Odour Intensity Referencing Scale (OIRS) to which an odour monitor or pollution inspector compares the odour intensity of a sample (McGinley, 2002; Powers, 2004). It is employed in standard practices such as the United States' *Standard Practice for Referencing Suprathreshold Odour Intensity* (ASTM E544, 2010). Beside these, odour may also be measured using the *ranking method* in which panellists rank samples on an ordinal scale (Powers, 2004). This method has been recommended for latrine improvement research for assessing latrine users' perception of the odour intensity after introducing an odour control technique (Ryan and Mara, 1983b).

Common to all of the above methods is the use of human agents for the assessment of odour intensity. This raises concerns about the reliability and reproducibility of these methods due to the potential variability in the sensitivity of an individual assessor or a panel of assessors (Powers, 2004). Human-dependent odour measuring techniques have, therefore, been criticised as being subjective.

b. Non-human-dependent techniques

In response to the limitations of human-dependent techniques, more recent methods have sought to eliminate the subjective judgement of human assessors. These include the use of surrogate compounds and the electronic nose. Compounds whose concentrations correlate well with odour measures are used as surrogates or proxies for odour intensity (Powers, 2004). Even though the use of surrogate compounds is an objective method, it is criticised as being mere concentrations of a compound rather than a representation of the experience of odour sensation perceived by humans (Powers, 2004; Sironi et al, 2007).

On the other hand, electronic noses have been developed with a complex human-nose-like structure to mimic the human sense of smell (Pearce, 1997; Sankaran et al, 2012). They employ a pattern recognition system to recognise simple and complex odours (Gardner and Bartlett, 1994). Nevertheless, the use of the electronic nose is still an emerging technology whose applications have only received attention in industrialised countries due to their high cost.

For environmental sanitation research in low-income countries there still remains the challenge of how to objectively determine the level of odour in latrines to assess the improvements introduced by new latrine designs and maintenance practices. In this regard, the emergence of portable gas detectors for real-time measurements of concentrations of volatile excreta constituents offers an opportunity to advance the use of surrogate compounds for odour measurement in latrines. The question of the concentrations of the surrogate compound not being representative of the experience of odour sensation perceived by humans could be potentially resolved by comparing the results with the latrine users' perception of odour and benchmarking the concentrations of the surrogate compound with respect to latrine users' perception of odour. After establishing the relationship between the surrogate compound and the perception of latrine users, the concentrations of the surrogate compound could then be used to objectively provide an estimate for the level of odour in a latrine without any human agency.

2.4.6 Fly control measures

The installation of a vent pipe and water traps as discussed above are also meant to control the proliferation of flies in latrines. For the VIP latrine, the following specific measures are recommended for controlling flies and other insects (Curtis and Hawkins, 1982; Franceys et al., 1992; Mara, 1984; Ryan and Mara, 1983a):

a. The vent pipe should be installed as vertical as possible to easily direct flies in the pit to the light of the sky.
b. The top of the vent pipe should be covered with an insect screen having apertures not exceeding 1.2 mm x 1.5 mm to prevent entry of flies and mosquitoes.
c. The toilet room should be kept as dark as possible so that flies in the pit would not be attracted to light in the toilet room.
d. The door should be closed when the toilet is not in use to keep the room dark.
e. An insect screen may be used to cover the squat hole when not in use.

In recent times, efforts to improve the VIP have replaced masonry seats with prefabricated porcelain bowls fitted with plastic seats and covers like those used in water closet toilets. In addition to its aesthetic value, the smooth surface of the porcelain bowl allows easy cleaning while the plastic seat offers a more comfortable seating arrangement. Also, the plastic cover supposedly prevents flies from entering or leaving the bowl or pit. However, complete covering of the toilet seat is known to disrupt the chimney effect as noted above. Based on successful use of insect traps over

VIP squat holes in Tanzania (Curtis, 1981), a potential improvement could be the replacement of the solid cover with an insect screen fitted in a plastic frame. However, the introduction of screened seat covers could also interfere with the chimney effect due to the reduced flow area and head losses associated with airflow through the fly screen (Ryan & Mara, 1983a). Such interference may be compensated for by a revision of existing guidelines on vent pipe dimensions but no such investigation has been reported.

2.5 Research Gaps

A review of existing literature reveals that adapting existing guidelines on pro-poor sanitation systems to the evolving conditions of low-income peri-urban areas and urban slums has not been given much attention. Since pioneering research in the late 20th Century developed the existing VIP design codes and guidelines, not much further work has been done to re-evaluate the relevance of these guidelines in some specific geophysical contexts such as the low-income peri-urban setting. Consequently, not much recent work has been seen in which modifications of the conventional designs have been tested in a bid to introduce innovations that address challenges with existing designs.

Further research is needed to explore opportunities for relaxing or modifying existing design codes to respond to the infrastructural limitations of peri-urban areas. Notably, population explosions in these areas and the inability of governments to match population growth with public infrastructure, especially water supply, place constraints on the selection and design of some sanitation technologies. For instance, lack of regular water supply implies that most households have to depend on dry sanitation systems, with the ventilated improved pit (VIP) latrine becoming increasingly popular in these areas. However, the performance of this technology is very sensitive to environmental factors such as wind speed and direction that are influenced by uncontrolled land development. Particularly, multiple extensions to houses in response to increasing demand for residential accommodation tend to alter the circulation of air within the neighbourhood and lead to situations where existing VIP latrines that were originally built with openings facing the wind direction later become disoriented as the wind direction changes. In such cases, future research needs to explore the feasibility of a VIP latrine design that would be independent of the direction of wind.

Furthermore, existing literature such as Ryan and Mara (1983a) recommend the use of user perceptions to evaluate the impact of technological innovations on odour in latrines. Although there has been some effort to quantify odour in terms of the concentrations of volatile constituents of excreta by Lin et al. (2013), the question of the relationship between such concentrations and the actual human experience of and tolerance for odour in latrines has not been satisfactorily answered.

This thesis sought to fill these research gaps by evaluating the improvement resulting from field modifications of the conventional VIP latrine in the coastal periurban setting of Ghana. It also sought to test the relationship between the concentrations of selected volatile constituents of excreta in latrine cubicles, namely hydrogen sulphide and ammonia, and the perception of odour reported by the latrine users.

3 MATERIALS AND CHAPTER 3: MATERIALS AND METHODSMETHODS

3.1 The Study Area

3.1.1 Location and rationale for selection

The study was conducted in Prampram, the administrative capital of the NingoPrampram District, which is one of sixteen (16) local government areas in the Greater Accra Region of Ghana. The Ningo-Prampram District, with an estimated population of 73,386, is situated between latitudes 5^{0}45’N and 6^{0}05’N and longitudes 0^{0}05’W and 0^{0}20’W. The District lies along the coast of the Gulf of Guinea in the south-eastern part of Ghana and covers a total land area of 750 square km (NPDA, 2012).

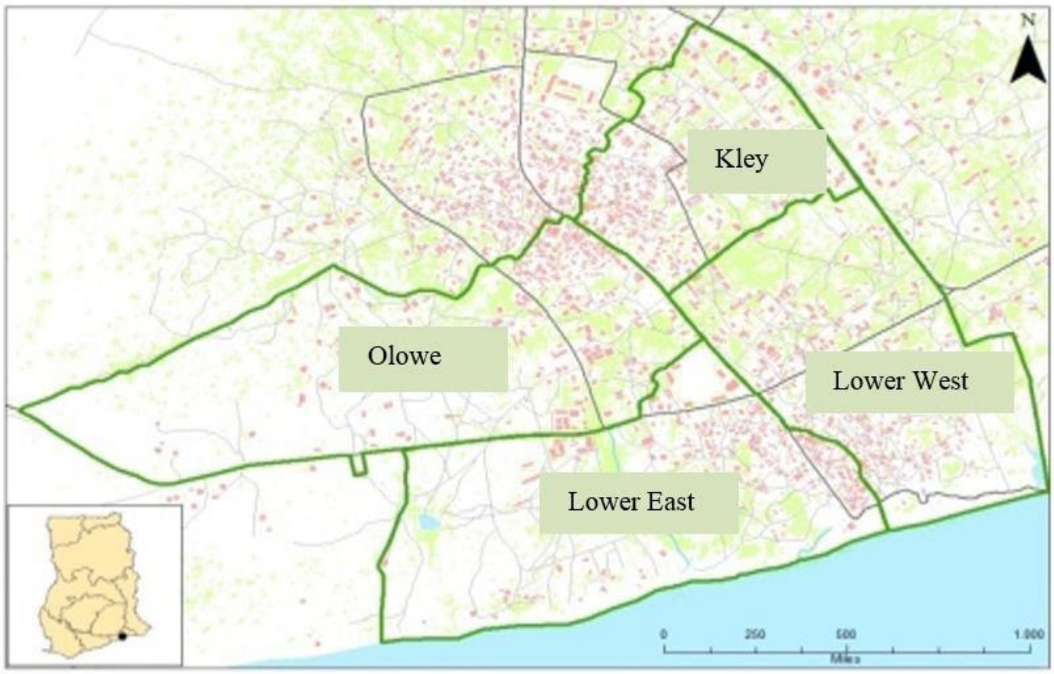


Figure 3-1: Layout of Prampram Town

Credit: SUSA Ghana and Dodowa Health Research Centre, Ghana

The District shares a boundary with the Tema Metropolis where Ghana's most important port, the Tema Harbour, is located. Many communities in the District, including Prampram, are less than an hour drive from Accra, the national capital. Prampram was selected for this study due to its proximity to the Accra and Tema Metropolitan Areas, which makes it experience nearly all the socio-economic and physical characteristics that constrain the provision of sanitation in peri-urban settings as described in the previous chapter. Whiles many other communities would satisfied this criteria, Prampram was purposively selected for the broader SUSA Ghana project which included this PhD study. The choice was also informed by the existence in the community of the Demographic and Health Surveillance System managed by the Dodowa Health Research Centre, a partner institution of the SUSA Ghana project.

3.1.2 Demographic and socio-cultural characteristics

The Prampram Township has a population of about 7800 and 1635 households (DHRC, 2012). Due to its proximity to the Tema and Accra Metropolitan Areas, the Township is growing rapidly with a spill-over effect of population explosions in these Metropolitan Areas. Rapid urbanisation of the Township is also attributable to the recent establishment of the Central University College within a 15-minute drive from the Township. The Town thus provides accommodation to staff and students of the University College.

Prampram is a traditional community, which has maintained its core traditions and cultural values in spite of the rapid urbanisation. Traditionally the Township is divided into an upper and a lower hemisphere (Upper Prampram and Lower Prampram) with the Lower Prampram suburb lying along the coastal line and

Upper Prampram being farther north from the sea. Traditionally, the Upper and Lower Suburbs, with their respective sub-chiefs under the Prampram Traditional Council, form the basis of segmenting the township for various traditional and developmental activities. Politically, each hemisphere is divided into two Electoral Areas, namely Olowe and Kley in Upper Prampram and Lower East and Lower West in Lower Prampram.

The main occupation of the residents are fishing, farming and trading. Livelihoods in the Upper suburb, where vegetable farming has been the main source of income, have been more affected by rapid urbanisation due to the conversion of agricultural lands into residential plots. There are two health facilities in the Township, a public Health Centre and a private clinic.

3.1.3 Water supply and sanitation

The state of water supply and environmental sanitation is similar to the trend in many Ghanaian peri-urban townships. The main source of water supply is piped water from the distribution network of the Ghana Water Company Limited. However, actual flow of water into the community occurs once or twice in a week. Residents who do not have adequate capacity to store water rely on vendors who receive bulk supply from tanker trucks at a relatively higher price. No sewerage infrastructure exists in the community so all residents depend on on-site sanitation technologies for excreta collection and disposal. Generally, household latrine coverage is low; many residents depend on public toilets and the practice of open defecation at the beaches and in bushes is rampant (Hua et al, 2011).

3.2 Research Approach

3.2.1 Assessment of usage and barriers to use of latrines

The study was designed to assess usage of all types of existing latrines in terms of the proportions of households using various types of technologies and the proportion of latrine users who actually used their latrines within 24 hours of being surveyed. Factors affecting the use of latrines were qualitatively identified through focus group discussions. Barriers to latrine usage were identified as the reasons reported by prospective latrine users for avoiding their respective latrines.

3.2.2 Assessment of factors influencing odour levels in latrines

Potential factors affecting the level of odour in latrines were assessed in terms of how they influence the concentration of hydrogen sulphide and ammonia in the latrine cubicles. To use as surrogates for the level of odour in latrines, this study determined the correlation between the concentrations of hydrogen sulphide and ammonia in latrine cubicles and the perception of the level of odour reported by the latrine users. The concentrations of the gases were measured with a portable gas detector as described in Section 3.4.4.3 of this chapter while the users' perception of odour was assessed on an ordinal scale as described in Section 3.4.2.

3.2.3 Testing of modifications of the VIP latrine

This study was designed to test how some modifications of the conventional VIP latrine design would affect the ventilation rate through the vent pipe, which is recognised as the key feature of the technology responsible for odour control (Ryan and Mara, 1983a; Mara, 1984). The following modifications were tested in an experimental VIP latrine:

- **Introduction of a window in each side of the superstructure** to ensure entry of air into the latrine irrespective of the direction of the local winds. The conventional VIP design recommends the provision of a window or opening only in the windward direction to avoid loss of air pressure difference which causes up-draught in the vent pipe.

- **Installation of an insect screen in openings** to prevent entry of insects, rodents and reptiles. The conventional VIP design does not recommend the use of such insect screens in order to avoid head losses across the net.

- **Variation in the diameter of the vent pipe** to determine the optimum diameter that could achieve the recommended ventilation rate or compensate for any effect of the above modifications on the ventilation rate. The recommended diameter for single pit VIPs is 150 mm or 100 mm where local winds exceed 3 m/s.

- **Variation in the height of the vent pipe above the roo**f to determine the optimum height that combines with the above factors to achieve the recommended ventilation rate or compensate for any effect of the above modifications on the ventilation rate. The recommended height above a slanted roof, as used in the experimental VIP, is 500 mm from the highest point of the roof.

3.3 Sampling of Latrines and Latrine Users

The study involved three types of latrines, namely household, shared and public. Although the JMP defines shared latrines to include those shared at home by two or more households as well as communal or public latrines, this thesis distinguishes between these two categories to reflect the formulation of the post-2015 water and sanitation targets which recognises latrines shared at home and excludes communal latrines (WHO/UNICEF, 2013). Shared latrines, in this thesis, refer to those shared at home by two or more households while communal or public latrines are those that are open to all persons and may be subject to the payment of a user fee. The term 'private latrines' is used to refer to both household and shared latrines whose use is restricted to specific eligible users.

A total of 88 private latrines comprising the simple pit, the ventilated improved pit and the water closet technologies, were identified using random walks guided by a household database obtained from the Dodowa Health Research Centre, which maintains a demographic and health surveillance system in the study area. The selected latrines comprised 41 household and 47 shared ones. For each private latrine, the owner of the facility and four other users comprising an adult male and female, and a young male and female, were targeted to be included in a questionnaire survey. Thus, the number of respondents per latrine ranged between 1 and 5 depending on the sexes and age groups of the users. A total of 189 users of private latrines were involved in the study.

All seven public toilets used in the community were also included in the study. Users of public latrines were selected to participate in the study from those who visited the facility on the day of the survey. 10% of male and female users were sampled guided by previously conducted user head counts. The first user at the age of 13 or above to exit the facility at the start of a session and willing to participate in the study was selected. Thereafter, the next user was surveyed until the number of male and female respondents reached 10% of the average daily patronage. A total of 165 users were selected from the seven communal latrines.

The study also involved households without access to sanitation at home who were expected to be using communal latrines or practising open defecation. Households were selected from within a 500 metre radius around each of the 7 communal latrines. Thirty nine to 42 households, one per house, were sampled from every other house along a route randomly selected from the latrine location. The questionnaire was administered to one respondent of 18 years or above who volunteered to participate in the study. In all, 283 study participants were selected from households without private latrines.

3.4 Data Collection Techniques

3.4.1 Focus group discussions

Five focus group discussions were held as part of the assessment of usage and barriers to use of latrines. They comprised two male and two female groups, with each gender group divided into adults and youths between the ages of 13 and 17 years. The fifth group was made up of communal latrine caretakers that were responsible for the operation and maintenance of communal latrines including the collection of user fees. Each of the gender groups was made up of 8—10 participants. The communal latrine caretakers' group was made up of five caretakers (2 males, 3 females) from 5 out of 7 communal latrines in the community.

At each meeting, the key question addressed by the participants was what factors they perceived to encourage or discourage them from using a particular latrine, whether private or public. The factors mentioned by the groups in the open discussion were recorded under themes that were pre-identified in literature. The groups then ranked the relative importance of the themes as shown in Table 4-5 in Chapter 4. Where a group did not mention any factor associated with a particular theme, such themes were introduced to them and included in the ranking. This was intended to assess how important the groups considered those themes they initially overlooked as compared to the ones which they identified themselves.

The youth group discussions were held in English while the adult and latrine caretakers' discussions were held in the local Ga-Dangme language, though some participants occasionally spoke in English or Akan, Ghana's most popular local language. The youth group discussions were moderated by the researcher. For the adult and latrine caretakers' groups, the researcher was assisted by a native GaDangme speaker who helped to interpret contributions made in that language between the researcher and participants that did not understand either English or Akan. On average, each group discussion lasted for about an hour.

3.4.2 Questionnaire surveys

Questionnaires were orally administered to the three categories of study participants described above as part of the assessment of usage and barriers to use of latrines, as well as the user perception of the level of odour in latrines. The questionnaire administered to households that had access to a latrine at home (either household or shared) sought to assess whether the respondents consistently used their private facility or what factors occasionally compelled them to practise open defecation or use a communal latrine. The questionnaire also assessed the perceptions of the respondents of the level of odour in the latrines they used using the ranking method in which participants are asked to indicate the level of odour they perceive on an ordinal scale (Powers, 2004; Ryan and Mara, 1983b). In this study, the participants were asked to indicate their perception of the level of odour on a three-level ordinal scale: "the odour level is bad or very intense", "the odour level is moderate or acceptable" and "there is no bad odour". A similar questionnaire was administered to users of public latrines as they visited the latrines to assess their perception of the level of odour. Another questionnaire administered to households living within 500m of public latrines sought to establish whether the respondents consistently used the nearest communal latrine and what factors motivated or discouraged them from consistently using the communal latrine.

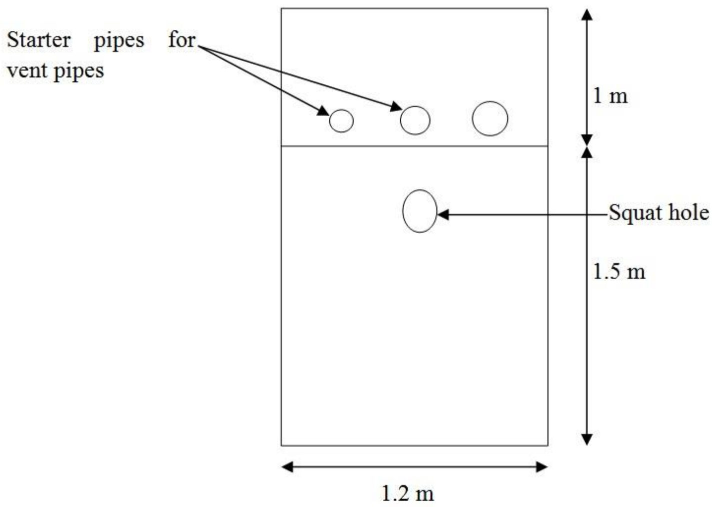
3.4.3 Observations

Observations were made at both private and communal latrines to appreciate their designs and physical conditions as part of the assessment of usage and barriers to use of latrines. It was useful in obtaining an understanding of barriers reported by study participants. The user population of communal latrines were also observed through headcounts conducted from 4 am to 10 pm for seven consecutive days.

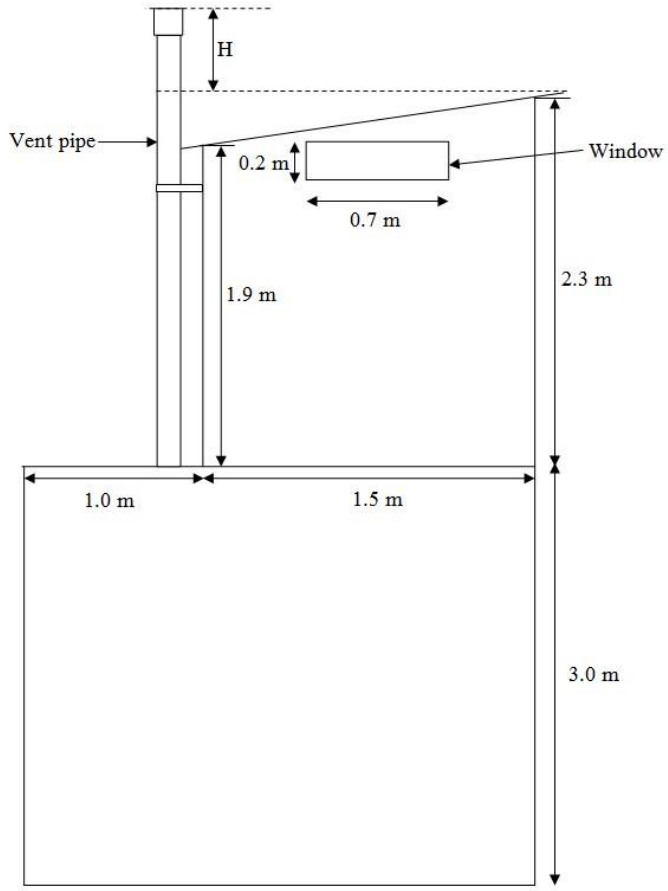
3.4.4 Field measurements

a. <u>Description of experimental VIP latrine</u>

The experimental VIP latrine which had internal cubicle dimensions of 1.2 m x 1.5 m was built on a pit of internal dimensions 1.2 x 2.5 x 3.0 m as shown in Figure 3-2



(a) Plan



(b) Side elevation

Figure 3-2: Plan and side elevation of experimental VIP latrine

A window of dimensions 0.2 x 0.7 m was provided in each side of the latrine in a wooden frame that allowed the installation of an insect screen of apertures 1.2 mm x

1.2 mm as and when it was required in the experimental setup. The dimension of the window was chosen so that the area of the opening was at least three times the crosssectional area of the biggest vent pipe to be tested as recommended by Ryan and Mara (1983a). Thus, 0.2 x 0.7 cm was chosen to arbitrarily exceed three times the cross-sectional area of a 200 mm diameter vent pipe, which was the biggest used in the study. The wooden frame also allowed closure of any window at any time by covering with a piece of plywood nailed into the frame as shown in Figure 3-3

Figure 3-3: External views of the experimental VIP latrine

For the purpose of installing vent pipes of variable diameters (100 mm, 150 mm and 200 mm), three starter pipes for these pipe diameters were cast into the concrete slab behind the latrine. However, only one vent pipe was installed at a time while the other two starter pipes were capped. Table 3-1 shows a summary of the design criteria that were modified. The latrine was constructed close to the compound of a basic school where it was used by an average of 20 school children daily during the monitoring.

Table 3-1: Summary of modified design criteria

Design criterion	Conventional design guideline	Modification tested
Position of windows/openings	To be provided only in windward side of latrine	A window provided in each side of the latrine
Installation of insect screens in windows	Not recommended	Insect screens installed in windows
Diameter of vent pipe	150 mm for PVC pipes	100 mm and 200 mm in addition to the standard (150 mm)
Height of vent pipe	A minimum of 500 mm above roof	250 mm, 750 mm and 1000 mm in addition to the standard (500 mm)

b. <u>Setup combinations</u>

The experimental latrine was set up to test the effect of only one factor at a time. Three pipe diameters of 100 mm, 150 mm and 200 mm were tested at the recommended minimum height of 500 mm. Each diameter was repeated for heights (H) of 250 mm, 750 mm and 1000 mm. For each pipe diameter and height, the latrine was set up with only one window opened in the windward direction as in a standard VIP. Then, for the same diameter and height, all four windows were opened. These two setups were then repeated with an insect screen installed in the window(s). Table 3-2 summarises how the various factors were combined in 16 setups involving the 100 mm diameter vent pipe.

Table 3-2: Setup combinations for 100 mm diameter vent pipe

Setup	Diameter (mm)	Height (mm)	Window type	Net installed
1	100	250	Standard	No
2	100	250	Multiple	No
3	100	250	Standard	Yes
4	100	250	Multiple	Yes
5	100	500	Standard	No
6	100	500	Multiple	No
7	100	500	Standard	Yes
8	100	500	Multiple	Yes
9	100	750	Standard	No
10	100	750	Multiple	No
11	100	750	Standard	Yes
12	100	750	Multiple	Yes
13	100	1000	Standard	No
14	100	1000	Multiple	No
15	100	1000	Standard	Yes
16	100	1000	Multiple	Yes

For the three different diameters, a total of 48 different setups were studied. Each setup was monitored for a day from 5am to 4pm. However, setups of the commonest design in which a 100 mm diameter pipe is installed to a height of 500 mm above the roof, with no insect screen in the window(s), were repeated for two additional days each for both the standard window and the multiple windows. The ventilation rate and air temperature in the vent pipe were measured at hourly intervals as well as the external weather conditions comprising the wind speed, temperature, humidity and absolute pressure.

In addition to these setups, additional measurements were taken to verify the assumption that the ventilation rate in a standard latrine would be drastically reduced if the direction of wind changes and the only window provided is on the leeward side.

This was done by closing three windows and leaving only the one in the leeward side of the latrine opened. Further measurements were taken by closing all the windows to test the relative importance of the circulation of air through the superstructure and the action of wind on top of the vent pipe.

Aside from these, 6 existing latrines in the community with varying levels of odour, measured in terms of the concentration of hydrogen sulphide, were monitored to verify the relationship between the ventilation rates in their vent pipes and the level of odour. This was intended to verify whether odour-free conditions could be guaranteed when the recommended ventilation rate is achieved or other operation and maintenance factors could influence the level of odour irrespective of the design of the latrine.

c. Measurement of concentrations of hydrogen sulphide and ammonia in latrines

Concentration of hydrogen sulphide and ammonia were measured using the Aeroqual Series 500 portable gas detector with hydrogen sulphide and ammonia sensors shown in Figure 3-4. The device, produced by Aeroqual Limited of New Zealand, has a detection limit of 0.01 ppm for hydrogen sulphide and 0.2 ppm for ammonia. This device was selected on the basis of cost, portability, simplicity of operation and ability to detect levels of the surrogate compounds below the recommended threshold for annoyance. The device was initially calibrated and used within the validity period of the calibration certificate. After switching on the device, it was allowed to warm up for a minimum of 10 minutes to burn off any contaminants as specified in the user guide.

Figure 3-4: The Aeroqual Series 500 portable gas detector

Figure 3-5: Positioning of gas detector to take measurements in a VIP latrine

In-between readings, it was kept in stand-by mode to keep it warm. In each latrine the device was positioned at the edge of the seat or squat hole as shown in Figure 3-5 and allowed to log the concentration of the gases for 10 continuous minutes with data logging set at a minute interval. During data logging, the door of the cubicle was closed just as it is when the latrine is being used.

d. <u>Measurement of ventilation rates and air temperature in vent pipes</u>

Ventilation rates and air temperature in vent pipes were measured with the aid of a hot wire anemometer, Airflow Model TA430 shown in Figure 3-6, manufactured by TSI Incorporated of the United States of America, following procedures described in the device's *Operation and Service Manual*. The probe of the anemometer was horizontally inserted into a hole drilled in the vent pipe at half-way along the pipe length (Ryan and Mara, 1983b) and taped to avoid any escape of air as shown in Figure 3-7. For each experimental setup, data was logged at a minute interval for 10 continuous minutes. This was repeated at hourly intervals over the period of monitoring (05:00—17:00 GMT).

Figure 3-6: The Airflow Model TA430

Figure 3-7: The Airflow Model TA430 as used in the field

e. Measurement of elements of weather

Elements of weather comprising external wind speed, temperature, humidity and atmospheric pressure were measured with the aid of the PCE-FWS 20 Weather Station manufactured by PCE Instruments UK. The device was mounted ***"at a point near as possible to, and at the same height as, the top of the vent pipe"*** (Ryan and Mara, 1983b; p. 6) as shown in Figure 3-7. The device was programmed to log data at 5-minute intervals, which was its minimum data logging interval.

f. Geotechnical investigations

Geotechnical investigations were conducted to assess effect of the nature of soils on the on the function of latrines. Specifically, tests were conducted to verify whether the infiltration rate of soils at latrine locations affected the production and emission of gases from the latrine pits by influencing the moisture content of excreta. The investigations were conducted by experts from the Geotechnical Laboratory of the Civil Engineering Department. Due to budgetary constraints, the tests were limited to five locations spread across the study area.

3.5 Data Analysis

3.5.1 Analysis of proceedings of focus group discussions

Proceedings of focus group discussions were recorded in audio format and transcribed. Native Ga-Dangme and Akan speakers translated contributions made in those languages into English. The factors mentioned by the group members as influencing the choice of latrines were organised under themes that were predetermined from literature. The relative importance of the each theme was determined by calculating the average rank assigned by the various focus groups.

3.5.2 Analysis of questionnaire survey

From the results of the questionnaire survey, persons who failed to use their respective latrines were marked as 'sanitation defaulters'. Those who had access to private latrines but failed to use them over the previous 24 hours in favour of open defecation or a communal latrine were marked as defaulters of private latrines. Similarly, those who lived within 500 metres of a communal latrine but failed to use them in favour of open defecation were marked as defaulters of communal latrines. Those who did not feel like defecating or were absent from home were not treated as defaulters. Reasons cited by defaulters for not using their sanitation facilities are reported as barriers. Multiple barriers were cited by some respondents. Frequencies of barriers were recorded and their prevalence expressed as a percentage of the total frequencies.

Identified barriers were grouped into technical and non-technical categories. Barriers classified as technical are those relating to design and construction but also includes operational and maintenance factors that affect technical performance indicators such as odour and fly control.

3.5.3 Analysis of relationship between surrogate compounds and latrine users' perception of odour

The concentrations of the surrogate gases were calculated for various typologies of latrines that are known to exhibit certain patterns of odour levels such as dry and wet sanitation systems. The three levels of odour perception, i.e. 'bad or very intensive odour', 'moderate or acceptable odour' and 'no bad odour' were assigned numerical values of -1, 0 and 1 respectively. For each latrine, an average or composite perception (CP: $-1 \leq CP \leq 1$) was calculated and used for further analysis.

Table 3-3: Classification of latrines based on composite user perception

Classification	Composite user perception
Bad or very intensive odour	$CP < -0.33$
Moderate or acceptable odour	$-0.33 \leq CP \leq 0.33$
No bad odour	$CP > 0.33$

The Pearson correlation coefficient between the average concentrations of the surrogate compounds and composite perception of each latrine was determined to assess whether the concentrations of the compounds reflected the latrine users' perception of odour. The latrines were then classified into three depending on whether the composite perception fell within the lower, middle or upper third of the range of perception as shown in Table 3-3. Subsequently, the means of concentrations of the surrogate compounds for latrines in the different ranges of composite perception and different typologies were calculated and compared using analysis of variance (ANOVA) to verify whether they were statistically different.

3.5.4 Statistical tools

Prevalence of factors measured in percentages such as barriers to latrine usage was compared using odds ratios. The student t-test was used to compare the difference of two means while comparison of three or more means was done using analysis of variance (ANOVA). The linear regression model was used to assess the influence of various factors on the ventilation rate in a vent pipe. Significance testing was done at 5% significance level. Statistical analyses were done using the SPSS statistical software. However, the development of a regression model for ventilation rates in vent pipes was done in the Minitab statistical software.

4CHAPTER USAGE AND BARRIERS TO USE OF LATRINES IN 4: USAGE AND BARRIERS TO USE OF LATRINES IN THE

LOW-INCOME PERI-URBAN SETTING

THE LOW-INCOME PERI-URBAN SETTING

4.1 Introduction

This Chapter presents the results of a study conducted in Prampram, a coastal periurban community in Ghana, to understand the factors influencing latrine usage and the barriers or constraints that discourage regular use of existing latrines. The study covered household, shared and communal latrines. The Chapter also discusses potential interventions to improve latrine usage in such settings.

Data were collected through five focus group discussions, questionnaire surveys involving 189 users of 88 private latrines and 283 expected users of seven communal latrines, as well as structured observations. Group discussions were recorded in audio format and transcribed. The overall importance of the various themes were compared by calculating the average rank assigned by the various focus groups. The results of the FGDs are presented under Section 4.3 as ‘Factors affecting latrine usage’. The results of the quantitative survey have been presented under Section 4.4 as ‘Barriers to usage of existing latrines’. Persons who failed to use their respective latrines were marked as 'sanitation defaulters'. Reasons cited for not using sanitation facilities are reported as barriers. Frequencies of barriers were recorded and their prevalence expressed as a percentage of the total frequencies.

4.2 Existing Technologies and their Usage

4.2.1 Existing technology options

Table 4-1 shows the technology options used by households that have access to private latrines at home. Only 15% of all households in Prampram have access to a private latrine including those shared by two or more households. The ventilated improved pit (VIP) latrine is the most popular sanitation technology, used by 47% of households with private latrines, followed by the water closet and pit latrine that are used by 29% and 21% respectively. Among the technologies defined as 'improved' by the JMP, the pour-flush is the least used, with less than 1% of households with private latrines using the technology. Although national policy bans the use of the bucket latrine and the conservancy labour system (Jenkins and Scott, 2007) for being unhygienic (MLGRD, 2010a), it is still used by nearly 3% of households with private latrines.

Table 4-1: Technology options used by households with private latrines

Technology options	% of households with private latrines using the technology option (N[1]=244)	% of all households in Prampram using the technology option (N=1635)
Water closet	28.7	4.3
Ventilated Improved Pit (VIP)	46.7	7.0
Pit latrine	21.3	3.2
Pour-flush	0.8	0.1
Bucket latrine[2]	2.5	0.4
Total	**100**	**14.9**

1. Number of households using 88 private latrines; 2. Not qualified as an improved sanitation facility

Source: Own field data/SUSA Ghana baseline survey (Hua et al, 2011)

All households depend on on-site technologies because no sewerage network exists in the town. Seventy per cent of households with private latrines rely on dry sanitation technologies. The predominance of dry technologies was attributed to, among other factors, poor water supply in the town. Some study participants revealed that they could afford the construction of the water closet technology but the poor water supply situation compelled them to adopt the VIP latrine. In one household, it was observed that the existing VIP latrine was converted from a water closet. The septic tank was left in the compound in the hope of converting back to a water closet if water supply improves in the future. Apart from the water supply situation, other reasons stated for the use of the dry technologies (simple pit and VIP) were their relatively lower cost and smaller space requirements.

Users of the water closet technology cited its potential to minimise odour and flies and the prestige accorded to it in the community as their motivation for adopting it, though some users of the technology admitted that it was challenging ensuring that water is always available for flushing. The pour-flush technology, which could be more appropriate due to the small quantity of water it requires, is not common in the community.

Out of seven communal latrines in the community, one had the water closet technology and another used the pour-flush technology without a water seal while the remaining five used the VIP technology. Beside these, one water closet and a VIP facility had been abandoned. The VIP was full and could not be desludged while the water closet was closed due to management and maintenance challenges.

The poor water supply situation in the community makes the greater reliance on dry sanitation systems by households appropriate. For private latrines, the preference for the VIP by many (47%) households with private latrines could be attributed to their improved ventilation, hence, their potential to minimise the emission of odour and heat (Ryan and Mara, 1983a; Mara, 1984). This preference is consistent with the identification of odour and heat control by the focus groups (Section 4.3) as a factor that influences latrine usage in the community. Even though the adoption of dry sanitation systems is appropriate, their construction in some cases was not done in line with relevant technical guidelines. For instance, the lengths of vent pipes on some VIP latrines were found to be less than the recommended 500 mm above flat and sloppy roofs, or up to the highest point on conical roofs (Mara, 1984). Besides, all private VIP latrines had vent pipes of 100 mm diameter, which is only recommended where the average wind speeds reach 3 m/s (Ryan and Mara, 1983a). Vent pipe sizes of 150 mm would be more appropriate since the average wind speed was found to be 2.1 m/s as reported in Chapter 6 of this thesis. Inadequate vent size and height leads to reduced ventilation which is the main mechanism for reducing odour and heat in VIP latrines (Ryan and Mara, 1983a; Mara, 1984). Besides, it was observed that some relevant operational guidelines were not followed. For instance, some twin-pit VIP latrines were observed to have both squat holes opened and in use simultaneously. This practice defeats the purpose of pit rotation that allows such latrines to be used continuously (Mara, 1984).

For communal latrines, the known poor performance of VIPs under high faecal loading rates makes their use at the communal level inappropriate (MLGRD, 2010b). Under high faecal loading rate, the practice of pit rotation (Mara, 1984) is not possible since cycle duration becomes too short to allow complete decomposition of excreta for manual removal. Desludging by a cesspit emptier is often not feasible because by the time the pit becomes full, the initial sludge deposits would have partially decomposed and hardened, making it difficult to dislodge by a cesspit emptier. On the other hand, the management of the water closet technology as a communal facility in a water-scarce community could be inefficient and expensive. This was observed in the communal water closet facility in the study area. In such a case, the pour-flush technology would be most appropriate. Compared to the water closet, the pour-flush uses minimal water, i.e., 1.5—2 litres per flush (Roy et al., 1984; Mara, 1985) as compared to nine litres per flush for a standard water closet. Also, unlike a VIP, sludge removal by a cesspit emptier can be easily done since regular flushing prevents the hardening of sludge.

4.2.2 Actual usage of available latrines

Table 4-2 presents data on the pattern of usage of private and communal latrines by their expected users over the 24 hours before the survey. The table shows the default rates among respondents who had access to private latrines, distinguishing among those who used household and shared latrines.

Table 4-2: Usage of private latrines

Parameter	Household facilities	Shared facilities	All private facilities
Number of facilities sampled	41	47	88
Average number of households per facility (standard deviation)	1.0 (0.0)	4.0 (1.8)	2.8 (2.0)
Average number of eligible users per facility (standard deviation)	3.6 (2.4)	9.7 (5.4)	6.8 (5.2)
Number of respondents	61	128	189
% who practised open defecation or used communal latrine over previous 24 hours	3.3%	3.1%	3.2%

Source: Own field data

Although usage of private toilets by the eligible users was found to be high, some users (about 3%) defaulted or failed to use their facilities over the previous 24 hours. Between users of household and shared latrines the difference in default rates was not statistically significant (odds ratio =1.05; p-value =1).

Table 4-3 shows the average daily patronage of the communal latrines based on user headcounts conducted from 0400 to 2200 GMT for seven consecutive days. It also shows the proportion of potential users of the various communal latrines who reported avoiding (defaulting) the use of the latrines over the previous 24 hours for various reasons reported in Section 4.4. Potential users of the communal latrines were defined as residents living within 500 m from the communal latrines who had no private latrines in their homes and were expected to be using the nearest communal latrine.

Table 4-3: Usage of communal latrines

Technology type	No of facilities in use	No. of cubicles	Average daily patronage [1]	Default rate among potential users [2] (N=283)
VIP	5	40	1044	71.1%
Water closet	1	10	145	97.5%
Pour-flush	1	32	322	74.4%
Total	**7**	**82**	**1511**	**75.3%**

*1. Calculated from user headcounts conducted from 0400 to 2200 GMT for seven consecutive days 2. Potential users were defined as residents living within 500 m from the communal latrines who had no private latrines in their homes and were expected to be using the communal latrines (**Source: Own field data**)*

It is seen from Table 4-3 that only about 25% of potential users of communal latrines reported using the nearest communal latrine over the previous 24 hours, with the rest practising open defecation. Reasons cited by the 75% who avoided the communal latrines to practice open defecation are analysed in Section 4.4. With 15% of households having access to latrines at home, the remaining 85% or 6630 of the total population of 7800 represent the potential users of communal latrines. This means the actual number of the 25% who reported using the communal latrines a day before the survey would be about 1658, which is fairly consistent with the results of user headcounts conducted at the communal latrines. From the user headcount survey, the daily patronage ranged from 1329 to 1657, with a seven-day average patronage of 1511.

The hourly pattern of patronage of communal latrines is shown in Figure 4-1. The accompanying data are presented in Appendix 4-1. On the average, 1511 persons visit the 7 communal latrines in a day. It is seen that the daily patronage of all the communal latrines peak in the mornings between the hours of 05:00 and 07:00 GMT and in the evenings between 17:00 and 19:00 GMT.

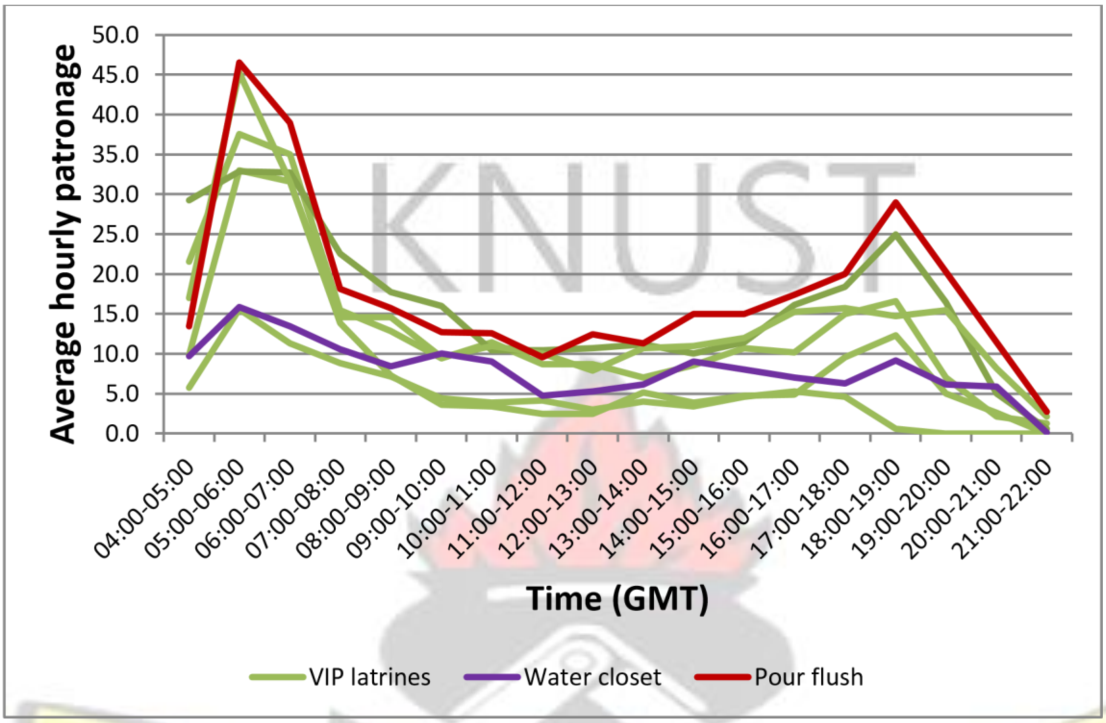


Figure 4-1: Hourly trend of patronage of communal latrines

A comparison of the usage of facilities under different ownership regimes (household, shared and communal latrines) provides some basis for pondering over the JMP's definition of 'improved sanitation' that recognises only facilities that are exclusively used by a single household. According to the JMP, only improved facilities (used by single households) are likely to be used consistently because those who do not have access to improved sanitation facilities are *"obliged to defecate in the open or use unsanitary facilities"* (WHO/UNICEF, 2006; p. 16). However, as shown in Table 4-2, the default rate among users of household (3.3%) and shared (3.1%) latrines was not statistically significant (odds ratio = 1.05; p-value = 1). This implies that having access to shared facilities at home could achieve as much impact on open defecation as exclusive access by a single household. This finding supports the JMP's emphasis on having access to latrines at home in the formulation of the post-2015

MDG targets on sanitation that prioritises the elimination of open defecation (WHO/UNICEF, 2014). Even though the average number of users of shared latrines was higher (9.7) as compared to household latrines (3.6), and could make them more likely to be unhygienic, this risk could be compensated for by the sharing of maintenance costs and cleaning responsibilities among the multiple households. It must, however, be noted that the sharing of latrines by too many households could lead to quarrels among users. As discussed later in Section 4.4, quarrels among users accounted for 12% of defaults among users of private latrines.

On the contrary, there was a significantly (three times) higher default rate among expected users of communal latrines (75%) as compared to users of latrines shared at home by two or more households (odds ratio = 3.09; p-value < 0.000). This confirms the observation that the availability of communal latrines does not necessarily lead to regular latrine usage (Biran et al., 2011). The implication of this finding is that the JMP's definition of improved sanitation is appropriate for excluding communal latrines. For latrines shared at home, it may be more appropriate to consider a limited number of households or a maximum user population per squat hole rather than classifying any level of sharing as unimproved. Another implication of this finding is that the pooling of resources among households for construction of a privately shared facility should be recognised as a potential tool for preventing open defecation and included in latrine promotion messages.

The hourly pattern of the patronage of communal latrines shows that the hours of 05:00—07:00 GMT and 17:00—19:00 GMT account for over 40% of the average daily patronage of the communal latrines, with the period 05:00—07:00 GMT alone accounting for nearly one-third (28%) of the patronage. This implies that managers and regulators of communal latrines need to pay maximum attention to the cleanliness of the latrines during these periods in order to minimise any risk of disease transmission through unhygienic conditions. It also suggests that adequate cleaning materials and personnel should be made available during these periods.

4.3 Factors Influencing Latrine Usage Identified by Focus Groups

Table 4-4 presents the factors identified by focus groups as influencing the participants' decision to use or avoid a particular latrine. The factors were organised into themes that were identified in literature. The relative importance of the various themes were ranked by each focus group. The results of the ranking of the themes is later presented in Table 4-5.

Table 4-4: Technical or technology-related factors affecting latrine usage in Prampram

Theme	Specific factors	Contributing group(s)
Safety	The structure should be strong and have no cracks	Young Males
	The size of the drop hole should not be too large so that one would not fall into the pit	Young Females
	It should not be possible for pests, reptiles and rodents to enter the cubicle or pit	Young males, Young females
	There should be a lighting system for night users	Young males
Level of odour and heat	There should not be excessive odour on the toilet so that the user's body will not smell after using it	All groups
	Chemicals should be applied to reduce the odour	Adult males, Adult females

	There should not be excessive heat from the pit because it increases the odour and gives women ‘white’ (local term for candidiasis)	Adult females, Communal latrine managers
Provision of a seat	A seat should be provided so that one can sit to avoid pains in the joints and to allow children, the aged and the physically challenged to use the toilet.	Adult females, Communal latrine managers
Flies nuisance	There should not be many flies on the toilet	Young females
Cleanliness	The toilet should be clean; there should be no contact with faeces or urine	All groups
	There should not be worms or maggots on the toilet	All groups
	The toilet should not be littered with anal cleansing materials	Young females, Adult females
	The toilet should be desludged promptly when it is full	Adult males
	There should be adequate water for flushing, if necessary, and for general cleaning	Young males, Adult males
	The technology should not require water for flushing so that it would be easy to keep clean.	Adult females
	Detergents and other cleansing chemicals should be used to clean the toilet	Young males, Young females
	There should be no dirt in the surroundings of the toilet	Young females
	Other users should not mess up the toilet room or squat on the toilet seat	Adult females
Accessibility	The toilet should be close to one’s home or location	Young males
	The toilet should be open or available all the time	Young males
	There should not be a long queue before using the toilet	Young females, Adult males

	The user fee should be affordable	Adult males
Hand washing facilities	There should be a hand washing facility	Young males, Young females

Source: Own field data

Table 4-5 presents the ranks assigned by each focus group to the various themes under which the factors affecting latrine usage were grouped. No group mentioned any factor relating to two themes found in literature, namely privacy and prevention of environmental pollution. These themes were introduced to the groups and included in the ranking. Nearly all groups ranked safety in terms of protection against structural collapse, falling through the squat hole and entry of reptiles and rodents etc. as the most important factor. Even though the adult females ranked cleanliness of the latrine above safety, their explanation showed that they actually valued a clean latrine because of the protection or 'safety' it provides against diseases but not just the sight or convenience of a clean toilet.

Table 4-5: Ranking of factors affecting latrine usage in Prampram by focus groups

Factors affecting latrine usage	**Ranking by Focus Groups**					
	AM	***AF***	***YM***	***YF***	***CLM***	***OVERALL***
Safety: The user should feel safe using the latrine in terms of protection against structural collapse and entry of reptiles etc.	1	3	1	1	1	1
Privacy: The privacy of the user should not be exposed	3/4	1/2	2	3	2/3/4	2
Seat: There should be a seat for the aged/children/disabled etc.	2	4	3/4	2	8/9	3

Pollution prevention: There should be no liquid discharges from the latrine that may pollute the environment	3/4	5/6/7	5	4	2/3/4	4
Cleanliness: The latrine should be clean	5	1/2	6	5	7	5
Odour and heat: There should not be excessive odour or heat in the latrine	6	5/6/7	3/4	8	2/3/4	6
Accessibility: The latrine should be readily accessible/available (no long queues or walking distance)	7/8	5/6/7	7	6	5/6	6
Fly prevention: There should not be many flies in the latrine	9	8	8	7	5/6	8
Hand washing facilities: Hand washing facilities should be provided	7/8	9	9	9	8/9	9

*NB: AM=Adult males; AF=Adult females; YM=Young males; YF=Young females; CLM=Communal latrine managers (**Source: Own field data**)*

The provision of hand washing facilities was the least important to nearly all the groups. The actual practice of hand washing was not observed among users of private latrines. For the communal latrines, none of the seven had a functioning hand washing facility. The adult female group explained that the availability of hand washing facilities at communal latrines is not much important to them because they can always wash their hands when they return home after visiting such facilities. In general, no obvious differences were observed in the relative importance assigned to the various factors by the different gender and age groups.

The factors identified by the focus groups as influencing latrine usage were generally consistent with those identified by other studies such as Appiah and

OduroKwarteng (2011), Biran et al. (2011) and Keraita et al. (2013). The frequent mentioning of factors relating to odour and heat emission could be associated with the fact that members of this coastal community have an age-old practice of open defecation on the beaches where they experience unlimited natural ventilation. Therefore, they could be easily irritated by the slightest level of odour and heat encountered in a latrine. This finding implies that technological innovation should pay much attention to increasing the level of ventilation in latrines.

An unusual observation from the focus group discussions was that no mention was made of privacy as a factor affecting latrine usage, not even by the female groups that are known to have a greater need for privacy (UNHR, 2011). However, after being introduced to them, privacy emerged as the second most important factor after safety. When asked about why they did not initially consider privacy as an important factor, a participant of the adult female group explained that they did not think about it because they do not have too much problem with privacy in relation to the toilet facilities they have in the community because there is a door for each cubicle. That notwithstanding, their attitude to privacy could also be due to the high prevalence of open defecation in the community. Open defecation at the beaches is customary, with specific sites designated for males and females, but within each sex group, there is no privacy. In that case, the provision of separate cubicles with doors, as observed at communal latrines, may be enough to address any concerns of privacy.

A comparison of the findings of the focus group discussions and the household surveys indicate that the most important factors recognised by focus groups as influencing their decision to use or avoid a latrine (safety, privacy and provision of seats for the aged, children and the physically challenged) were adequately catered for by existing latrines in the community. This is seen in the fact that the reasons cited by survey respondents for failing to use their latrines, as presented in Section 4.4, were not much related to these important factors. On the other hand, intense odour, desludging challenges and unhygienic conditions which were cited by many defaulters were actually observed in latrines.

4.4 Barriers to Usage of Existing Latrines

Table 4-6 presents the barriers cited by private and communal latrine defaulters for failing to use their respective latrines. The barriers have been grouped into technical or technology-related and non-technical categories. Cited barriers were more related to non-technical than technical factors. For communal latrines, intense odour was the most frequently cited technical barrier. With regard to private latrines, technical barriers mostly resulted from intense odour, desludging challenges and closure of latrines for chemical application to reduce sludge.

Table 4-6: Barriers to latrine usage reported by respondents of household surveys

Barriers	Frequency (%) among cited barriers to use of private latrines (N=65)*	Frequency (%) among cited barriers to use of communal latrines (N=177)*
Technical/technology-related		
Intense odour (ranked 6th from FGD)	7	23
Pit full (awaiting emptying or unable to empty)	7	-
Latrine closed for chemical application for sludge reduction	7	-
Having to squat (ranked 3rd from FGD)	3	-
No water for flushing	3	-
Heat from toilet	-	3
Safety concerns	-	2

Fly nuisance (ranked 8th from FGD)	-	1
All technology-related	***27***	***29***
Non-technical		
Latine inaccessible: Busy Key misplaced Locked or key hidden by landlord	 11 7 10	-
Unhygienic condition/poor user habits (ranked 5th from FGD)	15	7
Quarrels among users	12	-
Sheer preference for open defecation	10	11
Distance	-	28
User fee	-	21
Others	8	4
All non-technical	***73***	***71***

** N=Number of times various barriers were cited. Some respondents cited no barriers; others cited multiple barriers (**Source: Own field data**)*

Although intense odour was cited by defaulters of both communal and private latrines, it was more frequently cited by defaulters of communal latrines (23%) than private latrines (7%). The results indicate that even though the focus groups ranked intense odour as the 6th most important factor that influences their choice of latrines out of nine factors, it poses more challenges with the use of existing latrines while those factors which were ranked as being more important are already well addressed in the existing latrines. For instance, the focus groups identified privacy is a key factor in selecting a latrine but it was not cited as a barrier to latrine usage. This implies that the residents have no problem with the level of privacy they enjoy with the existing latrines while intense odour is a major technical challenge that requires attention in technology development.

Intense odour may result from poor design and construction of latrines as well as unhygienic usage and maintenance. Generally, technical challenges were mostly associated with dry sanitation systems. The most prominent non-technical barrier to private latrine usage was the latrine being inaccessible (28%). This resulted from the formation of queues due to high user population especially among latrines shared by multiple households or the misplacement of latrine keys. Other non-technical factors were user-related factors such as unhygienic practices by some users (15%) and quarrels over cleaning and maintenance responsibilities (12%). For communal latrines, the major non-technical barriers cited by respondents were distance to the nearest latrine (28%), the user fee (21%) and unhygienic conditions (7%).

4.5 Potential Interventions to Address Barriers to Latrine Usage

The barriers to latrine usage in Prampram may be addressed by a combination of technical and non-technical interventions.

4.5.1 Potential technical interventions

Figure 4-2 shows potential technical interventions for overcoming the identified barriers based on literature recommendations and good practices observed in the study area.

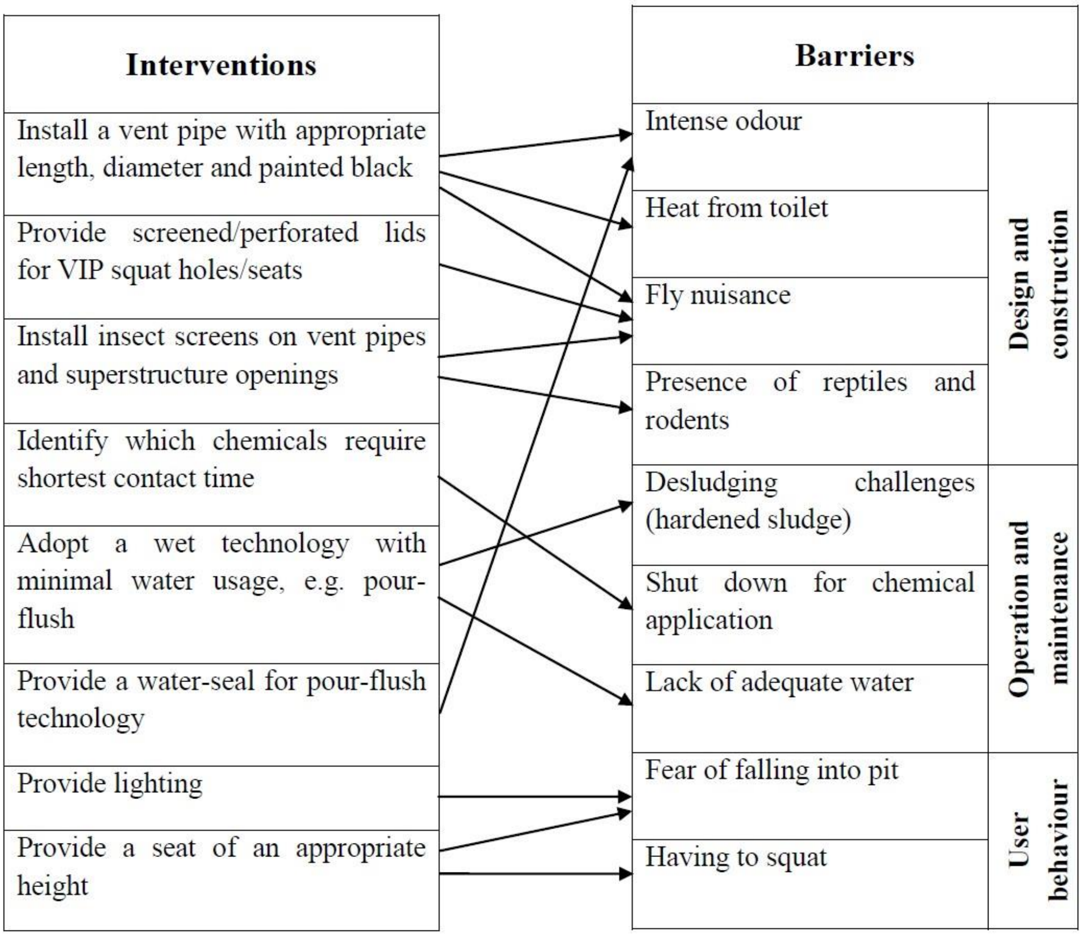


Figure 4-2: Technical intervention logic

They are aimed at addressing the fundamental technical challenges that create barriers to latrine usage. For instance, intense odour and heat from pits are often the result of poor ventilation in latrines and may primarily arise from poor design of vent pipes or incorrect positioning of superstructure openings in relation to the direction of wind. These defects were observed in some of the latrines in the community. Ventilation in VIPs as well as fly control may be improved by installing a vent pipe of appropriate dimensions to enhance the chimney effect (Ryan and Mara, 1983a; Mara, 1984).

Adoption of wet technologies is particularly recommended for public toilets. Their advantages were attested to by users and managers of a pour-flush public toilet recently constructed in the community. In addition to their capacity in handling high sludge loads, wet systems with a water-seal have a potential for controlling odour and heat emission as well as minimising fly nuisance. They also eliminate the challenge of hardened sludge which is associated with dry systems. Under the current circumstance where piped water is supplied to the community only once or twice per week, the development of sewerage systems is not feasible. Nevertheless, the pour-flush technology has a high chance of success if a moderate water storage capacity could be maintained.

Feelings of insecurity among toilet users were associated with the presence of reptiles or rodents in the toilet room and the fear of falling into the pit. Safety could thus be improved by designing the superstructure to prevent entry of rodents and reptiles. For instance, nets or other insect or reptile screens may be fitted on openings in the superstructure, though such openings would need to be enlarged to account for reduced air flow through the nets while maintaining privacy. Another safety measure is providing a squat hole of a maximum width not exceeding 200 mm (Mara, 1984) and providing smaller ones for children in selected cubicles in communal toilets. Safety could also be improved, especially for night users, by installation of a lighting system.

4.5.2 Potential non-technical interventions

The large number of private and communal latrine users who cited unhygienic practices by other users as their reason for defaulting the use of their latrines calls for measures to compel owners of private and communal latrines to ensure their hygienic maintenance. In this regard, special attention needs to be given to sanitary inspection in premises, which is one of the key tools for public health regulation emphasised in

Ghana's sanitation policy (MLGRD, 2010a). In particular, poor management practices of communal toilets such as inadequate cleaning and failure to desludge on time could be improved by public sector regulation and regular monitoring.

Furthermore, the establishment of a sanitation information desk at the offices of the local government (District Assembly) to guide households in technology selection and proper construction could lead to the construction of technically appropriate toilets to minimise the technical barriers discussed above. Nevertheless, such an intervention will need to be complimented with initiatives to deal with other socio-economic barriers such as financing, rights over land and the capacity of local artisans. The District Assembly could provide training on proper latrine construction to local artisans and issue them with licenses to operate in the District. A complaint system could then be instituted for feedback and monitoring of performance of artisans.

4.6 Summary of Key Findings

Most residents in the Ghanaian peri-urban township depend on dry sanitation systems due to irregular water supply, with the VIP being the commonest technology. Households that have access to private latrines highly patronise them, with shared latrines being no less consistently used than unshared ones as implied by the JMP. While additional studies in other communities are needed to confirm this finding, the results from Prampram give some evidence to the potential of privately shared latrines in preventing open defecation and the need to encourage co-tenants who cannot afford their own latrines to construct and share facilities. However, the findings of this study support the argument that public latrines do not guarantee regular latrine usage and should remain excluded from the definition of improved sanitation. Nevertheless, they should be provided in public places and in difficult areas where private latrines are not technically feasible for many households.

Participants of focus group discussions ranked safety and privacy as the most important factors that influence their decision to use or avoid a latrine facility. However, for those who failed to use their respective latrines, the reasons or barriers cited were those relating to odour and heat emission, unhygienic maintenance and lack of immediate access to facilities, which were also mentioned in the focus group discussions. Latrine usage in the study setting may be improved by increasing ventilation in latrines to minimise odour and heat emissions. This may require public sector support to households and latrine builders through development of technical guidelines, training and information services. For communal latrines, adopting wet technologies with a water-seal and a low water requirement can prevent hardening of sludge and allow easy desludging. The occurrence of unhygienic conditions in both private and communal latrines also calls for domestic sanitary inspection as well as public sector regulation and monitoring of communal latrines to demand their hygienic management.

5 FACTORS INFLUENCING ODOUR LEVELS IN LATRINES

CHAPTER 5: FACTORS INFLUENCING ODOUR LEVELS IN LATRINES

5.1 Introduction

The generation of offensive odours in some on-site sanitation systems, particularly the pit latrines, remains a critical determinant of latrine uptake and consistent usage among low-income households (Appiah and Oduro-Kwarteng, 2011; Keraita et al., 2013). This justifies continuing research to understand the factors which influence the level of odour and to optimise the mechanisms for controlling odours in latrines. In view of this, it is essential to have an objective means of measuring the level of odour to serve as a basis for assessing the efficiency of odour improvement techniques (Hudson et al., 2008; Sundberg et al., 2012).

The objective of this study was to understand the factors influencing the levels of odour in latrines measured in terms of the concentrations of hydrogen sulphide and ammonia which were initially examined as potential surrogates for odour. The Aeroqual 500 gas detector was used to measure the concentrations of hydrogen sulphide and ammonia in the latrines. A total of 189 users of private latrines and 165 users of communal latrines indicated their perception of odour on a three-level ordinal scale ranging from "the odour level is bad or very intense", "the odour level is moderate or acceptable" and "there is no bad odour". The three levels of odour perception were assigned numerical values of -1, 0 and 1 respectively. For each latrine, an average or composite perception (CP: $-1 \leq CP \leq 1$) was calculated and used for further analysis.

The Pearson correlation coefficient between the average concentrations of the surrogate compounds and composite perception of each latrine was determined to assess whether the concentrations of the compounds correlated with or reflected the latrine users' perception of odour. Analysis of variance and correlations were used to test the association between the levels of the surrogate compounds and various factors that could influence the concentrations of volatile constituents of excreta in the latrine cubicles.

5.2 Concentrations of Hydrogen Sulphide and Ammonia in Latrines

This section presents the concentrations of the surrogate gases for latrines of various typologies. The results are presented for latrines of different technologies and sharing status. Due to their peculiar characteristics, communal latrines were excluded from the comparison of odour levels among different technologies.

5.2.1 Concentrations of hydrogen sulphide and ammonia in latrines of different technologies

Table 5-1 shows the concentrations of hydrogen sulphide and ammonia among private latrines (used at home by one or more households) of different technologies. The concentrations of both hydrogen sulphide and ammonia varied significantly among the different types of technologies used at home by single or multiple households. For each surrogate compound, the concentrations were lowest in water closet (WC) technologies, moderate in ventilated improved pit (VIP) latrines and highest in traditional pit latrines, with the difference being significant at 1% level for each compound.

Table 5-1: Concentrations of surrogate compounds in latrines of different technologies

Technologies	N	Hydrogen sulphide concentration (ppm)		Ammonia concentration (ppm)	
		Mean (SD)	***F-stat (p-value)***	***Mean (SD)***	***F-stat (p-value)***
WC	13	0.01 (0.02)	F=4.972 (0.009)**	0.00	F=6.461 (0.002)**
VIP	70	0.03 (0.06)		0.30 (1.39)	
Simple pit	5	0.13 (0.22)		3.27 (6.26)	
Total	88	0.03 (0.08)		0.42 (1.96)	

*N=number in sample; SD=standard deviation; ** Significant at 1% level (**Source: Own field data**)*

This trend is consistent with the known differences in odour levels associated with these sanitation technologies. While the simple pit latrine is known to be most associated with bad odours, the water closet toilet with a well maintained water seal has no odour problems (Brikke and Bredero, 2003; Cotton et al., 1995; Franceys et al., 1992). The ventilated improved pit latrine has an odour control capability inbetween that of the simple pit latrine and the water closet. Although this sanitation technology is expected to be capable of achieving odourless conditions with a vent pipe of appropriate dimensions (Ryan and Mara, 1983a), it is often found with some level of odour, usually, due to improper design, construction or maintenance. This was observed among some of the latrines studied in Prampram.

5.2.2 Concentrations of hydrogen sulphide and ammonia in latrines of different sharing status

Table 5-2 presents a comparison of the concentrations of the surrogate compounds between latrines used by a single household and those shared at home by two or more households.

Table 5-2: Concentrations of surrogate compounds in household and shared latrines

Sharing status (all technologies)	N	Hydrogen sulphide concentration (ppm)		Ammonia concentration (ppm)	
		Mean (SD)	***t-stat (p-value)***	***Mean (SD)***	***t-stat (p-value)***
Household	41	0.02 (0.04)	t=1.632 (0.205)	0.29 (1.68)	t=0.348 (0.557)
Shared at home	47	0.04 (0.10)		0.54 (2.18)	
Total	88	0.03 (0.08)		0.42 (1.96)	

*N=number in sample; SD=standard deviation (**Source: Own field data**)*

Generally, latrines used exclusively by single households had lower concentrations of both hydrogen sulphide and ammonia as compared to those shared at home by multiple households but the differences were not statistically significant at 5% confidence level. This comparison did not account for the possible influence of technology differences between the two categories due to the few number of some technology options (simple pit and WC technologies). However, when the analysis was done for only VIP latrines, which dominated each of the ownership categories, the same trend was observed as seen in Table 5-3.

Table 5-3: Concentrations of surrogate compounds in household and shared VIP latrines

Sharing status (VIP technologies only)	N	Hydrogen sulphide concentration (ppm)		Ammonia concentration (ppm)	
		Mean (SD)	***t-stat (p-value)***	***Mean (SD)***	***t-stat (p-value)***
Household	29	0.02 (0.04)	t=0.622 (0.536)	0.41 (2.00)	t=0.497 (0.622)
Shared at home	41	0.03 (0.07)		0.22 (0.71)	
Total	70	0.03 (0.06)		0.30 (1.39)	

*N=number in sample; SD=standard deviation (**Source: Own field data)***

On the contrary, Table 5-4 shows that communal facilities had higher levels of both hydrogen sulphide and ammonia as compared to those used at home by one or more households, with the difference being significant at 5% confidence level.

Table 5-4: Concentrations of surrogate compounds in private and communal latrines

Private versus communal latrines (all technologies)	**N**	**Hydrogen sulphide concentration (ppm)**		**Ammonia concentration (ppm)**	
		Mean (SD)	***t-stat (p-value)***	***Mean (SD)***	***t-stat (p-value)***
Private (household or shared at home)	88	0.03 (0.08)	t=4.209 (0.043)*	0.42 (1.96)	t=4.512 (0.036)*
Communal	7	0.10 (0.13)		2.15 (3.31)	
Total	95	0.04 (0.08)		0.55 (2.11)	

*N=number in sample; SD=standard deviation; * Significant at 5% level* (***Source: Own field data)***

Similarly, when the comparison between private and communal latrines was restricted to only VIP latrines, the same trend was observed as shown in Table 5-5 but the difference was significant at 1% confidence level.

Table 5-5: Concentrations of surrogate compounds in private and communal VIP latrines

Private versus communal latrines (VIP technologies only)	**N**	**Hydrogen sulphide concentration (ppm)**		**Ammonia concentration (ppm)**	
		Mean (SD)	***t-stat (p-value)***	***Mean (SD)***	***t-stat (p-value)***
Private (household or shared at home)	70	0.03 (0.06)	t=3.252 (0.002)**	0.30 (1.39)	t=4.512 (0.000)**
Communal	5	0.13 (0.14)		2.99 (3.66)	
Total	75	0.03 (0.07)		0.48 (1.72)	

*N=number in sample; SD=standard deviation; ** Significant at 1% level* (***Source: Own field data)***

The significantly higher concentrations of the surrogate compounds measured in communal latrines is a confirmation of previously reported high levels of odour perceived by users of communal latrines in Ghana as compared to latrines used at home (Appiah and Oduro-Kwarteng, 2011). On the other hand, the insignificant difference between the concentrations of the compounds in latrines used by single households and those shared at home gives credence to recent arguments that latrines shared by two or more households should be considered as improved because they are not necessarily worse than those used by single households. In response to this argument, the WHO and UNICEF's Joint Monitoring Programme's formulation of the post-2015 MDG target on sanitation emphasises access to sanitation at home irrespective of its sharing status as against the current target that requires each household to have its own sanitation facility. Nevertheless, the results demonstrate that communal latrines could have significantly higher levels of odour that may be a barrier to consistent usage as reported by Obeng et al. (2015).

5.3 Correlation between Concentrations of Surrogate Compounds and User Perception of Odour

Table 5-6 shows the concentrations of the surrogate compounds for latrines that were classified as having very intensive odour, moderate odour or no bad odour, depending on whether their composite perception fell within the lower, middle or upper third of the range of composite perception (CP: $-1 \leq CP \leq 1$). It is seen from the table that the concentration of hydrogen sulphide significantly varies among latrines in the three categories of composite perception. A similar trend was observed for ammonia but the variation in the concentration of ammonia was only significant at 10% confidence level but not significant at 5% confidence level. Plots of the concentrations of the surrogate compounds versus the composite odour perception are shown in Figures 5-1 and 5-2.

Table 5-6: Concentrations of surrogate compounds for latrines of different user perception

User perception of odour	**N**	**Hydrogen sulphide concentration (ppm)**		**Ammonia concentration (ppm)**	
		Mean (SD)	F-statistic (p-value)	Mean (SD)	F-statistic (p-value)
Bad or very intensive odour (*CP*<-0.33)	7	0.10 (0.13)	3.513 (0.045)*	2.17 (3.30)	2.662 (0.067)
Moderate or acceptable odour (-0.33 ≤ *CP* ≤ 0.33)	67	0.04 (0.09)		0.52 (2.25)	
No bad odour (*CP*>0.33)	21	0.01 (0.02)		0.05 (0.22)	
Total	95	0.04 (0.08)		0.55 (2.11)	

*N=number in sample; SD=standard deviation; * Significant at 5% level (**Source: Own field data**)*

Latrines perceived by the users as having a bad or very intensive odour (with composite perception, *CP*<-0.33) had the highest levels of both hydrogen sulphide (Mean=0.10 ppm; SD=0.13 ppm) and ammonia (Mean=2.17 ppm; SD=3.30 ppm) whereas those perceived as having no bad odour (*CP*>0.33) had the lowest for hydrogen sulphide (Mean=0.01 ppm; SD=0.01 ppm) and ammonia (Mean=0.09 ppm; SD=0.4 ppm). Latrines with odour levels perceived to be moderate or acceptable (-0.33 ≤ *CP* ≤ 0.33) were in-between with mean hydrogen sulphide and ammonia concentrations being 0.04 ppm and 0.52 ppm respectively. The variance among the mean concentrations of hydrogen sulphide in the three categories of perception was significant at 5% level (p=0.045) but the difference among ammonia concentrations was not significant at 5% level (p=0.067).

Table 5-7: Correlation matrix among hydrogen sulphide, ammonia and user perception

Variable	Pearson correlation coefficient (p-value)	
	Composite perception	Ammonia
Hydrogen sulphide	-0.234 (0.022)*	0.365 (0.000)**
Ammonia	-0.185 (0.072)	

** Correlation is significant at the 5% level; ** Correlation is significant at the 1% level*

*(**Source: Own field data**)*

As shown in Table 5-7 the Pearson correlation coefficient between hydrogen sulphide concentrations measured in the latrines and the composite perception of the users of the latrines was evaluated as -0.234, which is significant at 5% level (p=0.022) while that for ammonia was -0.185, which is not significant at 5%
(p=0.072). It was also noted that the concentration of hydrogen sulphide had a significant correlation with that of ammonia (Pearson correlation coefficient = 0.365; p=0.000).

The results show that the concentration of hydrogen sulphide is a better surrogate of the level of odour as compared to that of ammonia. Given the significant correlation between hydrogen sulphide concentration and odour perception, the concentration of the compound may be adopted as a surrogate for the level of odour in latrines. Even though the perception of odour among any group of people may be dependent on their norms and cultures, the mean concentrations of the compound for the three different ranges of odour perception are consistent with current guidelines for the avoidance of annoyance. For hydrogen sulphide, a guideline value of 0.1 ppm (1.5 mg/m^3) is recommended for long-term exposure (averaging time of 24 hours) to prevent adverse health effects (WHO, 2000). However, for avoidance of "substantial complaints about odour annoyance", it is recommended that the concentration of the compound should not be allowed to exceed 0.05 ppm (7 $\mu g/m^3$) for a 30-minute averaging period (WHO, 2000). The consistency between the perception of the study participants and existing guidelines is an indication that the relationship between odour perception and the concentrations of the surrogate compounds may be extended to other communities. However, further studies are needed in other locations to arrive at a nationally representative relationship between the surrogate compounds and odour perception.

The results of this study show that latrines perceived to have a moderate or acceptable level of odour had an average hydrogen sulphide concentration of 0.04 ppm. This suggests that a higher level of hydrogen sulphide may not be tolerated in a latrine than what is generally recommended for prevention of odour annoyance in the environment. The results also show that the private VIP latrines, with an average hydrogen sulphide concentration of 0.03 ppm can provide a satisfactory level of odour to the users. On the other hand, the simple pit latrine, having an average hydrogen sulphide concentration of 0.13 ppm, is very likely to cause odour nuisance to the users.

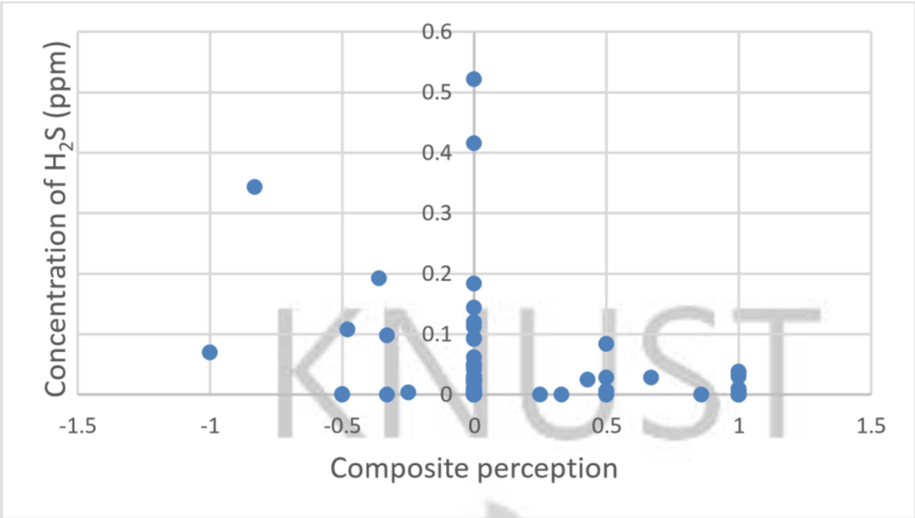


Figure 5-1: A plot of hydrogen sulphide concentration versus composite odour perception

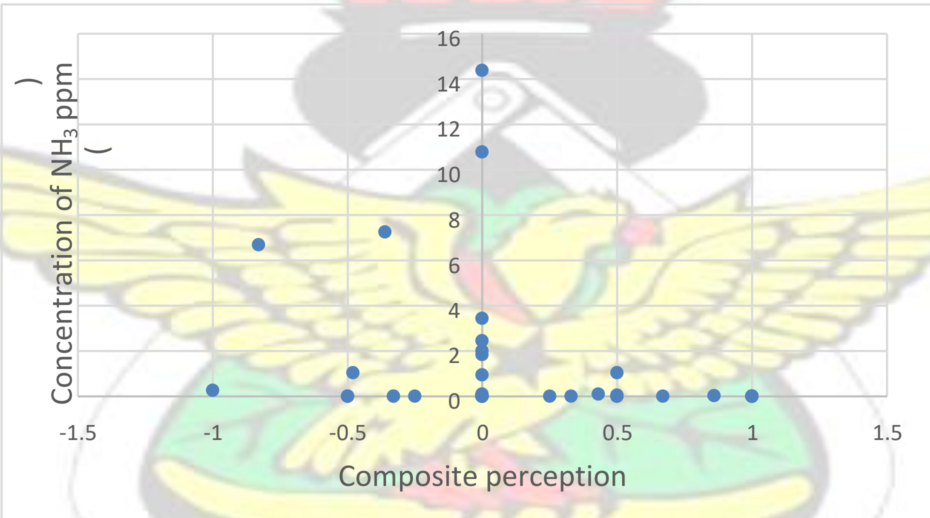


Figure 5-2: A plot of ammonia concentration versus composite odour perception

In this study, users of household latrines indicated how they perceived the level of odour in their latrines at the last time they used it in the day of the survey.

With this approach, a potential source of error could be the respondents' tendency to indicate a perceived odour level based on historical experience rather than the odour level on the day of the visit. This potential error could be avoided in future studies by requesting users to enter the latrine before being surveyed. They would then indicate how they perceived the level of the odour at that instant.

5.4 Influence of Soil Characteristics on Odour Levels

This section analyses the effect of soil factors that may influence the levels of the surrogate compounds measured in the latrines. This was informed by the assumption that low permeability, usually due to high proportions of clay and fine silt in the soil grading, would lead to a higher moisture content in excreta and, consequently, a higher level of odour or gas emissions (Panda, 2013). Geotechnical investigations were undertaken at the location of 5 VIP latrines to assess the characteristics of the soils and the influence of the permeability of the soils at the latrine locations on the concentrations of surrogate compounds

5.4.1 Soil characteristics

The results of tests conducted on these properties of the soils are summarised in

Table 5-8 while soil grading curves are presented in Figures 5-3 and 5-4. Determination of the water level using auger drilling showed that the water table was below 6 m, more than, at least, 2 m below the bottom of the latrine pits, which was indicated by artisans involved in the construction of the latrines as not exceeding 4 m.

Table 5-8: Soil characteristics at locations of selected VIP latrines

Toilet ID	Location Reference	Depth (m)	Soil Grading (%)				Infiltration rate (sec/mm)	H_2S Concentration (ppm)	NH_3 Con-centration (ppm)
			Gravel	*Sand*	*Silt*	*Clay*			
A	Lower Prampram	1.00-1.65	9.56	79.48	5.97	4.99	3.19	0.11	1.03
		2.30-5.00	2.2	70.54	7.23	20.03			
B	Kley	0.50-5.00	6.54	54.43	23.92	15.11	1.78	0.19	7.25
C	Olowe	0.62-2.00	2.16	71.3	21.38	5.16	0.89	0.34	6.68
		2.00-3.00	0	79.64	8.85	11.51			
D	Anglican School	0.30-3.00	6.22	53.27	12.32	28.19	29.88	0.00	0.00
E	Baptist School	0.66-1.50	0	70.2	8.34	21.46	16.8	0	0
		1.50-3.78	4.6	45.66	14.13	35.61			

Source: Field work undertaken by the Geotechnical Laboratory of the Civil Engineering Department, KNUST/Own field data

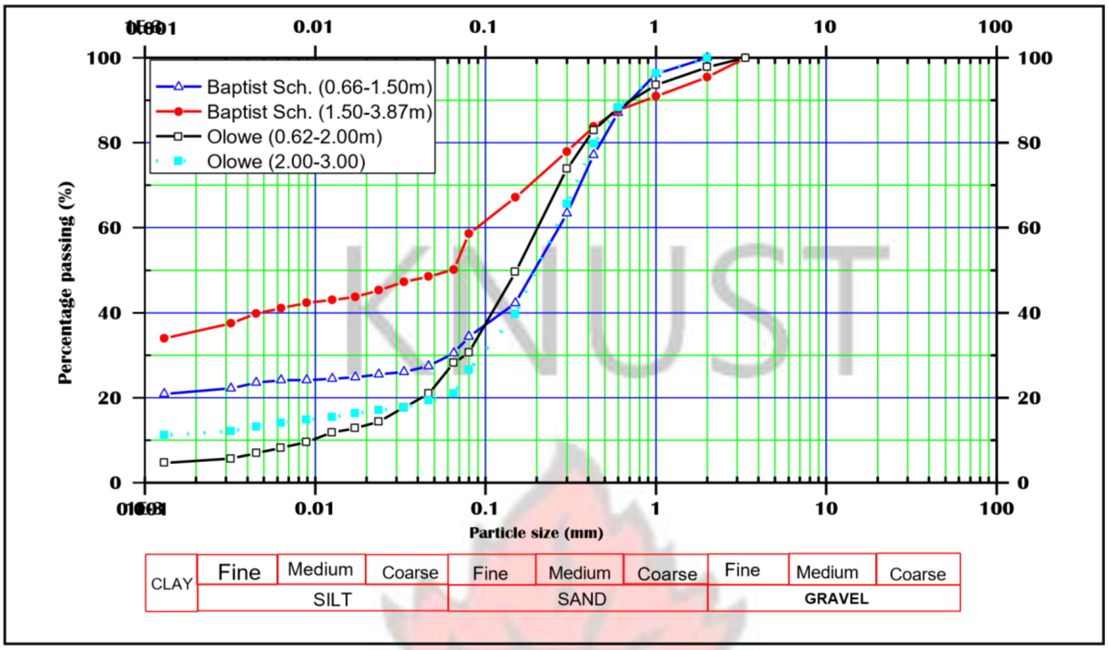


Figure 5-3: Soil grading curves for selected latrine locations

Source: Geotechnical Laboratory, Civil Engineering Department, KNUST

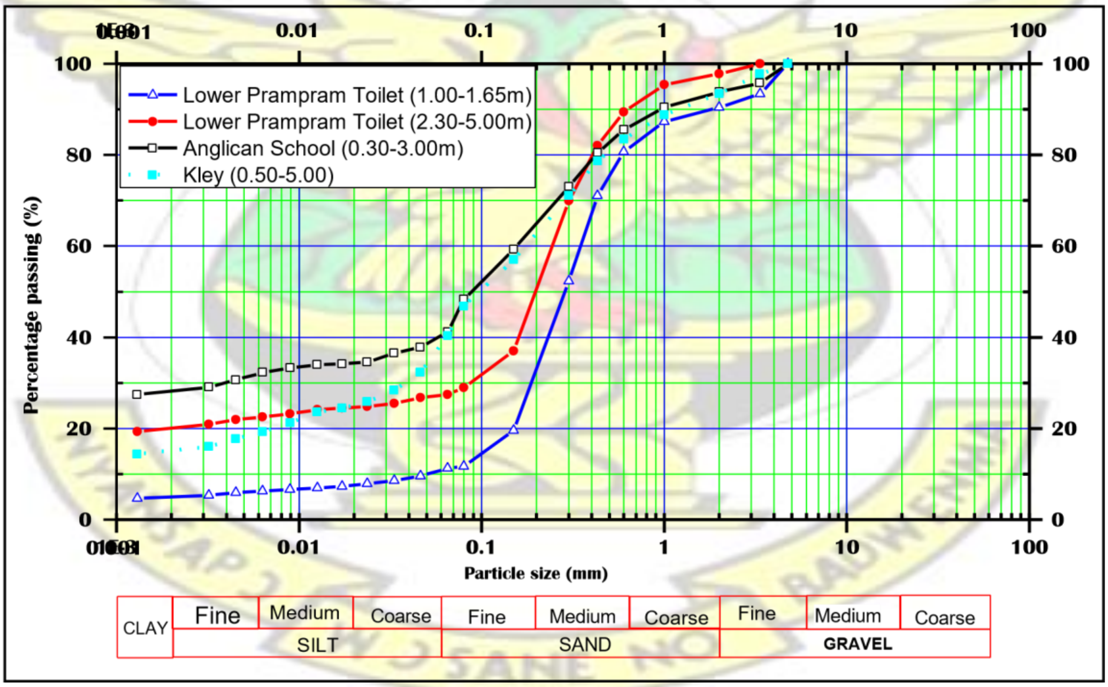


Figure 5-4: Soil grading curves for selected latrine locations

Source: Geotechnical Laboratory, Civil Engineering Department, KNUST

5.4.2 Influence of soil permeability on concentrations of surrogate compounds It was observed that VIP latrines sited at locations with poorer percolation (longer time per millimetre percolation) had lower levels of both hydrogen sulphide and ammonia as shown in Figure 5-5 but the relationships were not statistically significant. The Pearson correlation coefficient between percolation rate (in sec/mm) and hydrogen sulphide concentration was -0.79 (p-value=0.109) while the correlation between percolation and ammonia concentration was -0.73 (p-value=0.160). This observation is contrary to the expected relationship between percolation rate and the development of odour in latrines and suggests that some other factors have a stronger influence on the level of odour than the soil percolation rate.

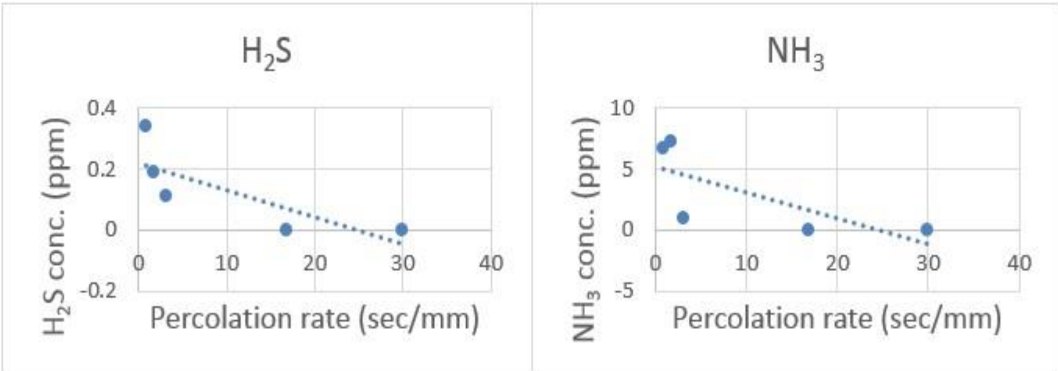


Figure 5-5: Variation of concentrations of surrogate compounds with percolation rate

5.5 Analysis of Other Factors that Influence Odour Levels

This section analyses the effect of potential factors that could influence the levels of the surrogate compounds measured in the VIP latrines. The factors analysed include:

i. the ventilation rates in the vent pipes
ii. the dimensions of the vent pipes
iii. operation and maintenance: the cleanliness of the latrines

5.5.1 Effect of ventilation rates in vent pipes on odour levels

Although the ventilation rate in the vent pipe of a VIP latrine is widely accepted as the main technology- or structure-related feature that determines the odour control efficiency of the VIP latrine, this relationship was verified among existing VIP latrines in Prampram to assess whether high odour in some latrines could be linked to low ventilation rates in the vent pipe.

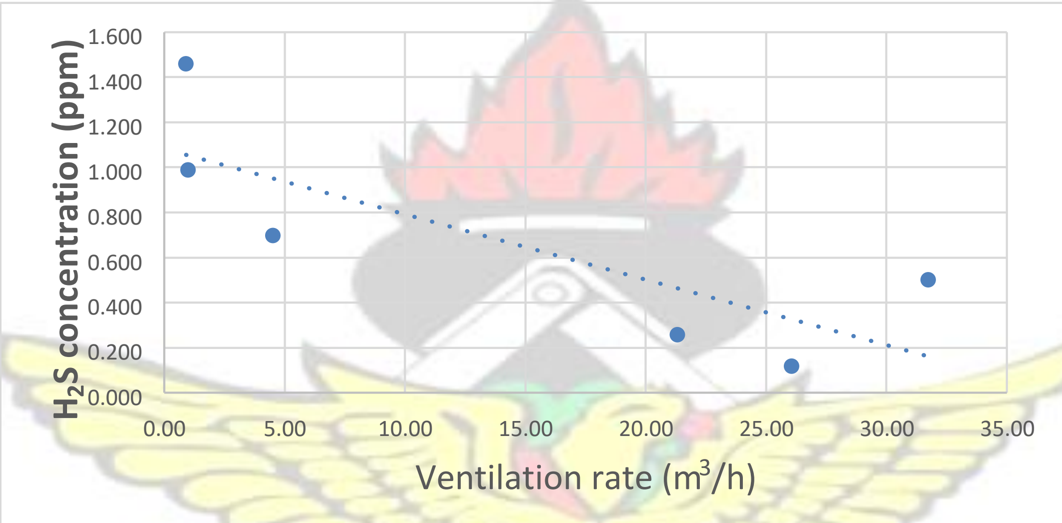


Figure 5-6: Relationship between hydrogen sulphide concentrations in VIP latrine cubicles and the ventilation rates through the vent pipes

Figure 5-6, based on data presented in Appendix 5-1, shows a plot of the levels of hydrogen sulphide against the ventilation rates measured in the vent pipes of the latrines. It is seen from the figure that the concentration of hydrogen sulphide decreased as the ventilation rate increased. The Pearson correlation coefficient between the two variables was found to be -0.8 (p-value=0.05). The small sample size, which resulted from equipment breakdown, accounts for why the high correlation coefficient of -0.8 still has a borderline significance at 5% confidence level but the results generally suggest that the concentration of hydrogen sulphide in the latrines is correlated to the ventilation rate in the vent pipes. This implies that enhancement in the ventilation rates in VIP latrines is a potential technical intervention to minimise odours and encourage latrine usage.

5.5.2 Effect of vent pipe design on odour levels

This analysis was done for only VIP latrines in which the installation of a vent pipe of appropriate dimensions is a crucial factor for achieving optimum ventilation and, hence, effective odour control. Communal VIP latrines were excluded from this analysis to avoid the confounding effect of their peculiar characteristics. For household and privately shared VIP latrines, it is expected that a vent pipe of diameter 150 mm will be installed to a minimum height of 500 mm above the roof. All the private VIP latrines were fitted with 100 mm diameter vent pipes so the influence of vent pipe diameter was not assessed. The concentrations of the surrogate compounds were compared between those latrines whose vent pipes met the minimum height of 500 mm and those that did not. Table 5-9 presents the results of this analysis. It is seen from the table that even though the average concentrations of the compounds were lower in the latrines with the minimum recommended height of vent pipe, the difference was not statistically significant at 5% confidence level for both hydrogen sulphide and ammonia.

Table 5-9: Influence of height of vent pipe on concentrations of surrogate compounds

Height of vent pipe above latrine roof (H)	**N**	**Hydrogen sulphide concentration (ppm)**		**Ammonia concentration (ppm)**	
		Mean (SD)	***t-stat (p-value)***	***Mean (SD)***	***t-stat (p-value)***
H < 500 mm	45	0.03 (0.07)	t=1.371 (0.176)	0.38 (1.70)	t=0.816 (0.418)
H ≥ 500 mm	25	0.02 (0.02)		0.16 (0.44)	

Total	70	0.03 (0.06)		0.30 (1.39)	

N=number in sample; SD=standard deviation (***Source: Own field data)***

5.5.3 Effect of cleanliness of latrines on odour levels

The cleanliness of the latrines were assessed in terms of the physical presence of faeces and urine on the latrine seat or squat hole. The results are presented in Table 5-10. Out of the 88 private toilets, only 2 had faeces around the seat or squat hole, making the analysis lack adequate data to draw a firm conclusion. However, those two toilets had significantly higher levels of hydrogen sulphide at an average of 0.27 ppm as compared to 0.03 ppm for those without faeces exposed (p= 000; significant at 1%). Their levels of ammonia were also higher but not significant at 5%.

With respect to urine, 33 out of the 88 latrines had urine on the seat or squat hole. From Table 5-10, it is seen that those that were messed with urine had significantly higher levels of ammonia (Mean=1.12 ppm) as compared to those without urine (Mean=0.01 ppm). They also had higher levels of hydrogen sulphide but the difference with those without urine was not significant at 5% confidence level.

Table 5-10: Influence of the presence of faeces and urine on latrine seat or squat hole

Presence of faeces and urine on toilet seat or squat hole	**N**	**Hydrogen sulphide concentration (ppm)**		**Ammonia concentration (ppm)**	
		Mean (SD)	***t-stat (p-value)***	***Mean (SD)***	***t-stat (p-value)***
Faeces present	2	0.27 (0.35)	t=26.53 (0.000)**	1.00 (1.41)	t=0.174 (0.677)
No faeces present	86	0.03 (0.08)		0.41 (1.97)	
Urine present	33	0.04 (0.10)	t=1.736 (0.191)	1.12 (3.10)	t=7.273 (0.008)**
No urine present	55	0.02 (0.06)		0.01 (0.01)	

Total	88	0.03 (0.08)		0.42 (1.96)	

*N=number in sample; SD=standard deviation; ** Significant at 1% level (**Source: Own field data)***

Thus, where the latrine seat or squat hole was messed with faeces, the average concentrations of hydrogen sulphide was significantly higher; where they were messed with urine, the average concentrations of ammonia was significantly higher. This trend is attributable to the well-known association between faeces and hydrogen sulphide and between urine and ammonia. The results imply that user habits and attitude to hygienic maintenance of latrines is a key determinant of odour in latrines.

5.6 Summary of Key Findings

The concentrations of the surrogate compounds correlated with the odour perception of the latrine users in Prampram, with the correlation between hydrogen sulphide concentration and user perception of odour being statistically significant at 5% confidence level while that of ammonia was only significant at 10% confidence level. The type of latrine technology and whether it is used privately at home or at the communal level significantly influenced the level of odour. For both hydrogen sulphide and ammonia, the water closet technology had the least levels, followed by the ventilated improved pit latrine, with the simple pit latrine having the highest levels. The variance among the average concentrations of the surrogate compounds measured on these technologies were statistically significant at 5% confidence level. Also, latrines used privately at home, whether by a single or multiple households, had significantly lower levels of the surrogate compounds, as compared to communal latrines, with the difference being statistically significant at 5% confidence level.

The odour levels in VIP latrines was significantly influenced by the ventilation rate through the vent pipe, with higher ventilation rates leading to lower odour levels. Furthermore, latrines that were kept clean, with no faeces on the seat or around the squat hole had significantly lower levels of hydrogen sulphide while those that were not messed with urine had significantly lower levels of ammonia. Nevertheless, whether the vent pipe was installed to the recommended minimum height of 500 mm or not did not significantly influence the odour levels. Similarly, the characteristics of the soils at latrine locations did not influence the levels of odour.

It is encouraging to note that the average level of hydrogen sulphide measured in VIP latrines used by single households or shared at home by two or more households (0.03 ppm) was less than the WHO recommended level for prevention of odour annoyance (0.05 ppm). This suggests that, apart from the water closet, the VIP has the potential of providing a satisfactory level of odour to its users. On the average, a hydrogen sulphide concentration of 0.04 ppm was perceived by the
latrine users as being tolerable or acceptable.

6 IMPROVCHAPTERING VENTILATION IN 6: IMPROVING VENTILATION IN THE VENTILATED THE VENTILATED IMPROVED PIT LATRINEIMPROVED PIT LA TRINE

6.1 Introduction

The ventilated improved pit (VIP) latrine addresses the challenge of intense odour associated with the simple pit latrine by the removal of odorous air from the latrine pit through the vent pipe. The rate of ventilation through the vent pipe is, therefore, the most important feature of the technology that distinguishes it from the simple pit latrine. Earlier studies conducted on the VIP latrine established that a minimum ventilation rate of 10 m^3/h is required to achieve odour-free conditions in the latrine cubicle but a rate of 20 m^3/h is recommended to guarantee an adequate factor of safety (Ryan and Mara, 1983a; Mara, 1984).

This chapter presents the results of how various design modifications affected the ventilation rate in the vent pipe of an experimental VIP latrine described in detail in Section 3.4.4.1 of Chapter 3 of this thesis. The experimental setups included:

i. a standard superstructure based on conventional design guidelines; ii. a superstructure with a window introduced in each side to allow entry of air into the latrine from multiple directions.

iii. the superstructure descriptions in (i) and (ii) above with an insect screen in window(s) or opening(s) to prevent entry of insects and reptiles.

iv. variations in the diameter and height of the vent pipes in each of the above superstructure descriptions to determine the effect of vent pipe dimensions on the ventilation rate.

In all the various trials, the level of hydrogen sulphide in the latrine cubicle was monitored together with the ventilation rate. However, hydrogen sulphide was not detected in any of the setups. Hence, the ventilation rate was used as the only criteria for assessing the odour control potential of the experimental setups. While monitoring the effect of these modifications on the ventilation rate, elements of weather known to influence the ventilation rate were also monitored. The relative effects of the various design modifications and environmental factors on the rate of ventilation were established using a multiple linear regression model.

6.2 Trend of Weather Conditions at the Study Site

Figures 6-1 to 6-4 show the hourly trend of the selected elements of weather monitored between 5:00 and 17:00 GMT. The figures also show error bars representing the standard errors associated with the hourly averages for 52 days for which the various experimental setups were monitored.

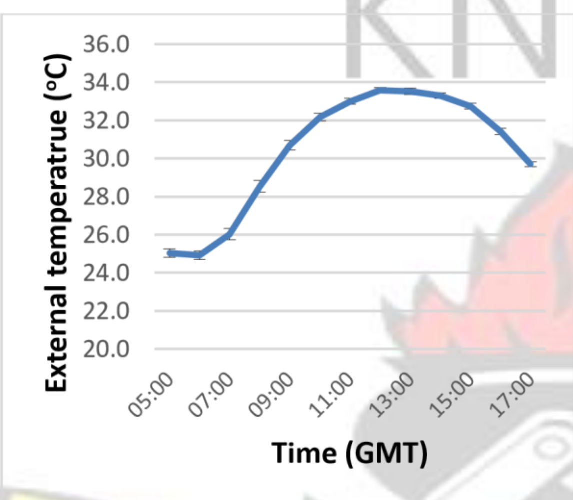


Figure 6-1: Hourly trend of external temperature

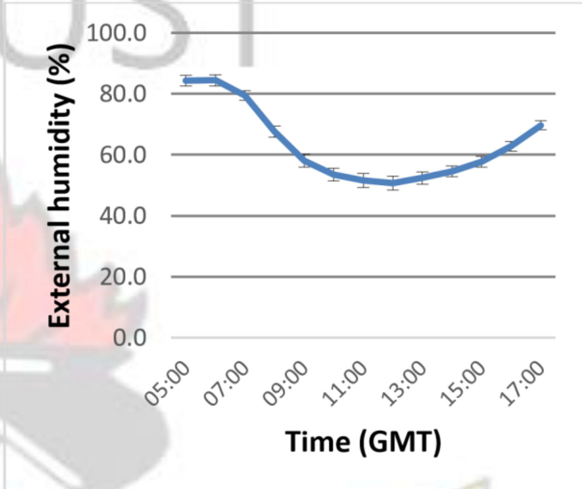


Figure 6-2: Hourly trend of external humidity

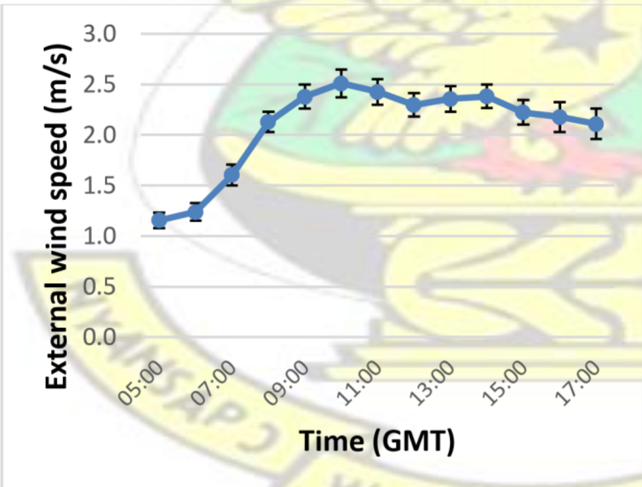


Figure 6-3: Hourly trend of external wind speed

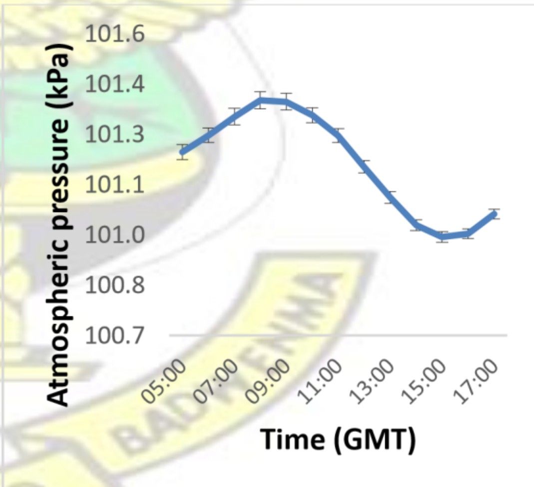


Figure 6-4: Hourly trend of atmospheric pressure

Detailed data on the elements of weather are presented in Appendix 6-1 while Table 6-1 below summarises the key descriptive statistics of the raw data.

Table 6-1: Summary statistics of the elements of weather

Parameter	Minimum	Maximum	Average	Standard Deviation
Ambient temperature (^oC)	20.40	36.00	30.40	3.40
Humidity (%)	10.00	93.00	63.50	18.10
Wind speed (m/s)	0.00*	5.50	2.10	1.00
Atmospheric pressure (kPa)	100.69	101.83	101.16	0.21

** Below a detection limit of 0.1 m/s* (***Source: Own field data)***

Among the elements of weather, the wind speed is regarded as the most important to influence the performance and, for that matter, the design of the VIP through Bernoulli's principle (Ryan and Mara, 1983).

6.3 Ventilation Rate in a VIP Latrine with a Conventional Superstructure

Based on conventional design guidelines, the superstructure of the VIP latrine is expected to have a window or other types of openings only in the windward direction, with none provided in other directions. For this 'standard' superstructure design, this section presents the results of how the ventilation rate in the vent pipe varied with the diameter and height of the vent pipe above the roof.

6.3.1 Variation of ventilation rate with vent pipe diameter

Figure 6-5 shows the hourly trend of the ventilation rates in vent pipes of diameters 100, 150 and 200 mm fitted to a VIP latrine with a standard superstructure. The figure also shows the minimum and recommended ventilation rates required to achieve odour-free conditions in the latrine cubicle. The trend of the ventilation rates in the three pipe diameters are shown for a constant vent pipe height of 500 mm above the highest point on the roof, which is the minimum recommended height. Data on the ventilation rate in the three pipe sizes measured at this constant height and three other heights (250 mm, 750 mm and 1000 mm) are presented in Appendix 6-2. It can be observed from Figure 6-5 that the ventilation rate increases with increasing vent pipe diameter. Also, at the height of 500 mm above the roof, the ventilation rate in each of the three pipe sizes was above the recommended rate of 20 m^3/h.

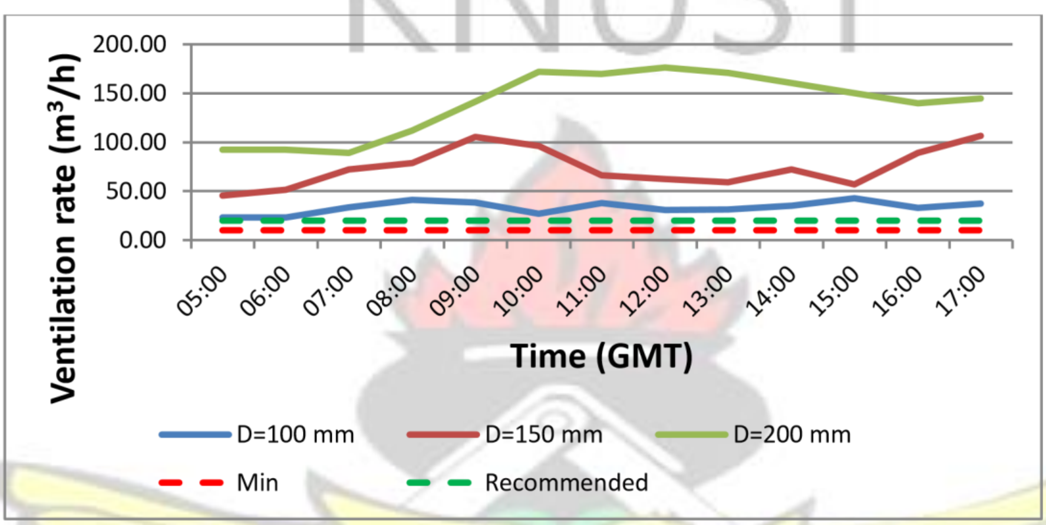


Figure 6-5: Ventilation rates in vent pipes of varying diameters installed to a height of 500 mm above the roof of a VIP latrine

Table 6-2 presents the averages and standard deviations of the ventilation rate measured in the three pipe diameters at the constant heights. The Table also shows the result of the analysis of variance (ANOVA) among the ventilation rates in the three pipe diameters for each constant height. It is seen that, at each constant height, the variance among the mean ventilation rates in the three pipe diameters is statistically significant at 1% confidence level (p=0.000 in each case).

Table 6-2: Ventilation rates in vent pipes of varying diameters and constant heights above a VIP latrine

Constant Height (mm)	Diameter (mm)	Ventilation rate (m^3/h)		F-statistic	p-value
		Mean	*SD*		
250	100	18.43	3.02	10.124	0.000**

	150	31.25	7.00		
	200	34.35	14.70		
500	100	33.49	6.33	74.855	0.000**
	150	74.10	20.03		
	200	139.41	32.35		
750	100	17.43	12.11	67.734	0.000**
	150	106.28	35.84		
	200	149.73	34.46		
1000	100	35.30	9.82	44.659	0.000**
	150	59.48	23.55		
	200	*124.17*	*34.54*		

NB: SD=Standard deviation *** Significant at 1% level* (***Source: Own field data)***

The results suggest that in spite of potential variation in wind speed and other weather conditions, a bigger pipe diameter guarantees a higher ventilation rate for any constant height. The results also confirm earlier findings that where the average wind speed is less than 3 m/s, a vent pipe diameter of 150 mm is required to achieve the recommended ventilation rate of 20 m^3/h (Mara, 1984). The average wind speed recorded at the study site was 2.1 m/s as shown in Table 6-1 and it can be seen from Table 6-2 that only the vent pipe diameters of 150 mm and 200 mm achieved an average ventilation rate above 20 m^3/h for all the heights. For the 100 mm diameter vent pipe, the average ventilation rates for heights 250 mm and 750 mm, being 18.43 and 17.43 m^3/h respectively, were below the recommended rate although they were above the minimum ventilation rate of 10 m^3/h. This suggests that most of the household VIP latrines in Prampram, all of which were found to be fitted with 100 mm diameter pipes as commonly done in Ghana, may not achieve the recommended ventilation rate.

6.3.2 Variation of ventilation rate with vent pipe height

Figure 6-6 shows the hourly trend of the ventilation rates in vent pipes installed to heights of 250, 500, 750 and 1000 mm above the highest point of the roof of a VIP latrine with a standard superstructure. The trend of the ventilation rates for the various heights are shown for a constant diameter of 150 mm, which is the minimum recommended size for a PVC pipe used in areas with average wind speeds below 3 m/s (Ryan and Mara, 1983a). In Figure 6-7, similar trend curves are shown for the same heights but for a diameter of 100 mm, which is the pipe size found to be used in all existing household VIP latrines that were studied in Prampram. The figures also show the minimum and recommended ventilation rates. The accompanying data are shown in Appendix 6-2.

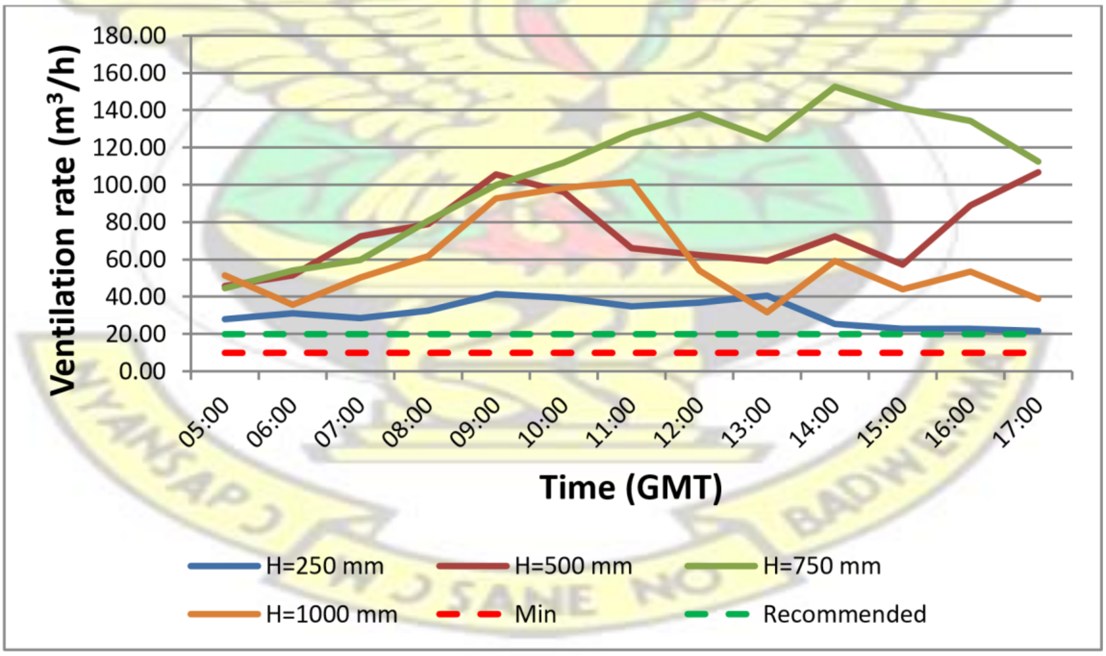


Figure 6-6: Ventilation rates in vent pipes of 150 mm diameter installed to varying heights above the roof of a VIP latrine

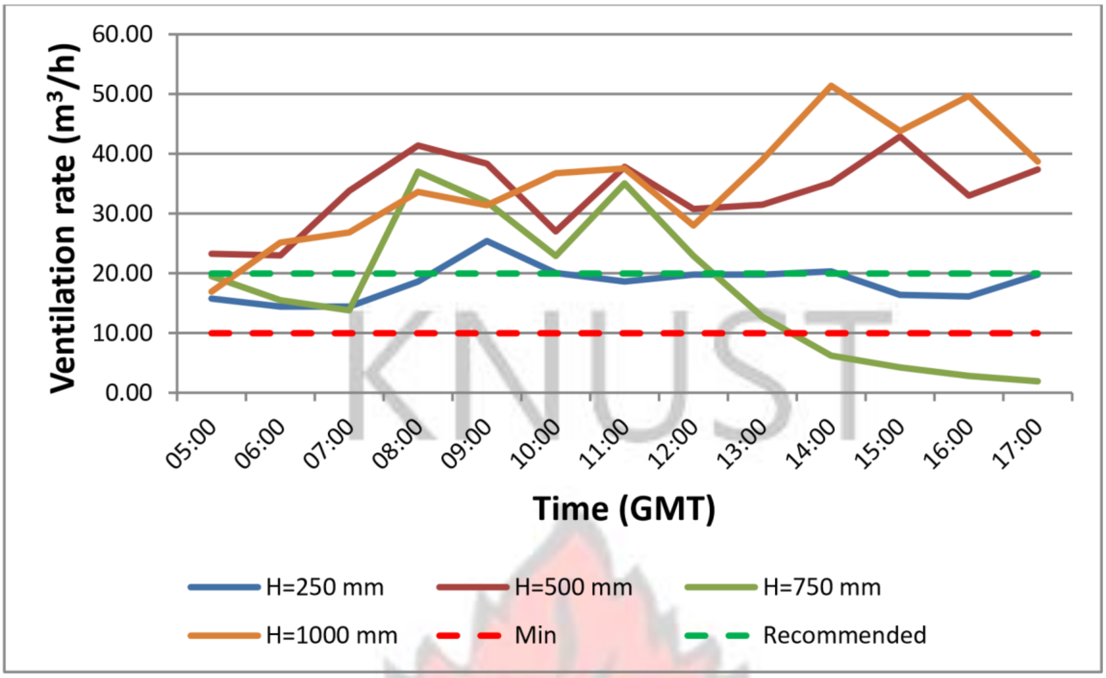


Figure 6-7: Ventilation rates in vent pipes of 100 mm diameter installed to varying heights above the roof of a VIP latrine

From Figures 6-6 and 6-7, it is observed that the effect of vent height on the ventilation rate is erratic. This observation is clearer in Table 6-3 which presents the analysis of variance among the mean ventilation rates for the four heights at constant diameter.

Table 6-3: Ventilation rates in vent pipes of constant diameter and varying heights above a VIP latrine

Constant diameter (mm)	Height above roof (mm)	Ventilation rate (m^3/h)		F-statistic	p-value
		Mean	*SD*		
100	250	18.43	3.02	16.217	0.000**
	500	33.49	6.33		
	750	17.43	12.10		
	1000	35.30	9.82		

150	250	31.25	7.00	22.151	0.000**
	500	74.10	20.03		
	750	106.29	35.84		
	1000	59.48	23.55		
200	250	34.35	14.70	39.749	0.000**
	500	139.41	32.35		
	750	149.73	34.46		
	1000	124.17	34.54		

NB: SD=Standard deviation *** Significant at 1% level* (***Source: Own field data)***

The Table reveals that even though the mean ventilation rates are significantly different for the various heights at constant diameter, the ventilation rate does not necessarily increase with increasing height. For instance, for the 100 mm diameter the mean ventilation rate was lower at the height of 750 mm (17.43 m^3/h) as compared to that of the height of 250 mm (18.43 m^3/h). Similarly, for the 150 and 200 mm diameter pipes, the ventilation rates at the height of 1000 mm were lower than those of the height of 500 mm. This suggests that, at constant vent pipe diameter, the ventilation rate is more influenced by the weather conditions, possibly the wind speed, than the height of the vent pipe. This is confirmed later in Section 6.6 by multiple regression analysis, which reveals that the external wind speed has much more influence on the ventilation rate than the height of the vent pipe. It should, however, be noted that the minimum recommended height of 500 mm needs to be maintained to ensure that the roof does not interfere with the action of the wind across the top of the vent pipe (Mara, 1984) and that odorous air from the pit is directed well above the latrine superstructure into the atmosphere.

6.4 Ventilation Rate in a VIP Latrine with Windows in All Four Sides

This section presents and discusses the results on the ventilation potential of a VIP latrine with a modified superstructure in which a window was provided in each side to allow entry of air into the cubicle from multiple directions. To distinguish it from the standard VIP in which a window is provided only in the windward direction, this modified design is referred to in this thesis as a multidirectional VIP. The results are presented to demonstrate the ventilation potential of the multidirectional design in an otherwise standard VIP, i.e. one with a recommended vent pipe diameter of 150 mm and a height of 500 mm above the highest point of the roof. The results, shown in Figure 6-8, also show the ventilation rates when the 150 mm diameter vent pipe was replaced with 100 and 200 mm diameter pipes of the same height. The accompanying data are shown in Appendix 6-3

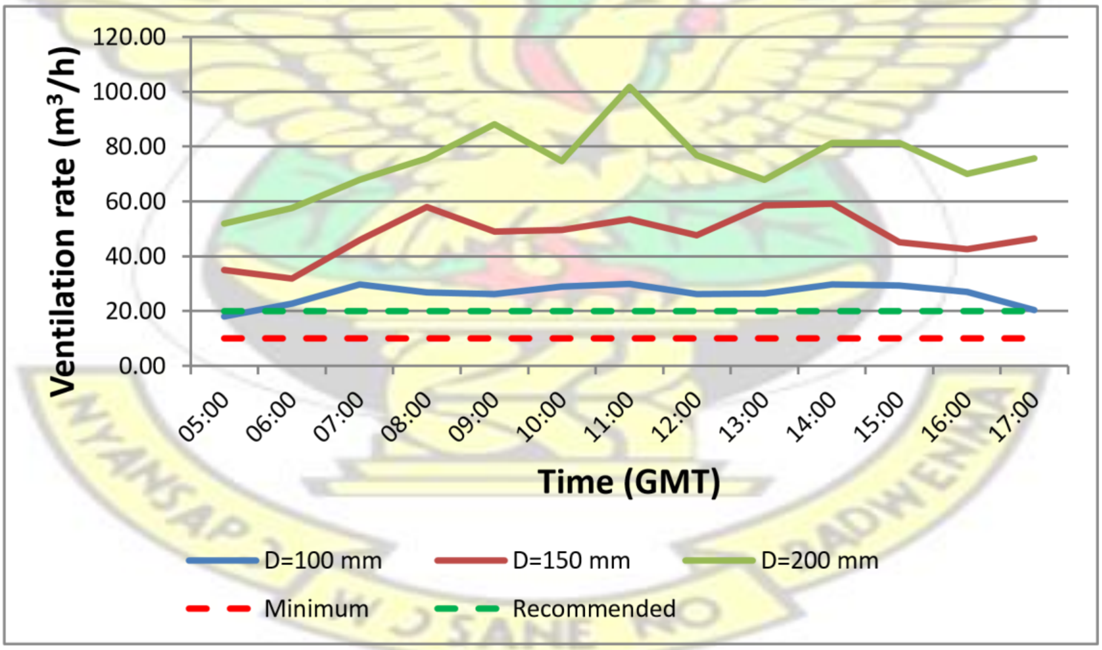


Figure 6-8: Ventilation rates in vent pipes of varying diameters installed to a height of 500 mm above the roof of a multidirectional VIP latrine

Figure 6-8 shows that the multidirectional design achieved the recommended ventilation rate under the prevailing weather conditions at Prampram. The average ventilation in the recommended vent pipe diameter of 150 mm was 47.83 m^3/h, which is more than twice the recommended rate of 20 m^3/h. The ventilation rate in the 100 mm diameter pipe (26.23 m^3/h) was also significantly higher than the recommended rate (t-statistic for paired samples = 5.986; p=0.000). Nevertheless, it can be seen from Figure 6-9 that the ventilation rates in the multidirectional VIP latrine were lower than those measured in the standard design. The results of statistical comparisons of the ventilation rates in the standard and multidirectional superstructure designs using the t-test for paired samples are presented in Table 6-4. As found in the case of the standard superstructure, the ventilation rate increased with increasing vent pipe diameter. The variance among the mean rates for the three pipe diameters was highly significant (F=93.777; p=0.000).

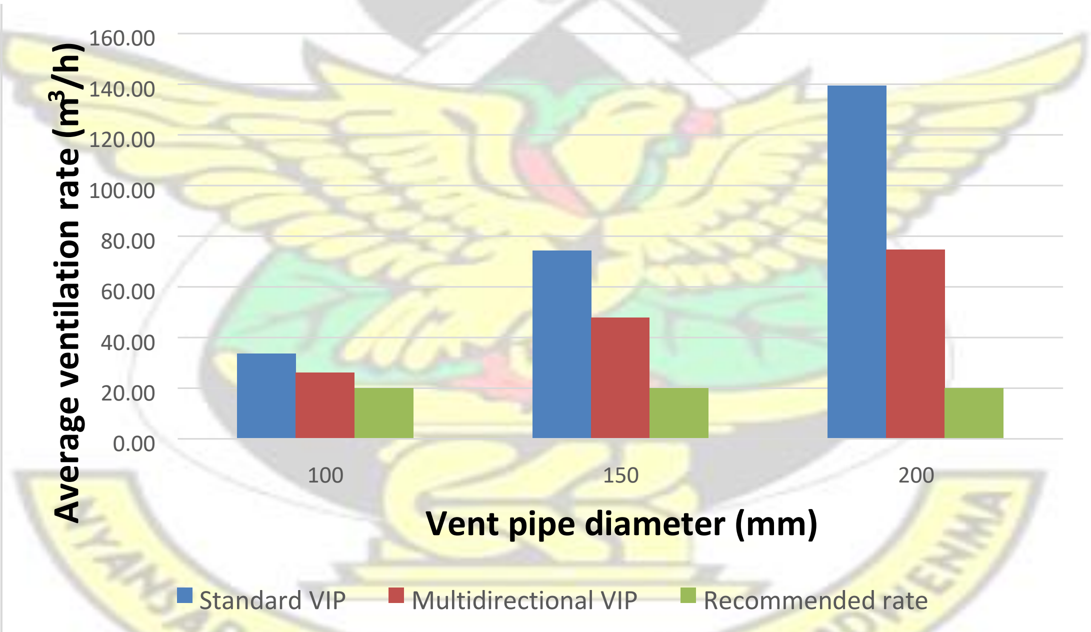


Figure 6-9: Comparison of ventilation rates in a standard and a multidirectional VIP

Table 6-4: Comparison of ventilation rates in a standard and a multidirectional VIP latrine

Diameter (mm)	Design type	Ventilation rate (m^3/h)		t-statistic for paired samples	p-value
		Mean	*SD*		

100	Standard	33.49	6.33	4.665	0.001**
	Multidirectional	26.23	3.76		
150	Standard	74.10	20.03	4.863	0.000**
	Multidirectional	47.83	8.37		
200	Standard	139.41	32.35	8.883	0.000**
	Multidirectional	74.69	12.69		

NB: SD=Standard deviation *** Significant at 1% level* (***Source: Own field data)***

The rationale behind the proposition of the multidirectional design is that it allows the entry of air into the latrine irrespective of the direction of the local winds. This design option relaxes the conventional design code which requires that a window or opening should be provided only in the windward side of the latrine in order to prevent a reduction in the ventilation rate due to loss of air pressure in the pit or the bottom of the vent pipe (Ryan and Mara, 1983a; Mara, 1984). Although this effect is confirmed in the above analysis, a number of challenges are encountered in the application of the conventional design concept in the low-income peri-urban setting. First, out of ignorance or site restrictions, some latrine builders implementing the conventional design concept tend to ignore the direction of the local winds in the siting of latrines. Consequently, the only side in which a window is provided in the standard design may not necessarily be in the windward side. Thus, the window or openings may be disoriented from the wind direction. Secondly, as observed in some neighbourhoods of Prampram, uncontrolled land development associated with the low-income peri-urban setting (Parkinson and Tayler, 2003) leads to the construction of unapproved structures and extensions to existing buildings in a manner that eventually alters the original circulation of the local winds. As a result, some existing VIP latrines that were originally built with openings facing the wind direction could later become disoriented. These reasons may account for a number of VIP latrines that were found in Prampram with openings not facing the local wind direction.

To verify the effect of a standard VIP having openings disoriented from the local wind direction, the experimental VIP latrine was set up with a 150 mm diameter vent pipe at a height of 500 mm above the roof and all the windows were sealed except one which was at the leeward side of the superstructure. The ventilation rate in the vent pipe was then monitored. The results, shown in Figure 610 and Table 6-5, 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 when a window was provided in the wind direction.

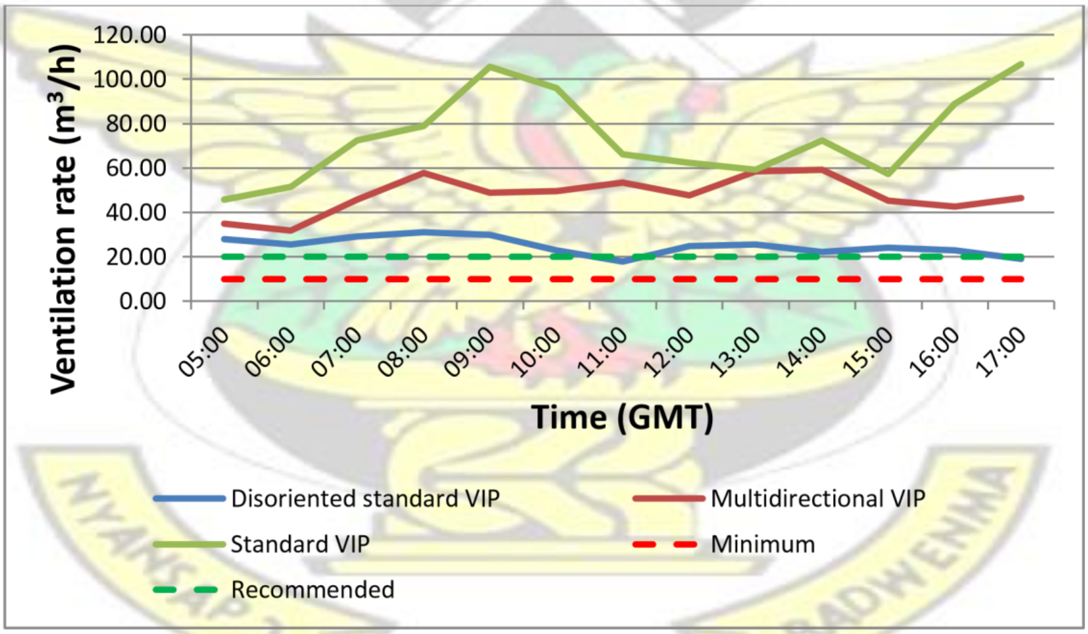


Figure 6-10: Ventilation rates in a multidimensional, standard and disoriented standard VIP latrines

Table 6-5: Comparison of ventilation rates in multidimensional, standard and disoriented standard VIP latrines

VIP description	Ventilation rate (m^3/h)	F-statistic	p-value

	Mean	***SD***		
Standard VIP	74.10	20.03	48.606	0.000**
Multidirectional VIP	47.83	8.37		
Disoriented standard VIP	24.85	4.01		

NB: SD=Standard deviation ** Significant at 1% level (***Source: Own field data)***

These results confirm that, indeed, maximum ventilation rates are achieved when openings are provided only in one side of the VIP latrine and that the side with the openings must be the windward side. But the findings of this study extend this knowledge to the extent that having the window or openings of a standard VIP latrine disoriented from the local wind direction could cause a much greater reduction in the ventilation rate than having openings in 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.

Nevertheless, a relevant question to address is how the ventilation rate in this modified design may be affected by variations in the elements of weather and how other design criteria such as the diameter of the vent pipe may be varied to compensate for a less favourable weather. This question may be addressed by a mathematical model that could explain how the various design parameters and elements of weather affect the ventilation rate through the vent pipe of a VIP latrine and predict the ventilation rate that may be attained for the modified design under varying weather conditions. This research explored this possibility and the findings are discussed in Section 6.6.

6.5 Ventilation Rates in VIP Latrines with Insect Screens Installed in Windows

Another design modification whose effect on the ventilation rate was explored in this research is the installation of insect screens in the window(s) or openings of the VIP latrine. The conventional VIP design concept does not recommend the use of insect screens in order to avoid head losses across the screen. However, the need often arises to prevent the entry of flies and rodents through the windows or openings in the superstructure. This makes it imperative to verify whether such screens could be used in the VIP latrines without adversely compromising the ventilation function of the technology and to verify whether any head loss across the screen could be compensated for by varying the diameter of the vent pipe. This section presents the results on the ventilation rates in the standard and multidirectional VIPs with insect screens of 1.2 x 1.2 mm aperture installed in the window(s).

Figure 6-11 shows how the ventilation rate in the standard VIP having an insect screen in the window compares with the ventilation rate when no screens were used. The comparison is shown for 100, 150 and 200 mm diameter vent pipes. Similar comparisons for the multidirectional VIP are shown in Figure 6-12. It is seen from the two figures that the use of insect screens generally reduced the ventilation rate, apparently, as a result of the loss of air pressure across the screen (Mara, 1984).

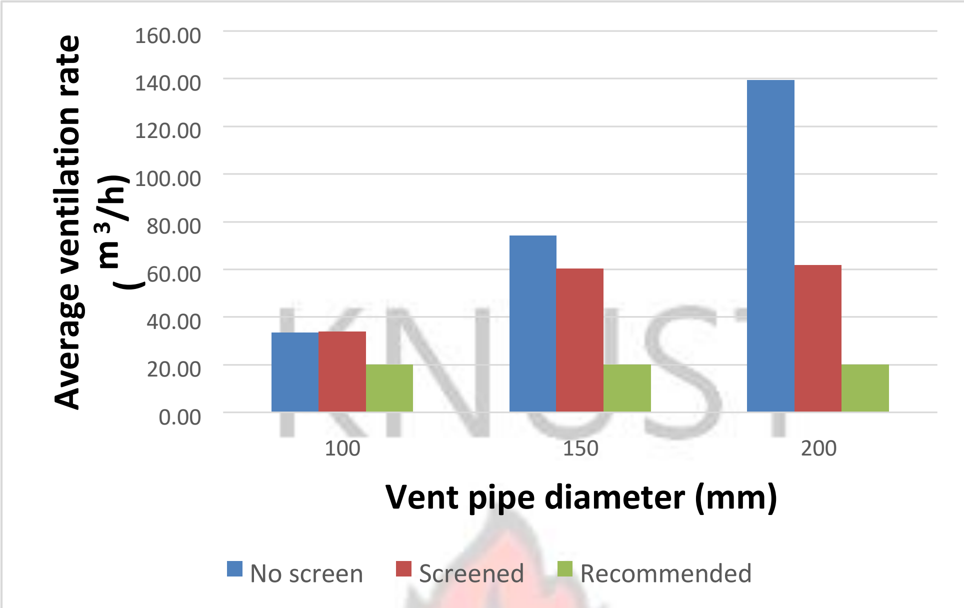


Figure 6-11: Comparison of average ventilation rates in a standard VIP with and without an insect screen in the window

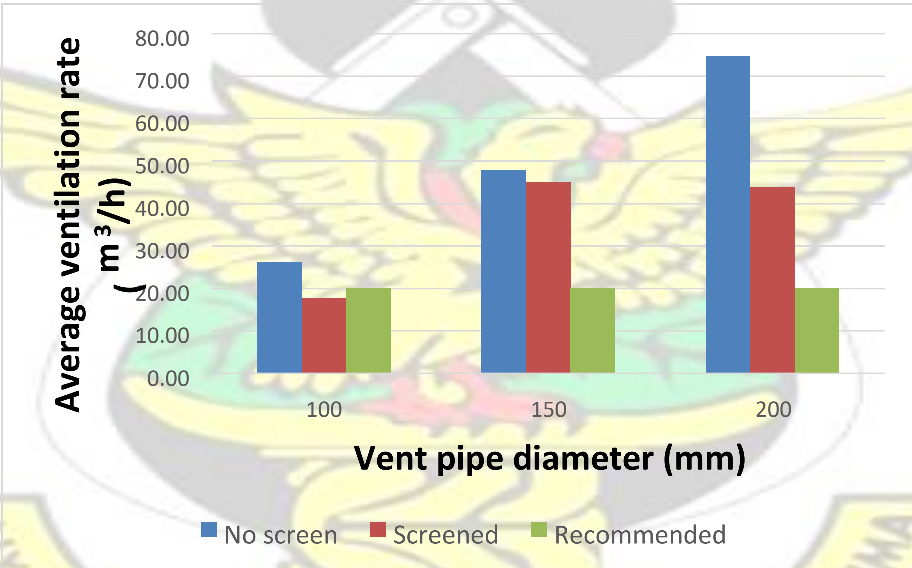


Figure 6-12: Comparison of average ventilation rates in a multidirectional VIP with and without an insect screen in the window

The statistical significance of this effect in the standard and multidirectional VIPs are presented in Table 6-6. Nevertheless, for setups in which the recommended vent pipe diameter of 150 mm or higher was used, the rate of ventilation in both the standard and multidirectional VIPs remained higher than the recommended rate of 20 m^3/h. For the

100 mm vent pipe, the ventilation rate in the multidimensional design (17.63 m^3/h) was significantly lower than the recommended rate (t-statistic for paired samples = -4.741; p=0.000). This suggests that the current practice of VIP construction in Prampram in which 100 mm diameter vent pipes are used would significantly compromise the ventilation function of the technology if windows or openings fitted with insect screens are provided in all sides of the superstructure. However, adequate ventilation would be achieved if the 100 mm vent pipes are replaced with 150 mm ones.

Table 6-6: Comparison of ventilation rates in VIPs with and without insect screens in windows

VIP type	Vent pipe diameter (mm)	Screen installed?	Ventilation rate (m^3/h)		t-stat (paired samples)	p-value
			Mean	***SD***		
Standard	100	No	33.49	6.33	-0.181	0.860
		Yes	33.93	8.07		
	150	No	74.10	20.03	2.948	0.012*
		Yes	60.40	15.94		
	200	No	139.41	32.35	5.861	0.000**
		Yes	61.82	22.04		
Multidimensional	100	No	26.23	3.76	7.034	0.000**
		Yes	17.63	1.80		
	150	No	47.83	8.37	1.944	0.076
		Yes	45.05	8.21		
	200	No	74.69	12.69	6.074	0.000**
		Yes	43.74	7.43		

NB: SD=Standard deviation ** Significant at 5% level; ** Significant at 1% level* (***Source: Own field data***)

6.6 Modelling of the Ventilation Rate in the VIP Latrine

6.6.1 Introduction

This research sought to understand how the VIP design criteria discussed above and the elements of weather influence the rate of ventilation through the vent pipe. Multiple linear regression analysis was used to identify which factors are most influential on the ventilation rate and to predict the ventilation rate that may be achieved by various design criteria and weather elements. The multiple linear regression model and the fitted model are specified in Equations (1) and (2) respectively (Simon, 2003) as:

$Yi = \beta_0 + \beta_1(x1)_i + \beta_2(x2)_i + \beta_3(x3)_i + \ldots + \beta_K(xK)_i + \varepsilon_i$ Equation (1) $\hat{Y} =$

$b_0 + b_1(x1) + b_2(x2) + b_3(x3) + \ldots + b_K(xK)$ Equation (2)

where:

- Y is a linear function of predictors x1, x2, x3… xK and some statistical noise or error term, ε.
- β_0 is the intercept
- β_j is the coefficient of the variable xj
- b_j in Equation (2) is an estimate of the corresponding β_j in Equation (1) This model is based on the assumptions that (Simon, 2003; Nau, 2014):

i. The relationship between the dependent and independent variables is linear.

ii. Consecutive errors in time series are statistically independent. iii. There exists a constant variance or homoscedasticity among the errors.

iv. The errors are normally distributed

6.6.2 Variable definition and basic statistics

Table 6-7 presents the definition and basic statistics of the dependent and independent variables that were considered in the multiple linear regression model.

The model for the ventilation rate in the vent pipe was initially specified as:

$lnQ = b_0 + b_1D + b_2Vwind + b_3SPT + b_4Hum + b_5SCR + b_6Temp + b_2H$ Equation (3)

Table 6-7: Variable definition and basic statistics

Variable	**Type**	**Variable definition (unit)**	**Mean**	**SD**
Q*	Continuous	Ventilation rate in vent pipe measured centrally at the mid-point of the overall length (m^3/h)	54.40	36.04
D	Continuous	Diameter of vent pipe (mm)	144.16	41.39
H	Continuous	Height of vent pipe above highest point of roof (mm)	624.26	264.26
SPT	Categorical	Type of superstructure: 1 if multidirectional and 0 if standard; 0 was the reference category	0.5	0.5
SCR	Categorical	Provision of insect screen in windows: 1 if screens are provided and 0 if otherwise; 0 was the reference category	0.5	0.5
Tpipe	Continuous	Temperature of air in vent pipe measured at same point as Q (°C)	30.35	3.19
Vwind	Continuous	Wind speed measured at the top of the vent pipe (m/s)	2.1	1.0
Temp	Continuous	External or ambient air temperature (°C)	30.51	3.29
Hum	Continuous	Relative humidity (%)	63.74	17.38
Patm	Continuous	Atmospheric pressure (kPa)	101.16	0.21

** Dependent variable; all others were independent variables* (***Source: Own field data)***

The dependent variable, Q, was transformed by taking natural logs prior to analysis to minimise skewness and linearize its relationship with the independent variables.

6.6.3 Verification of model assumptions and multicollinearity

The assumptions underlying the use of multiple linear regression are verified in this section. However, the independence of consecutive errors was not verified since the data was not time sequenced.

a. Linearity of the relationship between dependent and independent variables If the relationship between the dependent and independent variables is linear, the points of the scatter plot of the errors (residuals) are symmetrically distributed around the horizontal axis (Nau, 2014). Figure 6-13 shows the plot of residuals versus fitted values as being fairly symmetrical about the horizontal axis.

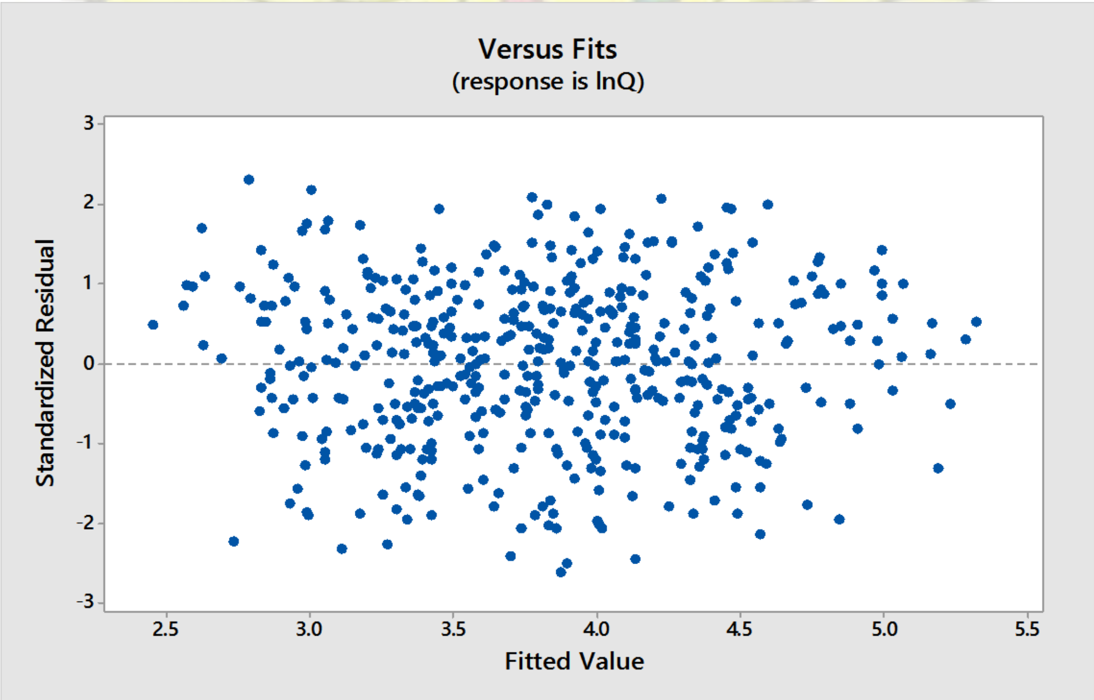


Figure 6-13: A plot of residuals versus fitted values

b. Homoscedasticity of errors

From the plot of residuals versus fitted values shown in Figure 6-13, the errors do not get larger in one direction by any significant amount, and this is a proof of homoscedasticity (Nau, 2014).

c. Normality of the distribution of errors

Figure 6-14 shows the normal probability plot of the standardised residuals.

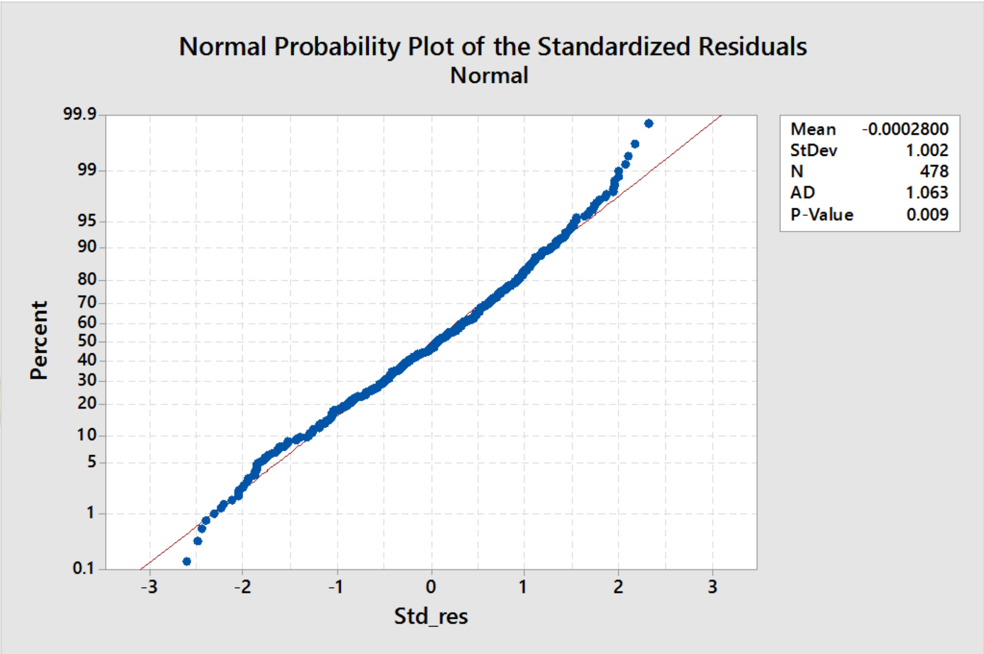


Figure 6-14: Normal probability plot of standardised residuals

If the errors are normally distributed, a normal probability plot of the residuals shows the points being close to the diagonal reference line as seen in Figure 6-14. Statistically, the Anderson-Darling test of normality confirms that the distribution of the standardised residuals is significantly normal (AD=1.063; p-value=0.009)

d. Check for multicollinearity

In addition to the model assumptions, it is required that a high degree of multicollinearity should not exist among the independent variables in a multiple linear regression model otherwise the variance of the regression coefficients would be inflated. As a rule of thumb, multicollinearity is ignored when no individual independent variable has a variance inflation factor (VIF) of 10 or higher (Simon, 2005). However, some analyst treat a VIFs of 5—10 as high collinearity (Minitab, 2015). Table 6-8 shows the Pearson correlation coefficients among the variables and the variance inflation factors for the independent variables when regressed on the dependent variable.

Table 6-8: Correlation matrix of variables

Variables	Pearson correlation (p-value)									VIF[2]
	LnQ[1]	D	H	SPT	SCR	Tpipe	Vwind	Temp	Hum	
D	0.72 (0.000)									1.23
H	0.24 (0.000)	0.10 (0.026)								1.86
SPT	-0.31 (0.000)	-0.04 (0.382)	-0.01 (0.857)							1.04
SCR	-0.02 (0.637)	0.01 (0.037)	0.08 (0.072)	0.01 (0.821)						1.05
Tpipe	0.00 (0.954)	-0.163 (0.000)	0.20 (0.000)	0.08 (0.095)	0.02 (0.716)					9.45
Vwind	0.43 (0.000)	-0.1 (0.036)	0.02 (0.751)	-0.14 (0.002)	-0.11 (0.016)	0.21 (0.000)				1.22
Temp	0.08 (0.075)	-0.04 (0.352)	0.20 (0.000)	0.07 (0.119)	0.05 (0.330)	0.90 (0.000)	0.26 (0.000)			8.89
Hum	0.16 (0.000)	0.01 (0.848)	0.46 (0.000)	-0.05 (0.275)	0.02 (0.666)	-0.32 (0.000)	-0.16 (0.001)	-0.47 (0.000)		3.24
Patm	-0.26 (0.000)	-0.01 (0.847)	-0.35 (0.000)	0.01 (0.841)	0.06 (0.196)	-0.61 (0.000)	-0.23 (0.000)	-0.44 (0.000)	-0.26 (000)	2.89

*NB: 1. Dependent variable; 2. VIF=Variance inflation factor (**Source: Own field data**)*

It is seen from the table that variables Tpipe (temperature of air in the vent pipe) and Temp (external/ambient air temperature) had VIFs close to 10. A potentially high collinearity associated with these variables was avoided by adopting the forward selection option of multiple linear regression, which eliminates variables that are either highly correlated with other variables or do not make a significant contribution to the inferential or predictive power of the model (Simon, 2005; Minitab, 2015).

6.6.4 Model selection and summary statistics

The multiple linear regression model was constructed by forward selection, with variables allowed to enter the model at a t-test probability level, α, of 0.25. A total of 624 observations were generated from 48 setup combinations. Ninety-six observations, comprising two randomly selected from each setup, which were reserved for model validation were not included in the model data. After removing observations with missing data and outliers, a total of 478 observations were used for developing the model. The primary data are presented in Appendix 6-5.

Based on the model selection criteria stated above, the height of vent pipe above the latrine roof (*H*), temperature of air inside the vent pipe (*Tpipe*) and atmospheric pressure (*Pabs*) were excluded from the model. This implies that these variables do not significantly contribute to the explanation of changes in the ventilation rate or are highly correlated with some other variables that better explain changes in the ventilation rate. Such variables may be excluded from a multiple linear regression by forward selection irrespective of their individual linear correlation with the dependent variable. It is recalled from Table 6-8 that the variable *Tpipe* is highly correlated with *Temp* (Pearson correlation coefficient = 0.9; p=0.000). *Tpipe* had the highest variance inflation factor (VIF) of 9.45 and a nearzero Pearson correlation coefficient (0.003; p=0.954) with the dependent variable. Although *H* and *Pabs* had significant correlations with the dependent variable, their contribution to changes in the dependent variable were judged to be insignificant.

Thus, the fitted model for the ventilation rate in the vent pipe was specified as:

$$lnQ = b_0 + b_1D + b_2Vwind + b_3SPT + b_4Hum + b_5SCR + b_6Temp \quad \text{Equation (4)}$$

The output of the regression analysis based on Equation (4) is presented in Table 6-9.

Table 6-9: Ventilation rate in a VIP latrine vent pipe related to selected design criteria and elements of weather

Predictors	**Unstandardized Coefficients**			**Change in R_j^2 (%)**	**VIF**
	b	***Std. Error***	***p-value***		
Constant	0.226	0.112	0.045*	-	-
D	0.0116	0.0002	0.000**	52.68	1.02
Vwind	0.287	0.009	0.000**	25.19	1.13
SPT	-0.323	0.017	0.000**	6.84	1.04
Hum	0.0101	0.0005	0.000**	6.53	1.29
SCR	-0.068	0.017	0.000**	0.30	1.03
Temp	0.028	0.003	0.000**	0.03	1.37
Model Summary: F-value=850.45; p=0.000; Adjusted R^2 =91.44; Predicted R^2=91.28					

*NB: *= Significant at 5% level; **= Significant at 1% level (**Source: Own field data**)*

The Table shows the estimates of the regression coefficients, *b*, their standard errors and the p-values associated with the t-test statistic on whether the coefficients are significantly different from zero. Also shown in the Table are the individual coefficient of determination, R_j^2, for each variable representing the percentage of the changes in the dependent variable that can be explained by the inclusion of the respective independent variable in the model. The individual variance inflation factors are also indicated.

It is seen from the table that the diameter of the vent pipe (*D)* has the greatest influence on the ventilation rate (Q), accounting for 52.68% of changes in Q. With b=0.0116, a unit or 1 mm change in diameter leads to 0.0116 change in lnQ if all other factors are held constant. Generally, if a variable Z is related to a variable X in a linear regression model such that $\ln Z = b_0 + b_j X$, then a unit change in X leads to a change of b_j in lnZ which is approximately equal to a percentage change of b_j in Z (Simon, 2003). Thus, a 1 mm increase in diameter leads to approximately 1.16% change in Q if all other factors are held constant. This implies that increasing the diameter by 50 mm, say from 100 mm to 150 mm or 150 mm to 200 mm, leads to a 50 x 1.16% or 58% increase in the ventilation rate if all other factors are held constant. Similarly, a unit (m/s) increase in the external wind speed (*Vwind)*, which is the second most influential factor, leads to an increase of 28.7% in the ventilation rate. *Vwind* accounts for 25.19% of the changes in Q. It is seen that the effect of temperature changes makes the least contribution (R^2=0.03%) to the explanation of changes in Q. This confirms earlier findings that the action of wind on top of the vent pipe (Bernoulli's principle) is more important than thermal induced ventilation (Ryan and Mara, 1983; Mara, 1984).

On the other hand, the multidirectional design (*SPT=1*), in which windows or openings are provided in all sides of the superstructure, significantly reduces the ventilation rate by 32.3% of the rate in an equivalent standard superstructure if all other factors remain constant. This factor accounted for 6.8% of the changes in Q. Similarly, the installation of insect screens in windows (*SCR*) reduced the ventilation rate by 6.8% but accounted for only 0.3% of the changes in the in the ventilation rate through the vent pipe. It should be noted that, all the above inferences are subject to the standard errors indicated in Table 6-9 for the various predictors. For instance, the standard error for the coefficient of the variable *SPT* is 0.017. This implies that, the multidirectional superstructure design reduces the ventilation rate by 32.3% ± 1.7%.

Overall, the regression model is statistically significant (F=850.45; p=0.000). The model had an adjusted coefficient of multiple determination, R^2, of 91.44%, which means that the model explains that percentage (91.44%) of the changes in the ventilation rate. Also, the predicted R^2 of 91.22% signifies that the model will explain that percentage of changes in the ventilation rate when a new set of data that were not included in the development of the model are used to predict an unknown ventilation rate.

6.6.5 Model validation and predictions

From the model output shown in Table 6-9, the values of the intercept and coefficients of the variables, rounded to three decimal places, are substituted in Equation 4 to obtain the following model equation:

$$lnQ = 0.226 + 0.012D + 0.287Vwind - 0.323SPT + 0.010Hum - 0.068SCR + 0.028Temp \quad \text{Equation (5)}$$

The model was validated with 96 observations by comparing the predicted ventilation rates with those that were observed in the field for each set of predictors. The full details of the model validation output are presented in Appendix 6-6 with the dependent variable, which was log-transformed prior to analysis, converted back to the original variable, Q. For each set of predictors, a 95% confidence and a 95% prediction intervals of the predicted Q is specified. The confidence interval is the range within which the mean Q for each set of predictors repeated for a number of times is expected to lie. On the other hand, the prediction interval specifies the range within which the Q for a set of predictors observed only once is expected to lie. Due to a higher uncertainty associated with a single observation of a set of predictors, the prediction interval is always wider than the confidence interval (Wiles, 2013). Since each set of predictors used for the validation was observed only once, the prediction interval forms the basis for assessing the validity of the model. Out of 96 sets of predictors, 92 had the observed Q falling within the respective prediction intervals. Four observed Qs fell outside the prediction interval. Thus, 96% of the observations fell within the predicted intervals, which indicates a high level of reliability.

6.7 Summary of Key Findings

To guarantee the recommended ventilation rate of 20 m^3/h in a VIP latrine, a vent pipe diameter of 150 mm should be installed. Thus, the 100 mm pipe commonly used in Ghana is inadequate. The height of the vent pipe is not relevant to the attainment of a high ventilation rate apart from being high enough to prevent obstructions to the action of wind and to direct odorous air into the atmosphere.

In relation to the design of the superstructure, the findings of this study confirm that, indeed, providing a window or an opening in only one direction, as in the standard design, achieves a higher ventilation rate than the case of the multidirectional design in which windows are provided in all sides of the superstructure. 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 about twice the rate in a standard VIP in which the only window was not facing the wind 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 rate can be maintained when a vent pipe of 150 mm diameter or bigger is used.

The regression analysis of factors affecting the ventilation rate showed that the diameter of the vent pipe is the most important factor which accounts for 53% of variations in the ventilation rate. Increasing the vent pipe from one standard size to another, i.e., 100 mm to 150 mm or 150 mm to 200 mm leads to an increase of 58% in ventilation rate, if all other factors are held constant. After vent pipe diameter, the wind speed is the second most important factor accounting for 25% of changes in the ventilation. A unit increase of 1 m/s in the wind speed leads to an increase of 28% in the ventilation rate, if all other factors are held constant. The adoption of the multidirectional design leads a reduction of 32% in the ventilation rate and accounts for 9% of the variations in the ventilation rate while the installation of insect screens reduces the ventilation rate by 9% and accounts of less than 1% of the variations in the ventilation rate. It follows that where the multidirectional design and use of insect screens are desired, their combined effect of 41% reduction in the ventilation rate could be compensated for by increasing the vent pipe diameter by 50 mm, which will increase the ventilation rate by 58%. Changes in the ambient air temperature was the least significant factor affecting the ventilation rate. This is consistent with earlier findings that thermal induced ventilation is not as important as compared to the action of wind on top of the vent pipe. The regression model developed in this study, with an adjusted coefficient of multiple determination, R^2=91.44%, could explain 91.44% of the variations in the ventilation rate. It also had predicted R^2 of 91.22%.

7 CONCLUSIONS AND IMPLICATIONSCHAPTER 7: CONCLUSIONS AND IMPLICATIONS

7.1 Introduction

Latrine usage in low-income peri-urban settings is influenced by several technical and non-technical factors that are associated with latrines and the socio-cultural context. Knowledge of such factors is required to guide technological innovation and other interventions to improve latrine usage. Furthermore, to result in improved latrine usage, technological innovations should be evaluated in terms of how they enhance the key properties of latrines that tend to create barriers to regular usage. This thesis assessed the usage and barriers to use of latrines in a low-income periurban setting in Ghana and assessed how some design modifications could make the ventilated improved pit latrine, the most widely used existing technology, more suitable to the peri-urban setting. With odour nuisance emerging as a key barrier related to the design or technological aspect of latrines, this thesis assessed the factors that affect the levels of odour in latrines after testing and adopting a methodology for the objective measurement of odour.

7.2 Conclusions on Research Objectives

7.2.1 Usage and barriers to use of latrines in the low-income peri-urban setting

Residents of Prampram, a low-income peri-urban setting in Ghana, mostly depend on dry sanitation systems, with the VIP latrine being the most widely used technology option. Households that have access to private latrines highly patronise them, with shared latrines being as consistently used as unshared ones. On the contrary, access to communal latrines does not necessarily guarantee regular latrine usage.

Barriers to the consistent use of existing facilities are those relating to odour and heat emission, unhygienic maintenance and lack of access to facilities due to various factors. For users of private latrines, lack of access resulted from the closure of the latrine due to desludging or some other maintenance challenges as well as long queues, especially, among shared latrine users. Among communal latrine users, lack of access was the result of inability or unwillingness to pay the user fee and having to walk a longer distance to the nearest latrine as compared to the nearest open defecation site. For both users of private and communal latrines, non-technical factors such as unhygienic user habits, poor maintenance and the user fees dominated reported barriers to consistent use of latrines as compared to technical factors.

7.2.2 Factors affecting levels of odour in latrines

The concentrations of hydrogen sulphide and ammonia in latrine cubicles generally reflect the level of odour as perceived by the latrine users in Prampram but hydrogen sulphide could be used as a more reliable surrogate of the level of odour. The factors which significantly influence the level of odour in latrines include the type of latrine technology and whether it is used privately at home or at the communal level. The water closet technology has the least level of odour, followed by the ventilated improved pit latrine, with the simple pit latrine having the highest level of odour. Latrines used privately at home have significantly lower levels of odour as compared to communal latrines but there is no difference in the odour levels in latrines used by a single household and those shared at home by multiple households.

Another factor that significantly influences the level of odour in VIP latrines is the ventilation rate through the vent pipe, with higher ventilation rates leading to lower odour levels. Furthermore, latrines that are kept clean, with no faeces or urine on the seat or around the squat hole have significantly lower levels of odour. On the other hand, whether or not the vent pipe of a VIP latrine is installed to the recommended minimum height of 500 mm does not significantly influence the odour level in the latrine cubicle but it is essential to maintain the minimum height in order to direct odorous gases into the atmosphere. Similarly, the characteristics of the soils at latrine locations is not a major influential factor.

It is encouraging to note that the average level of hydrogen sulphide measured in VIP latrines used by single households or shared at home by two or more households was less than the WHO recommended level for prevention of odour annoyance (0.05 ppm). Thus, apart from the water closet, the VIP has the potential of providing a satisfactory level of odour to its users. On the average, a hydrogen sulphide concentration of 0.04 ppm is perceived by latrine users as being tolerable or acceptable.

7.2.3 Improvement in modifications of the VIP latrine

Modification of the diameter of the vent pipe is the most important factor to enhance the ventilation rate in the VIP latrine. The 100 mm diameter vent pipe commonly used in Ghana does not always provide adequate factor of safety against low wind speeds and innovative design features like provision of openings in multiple directions and installation of insect screens, which may serve some useful purposes. Instead, a vent pipe diameter of 150 mm or bigger could compensate for such innovative modifications introduced in the superstructure design. Generally, changing the vent pipe from one standard size to another, which is a change in diameter of 50 mm, leads to a corresponding change of 58% in the ventilation rate. With an appropriate diameter of the vent pipe, the height above the roof is not relevant to the attainment of a high ventilation rate apart from being high enough to prevent obstructions to the action of wind and to direct odorous air into the atmosphere.

Regarding the design of the superstructure, the findings of this study confirm the conventional proposition that providing a window or an opening in only the windward direction achieves a higher ventilation rate than where windows are provided in all sides of the superstructure. Nevertheless, windows or other openings may be provided in multiple directions to make the odour control function of the VIP latrine unaffected by changes in the local wind direction provided a vent pipe diameter of 150 mm or bigger is used. With reference to the standard VIP latrine design, the combined effect of the multidirectional superstructure design and installation of insect screens on the ventilation rate can be compensated for by an increase of 50 mm in the vent pipe diameter.

7.3 Contribution to Knowledge

Globally, Ghana is the nation with the highest proportion (59%) of the population depending on shared latrines (WHO/UNICEF, 2014). Even though local stakeholders have often expressed dissatisfaction with the JMP's definition of improved latrines, which excludes latrines shared at home by two or more households, these local sentiments have not been backed with empirical evidence generated locally to demonstrate that latrines shared at home are not necessarily worse than those used by single households. This study has generated some evidence of the potential of privately shared latrines even though additional studies in other communities are needed to confirm this evidence. First, the study has demonstrated that privately shared latrines are no less patronised consistently than those used exclusively by a single household. Therefore they could be equally important in the prevention of open defecation as single-household latrines. Secondly, if the level of odour in a latrine is assumed to be an indicator of the level of hygienic maintenance of the latrine, this study has revealed that privately shared latrines could be as hygienic as single-household latrines.

Although hydrogen sulphide and ammonia have been always associated with excreta, this study, to the best of the knowledge of the author, is the first to generate empirical data on the real time levels of these compounds that could be expected in the ambient air in a latrine cubicle. While Lin et al (2013) reported a so-called "*first qualitative and quantitative study of volatile compounds sampled from seven pit latrines*" (p. 7876) the compounds they quantified did not include hydrogen sulphide and ammonia. Other studies on the levels of these volatile compounds were conducted at waste treatment plants (Gostelow et al., 2001; Heaney et al., 2011) and in livestock production (Webb et al., 2014) but not in latrines. Selecting an equipment for this exercise was challenging, with an initial choice having to be replaced, because no data was found published on a similar study conducted elsewhere to guide the choice of detection range among available equipment. Besides the generation of knowledge of the levels of these compounds in latrines, this study has brought some meaning to the levels by benchmarking them with the perception of the latrine users. If additional studies in other communities confirm this finding, this study could be a useful guide in the development of guidelines for the regulation of communal or public latrines to avoid odour nuisance.

Furthermore, this study has extended existing knowledge on the design of the VIP latrine. Although earlier studies identified factors that influenced the ventilation rate in the vent pipe, this study has established the relative contributions of the various factors to the ventilation rate in the vent pipe. The regression analysis of factors affecting the ventilation rate makes it possible to project the expected change in the ventilation rate arising from various design decisions and weather conditions. It also allows an estimation of the compensation required to be made in some design criteria to account for the effects of others. For instance, it is now known from this study that while the provision of openings in multiple directions and installation of insect screens could reduce the ventilation rate in the vent pipe, their combined effect may be restored by upgrading the vent pipe to the next bigger standard size. Thus, where such unconventional modifications are desirable, the necessary adjustment in vent pipe size could be made to ensure that the ventilation rate is not compromised.

7.4 Implications of the Study

7.4.1 Implications for policy and planning

Even though further studies in other communities may be needed to confirm the findings on how latrines shared at home by two or more households compare with those used by single households, the current findings suggest the need to recognise in policy formulation the potential of privately shared latrines in preventing open defecation in low-income peri-urban settings. Thus, latrine promotion initiatives and messages could include the latrine ownership ladder concept (Obeng et al, 2015), which encourages households to pull resources together to overcome various constraints that make it difficult for them to acquire their individual household latrines. However, the findings of this study support the argument that public latrines do not guarantee regular latrine usage and should remain excluded from the definition of improved sanitation.

Nevertheless, their provision should be allowed in public places and in difficult areas where private latrines are not technically feasible for many households.

Furthermore, since the barriers to latrine usage were more non-technical than technology-related, latrine usage could be more effectively enhanced by institutional and managerial interventions than technology development per se. In particular, the citing of unhygienic conditions for avoiding both private and communal latrines calls for domestic sanitary inspection as well as public sector regulation and monitoring of communal latrines to demand their hygienic management. To support appropriate design and construction, there is the need for public sector support to households and latrine builders in the form of technical guidelines, training and information services.

7.4.2 Implications for practice and technology development

For low-income peri-urban settings where water supply is irregular, the VIP technology can be adopted for private use by one or more households since it has the potential to achieve an acceptable level of odour. However, the findings on barriers to latrine use imply that the design of the technology should allow adequate ventilation to minimise odour and heat emissions. To be specific, a vent pipe of 150 mm diameter should be used instead of the 100 mm that is currently used in Ghana, especially where prevention of odour is an overriding goal over cost minimisation. The multidirectional superstructure design and installation of insect screens in openings should only be adopted where a vent pipe size of 150 mm or bigger is used. For communal latrines, adopting wet technologies with a water-seal and a low water requirement can prevent hardening of sludge and allow easy desludging. To this end, the VIP latrine should not be used as a communal latrine facility.

7.4.3 Implications for further research

Additional studies are needed in other communities to confirm the findings on how privately shared latrines compare with those used exclusively by single households. Similarly, the relationship between the odour perception of latrine users and the levels the surrogate compounds needs to be investigate in other communities. Such studies could be used to develop a nationally representative relationship between odour perception and the levels of the surrogate compounds. To measure the level of hydrogen sulphide in a simple, instantaneous and verifiable manner, the Aeroqual 500 series provides a detection limit of 0.01 ppm at a relatively cheaper cost than other gas detectors. However, for research aimed at distinguishing among much lower concentrations of the compound, an equipment with a lower detection limit would be more appropriate but relatively more expensive.

This study investigated the effect of provision of windows or opening in multiple directions and insect screens on the ventilation rate but the sizes of windows and insect screen aperture were not varied to determine an appropriate size for optimum ventilation. Existing literature (Ryan and Mara, 1983a) recommends a minimum window or opening size equivalent to three times the cross-sectional area of the vent pipe. However, this recommendation was based on research conducted on the standard superstructure design in which the window or opening is provided in only one (windward) direction. Even though this guideline was adopted in this research, further research is required to determine how the guideline may be modified when windows are provided in multiple directions.

Furthermore, pit emptying challenges emerged as another key technical barrier apart from intense odour. Therefore, there is the need for further research on innovative pit emptying mechanisms. Such research should include an analysis of the prospects of any innovative mechanism within the geophysical constraints of the peri-urban environment. A key constraint to analyse would be the existence of haphazard land development that leaves several houses inaccessible to trucks.

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APPENDICES

Appendix 4-1: Data on Patronage of Communal Latrines

HOURLY INTERVAL	AVERAGE HOURLY PATRONAGE*

	T1	T2	T3	T4	T5	T6	T7	Total
04:00-05:00	21.6	9.9	29.3	17.0	5.7	9.7	13.4	106.6
05:00-06:00	37.6	33.0	32.9	45.3	15.6	15.9	46.6	226.7
06:00-07:00	35.0	31.6	32.7	31.6	11.3	13.4	39.0	194.6
07:00-08:00	15.4	13.9	22.6	14.6	8.9	10.6	18.1	104.0
08:00-09:00	12.9	7.3	17.7	14.6	7.1	8.4	15.7	83.7
09:00-10:00	9.4	3.6	16.0	9.6	4.4	10.0	12.7	65.7
10:00-11:00	11.4	3.4	10.4	11.0	3.9	9.0	12.6	61.7
11:00-12:00	8.7	2.4	10.4	10.0	4.1	4.7	9.6	50.0
12:00-13:00	8.7	2.4	10.7	7.9	3.0	5.3	12.4	50.4
13:00-14:00	7.0	5.1	11.1	10.7	4.0	6.1	11.3	55.4
14:00-15:00	8.6	3.9	10.0	11.0	3.4	9.0	15.0	60.9
15:00-16:00	10.7	4.7	11.4	12.0	4.6	8.0	15.0	66.4
16:00-17:00	10.1	4.9	16.1	15.3	5.3	7.0	17.4	76.1
17:00-18:00	15.0	9.6	18.4	15.7	4.6	6.3	20.0	89.6
18:00-19:00	16.6	12.3	25.0	14.7	0.6	9.1	29.0	107.3
19:00-20:00	7.0	5.0	16.4	15.4	0.0	6.1	20.3	70.3
20:00-21:00	2.1	2.6	5.0	8.1	0.0	5.9	11.4	35.1
21:00-22:00	1.3	0.0	0.6	2.1	0.0	0.1	2.7	6.9
Total	**239.1**	**155.4**	**296.9**	**266.6**	**86.4**	**144.7**	**322.3**	**1511.4**

*NB: * Averages for seven consecutive days of user headcounts*

T1—T7 are individual communal latrines

Appendix 5-1: Data on Ventilation Rates and Hydrogen Sulphide Concentrations in Selected VIP Latrines in Prampram

S/N	Toilet ID	Ventilation rate (m^3/h)		H_2S concentration (ppm)	
		Average	*SD*	*Average*	*SD*
1	PR/LE/090/VIP	0.99	0.19	0.988	0.544
2	PR/KL/089/VIP	31.75	1.52	0.617	0.387

3	PR/KL/084/VIP	21.32	3.34	0.257	0.063
4	PR/LE/110/VIP	4.52	1.07	0.695	0.447
5	PR/AN/058/VIP	0.91	0.22	1.458	0.406
6	PR/LW/066/VIP	26.06	2.88	0.116	0.061

Appendix 6-1: Data on Local Weather Conditions

Time GMT	Wind speed (m/s)					Ambient temperature (ºC)					Humidity (%)					Atmospheric pressure (kPa)				
	Min	*Max*	*Avg*	*SD*	*SE*	*Min*	*Max*	*Avg*	*SD*	*SE*	*Min*	*Max*	*Avg*	*SD*	*SE*	*Min*	*Max*	*Avg*	*SD*	*SE*
05:00	0.1	2.5	1.2	0.6	0.08	20.8	27.3	25.0	1.6	0.23	41.0	93.0	84.4	12.4	1.73	100.9	101.6	101.2	0.2	0.02
06:00	0.0	3.1	1.2	0.6	0.09	20.7	26.8	24.9	1.6	0.23	32.7	93.0	84.4	12.8	1.79	101.0	101.7	101.2	0.2	0.02
07:00	0.3	4.1	1.6	0.7	0.10	20.4	28.4	26.0	2.1	0.30	41.7	90.7	79.4	11.2	1.57	101.0	101.8	101.3	0.2	0.02
08:00	0.8	3.8	2.1	0.7	0.10	23.0	31.1	28.5	2.2	0.30	23.3	83.0	67.7	13.4	1.84	101.0	101.8	101.4	0.2	0.03
09:00	0.1	4.1	2.4	0.9	0.12	26.5	33.9	30.7	1.8	0.25	15.3	74.7	58.0	15.1	2.07	101.0	101.8	101.3	0.2	0.02
10:00	0.6	4.4	2.5	1.0	0.14	28.3	34.9	32.2	1.4	0.19	12.3	69.7	53.5	15.5	2.13	101.0	101.7	101.3	0.2	0.02
11:00	0.9	4.9	2.4	0.9	0.13	29.7	35.4	33.0	1.0	0.14	10.0	66.7	51.6	16.4	2.28	101.0	101.6	101.2	0.1	0.02
12:00	1.1	4.7	2.3	0.8	0.12	31.3	35.4	33.6	1.0	0.14	10.7	67.3	50.8	16.4	2.25	100.9	101.5	101.2	0.1	0.02
13:00	1.2	4.8	2.4	0.9	0.13	31.1	35.8	33.5	1.2	0.16	10.0	70.0	52.4	14.7	2.02	100.8	101.4	101.1	0.1	0.02
14:00	0.9	5.0	2.4	0.9	0.12	31.2	36.0	33.3	1.0	0.14	22.3	69.3	54.5	12.8	1.76	100.7	101.3	101.0	0.1	0.02
15:00	1.0	4.9	2.2	0.9	0.12	29.7	35.1	32.7	1.1	0.15	26.0	77.0	57.7	12.2	1.68	100.7	101.2	100.9	0.1	0.02
16:00	0.8	5.5	2.2	1.1	0.15	29.1	34.3	31.4	1.2	0.17	35.3	81.0	62.8	11.4	1.57	100.7	101.2	101.0	0.1	0.01
17:00	0.1	5.2	2.1	1.1	0.15	27.8	31.8	29.7	0.9	0.13	42.7	84.0	69.7	10.8	1.51	100.8	101.3	101.0	0.1	0.01

NB: Min = Minimum Max = Maximum Avg = Average SD = Standard Deviation SE = Standard Error

Appendix 6-2: Hourly Ventilation Rates in a Standard VIP Latrine

Time (GMT)	Hourly ventilation rate (m³/h)													
	Reference		H=250 mm			H=500 mm			H=750 mm			H=1000 mm		
	Min	*Rec*	*D100*	*D150*	*D200*	*D100*	*D150*	*D200*	*D100*	*D150*	*D200*	*D100*	*D150*	*D200*
05:00	10	20	15.83	27.98	62.17	23.27	45.78	92.69	19.50	44.51	139.04	16.96	51.50	88.17
06:00	10	20	14.41	31.16	58.78	22.98	51.50	92.69	15.54	54.05	92.69	25.15	35.61	101.74
07:00	10	20	14.41	28.61	50.87	33.82	72.49	89.30	13.85	59.77	134.52	26.85	50.23	87.04
08:00	10	20	18.65	32.43	39.56	41.35	78.85	111.91	37.02	80.75	130.00	33.63	61.68	123.21
09:00	10	20	25.43	41.33	29.39	38.34	105.55	141.30	31.93	99.83	117.56	31.37	92.83	152.60
10:00	10	20	20.06	39.42	24.87	27.04	96.01	171.82	22.89	111.91	224.95	36.74	98.56	171.82
11:00	10	20	18.65	34.97	31.65	37.87	66.13	170.00	35.04	127.81	143.56	37.59	101.74	79.13
12:00	10	20	19.78	36.88	37.30	30.80	62.31	176.34	22.89	137.98	140.17	27.98	54.05	139.04
13:00	10	20	19.78	40.69	26.00	31.46	59.13	170.69	12.72	124.63	192.17	39.00	31.79	109.65
14:00	10	20	20.35	25.43	23.74	35.14	72.49	160.52	6.22	152.60	148.08	51.43	59.13	83.65
15:00	10	20	16.39	22.89	26.00	42.96	57.23	150.34	4.24	141.16	189.91	43.80	43.87	169.56
16:00	10	20	16.11	22.89	20.35	32.97	89.02	140.00	2.83	134.16	148.08	49.74	53.41	160.52
17:00	10	20	19.78	21.62	15.83	37.40	106.82	144.69	1.98	112.55	145.82	38.72	38.79	148.08
Average			18.43	31.25	34.35	33.49	74.10	139.41	17.43	106.28	149.73	35.30	59.48	124.17
Standard Deviation			3.02	7.00	14.70	6.33	20.03	32.35	12.11	35.84	34.46	9.82	23.55	34.54
Standard Error			0.23	0.54	1.13	0.49	1.54	2.49	0.93	2.76	2.65	0.76	1.81	2.66
Minimum			14.41	21.62	15.83	22.98	45.78	89.30	1.98	44.51	92.69	16.96	31.79	79.13
Maximum			25.43	41.33	62.17	42.96	106.82	176.34	37.02	152.60	224.95	51.43	101.74	171.82

NB: Min= Minimum ventilation required; Rec=Recommended ventilation; D100, D150 & D200 = 100, 150 and 200 mm diameter vent pipes respectively

Appendix 6-3: Hourly Ventilation Rates in a Multidirectional VIP Latrine

Time (GMT)	Hourly ventilation rate (m^3/h)				
	Reference		Vent pipe diameter (mm)		
	Min	***Rec***	***D100***	***D150***	***D200***
05:00	10	20	17.95	34.97	52.00
06:00	10	20	22.75	31.79	57.65
07:00	10	20	29.67	45.78	67.82
08:00	10	20	26.75	57.86	75.74
09:00	10	20	26.28	48.96	88.17
10:00	10	20	28.92	49.60	74.61
11:00	10	20	29.81	53.41	101.74
12:00	10	20	26.19	47.69	76.87
13:00	10	20	26.47	58.50	67.82
14:00	10	20	29.67	59.13	81.39
15:00	10	20	29.30	45.15	81.39
16:00	10	20	26.94	42.60	70.08
17:00	10	20	20.35	46.42	75.74
Average			26.23	47.84	74.69
Standard Deviation			3.76	8.37	12.68
Standard Error			0.29	0.64	0.98
Minimum			17.95	31.79	52.00
Maximum			29.81	59.13	101.74

NB: Min= Minimum ventilation required; Rec=Recommended ventilation; D100, D150 & D200 = 100, 150 and 200 mm diameter vent pipes respectively. Vent pipes were installed to a height of 500 mm above the highest point on the roof.

Appendix 6-4: Ventilation Rates in a VIP Latrine with Insect Screens in Windows

Time (GMT)	Hourly Ventilation Rate (m^3/h)							
	Reference		Standard VIP			Multidirectional VIP		
	Min	***Rec***	***D100***	***D150***	***D200***	***D100***	***D150***	***D200***
05:00	10	20	23.17	38.79	78.00	18.37	33.70	52.00
06:00	10	20	31.37	48.96	61.04	16.67	37.52	61.04
07:00	10	20	38.15	55.95	64.43	18.93	38.79	44.09
08:00	10	20	47.48	59.77	105.13	19.50	51.50	52.00
09:00	10	20	33.91	85.20	101.74	17.52	48.32	42.96
10:00	10	20	31.09	61.04	44.09	16.96	49.60	45.22
11:00	10	20	39.56	71.22	57.65	14.98	55.32	36.17
12:00	10	20	39.00	30.52	35.04	15.26	41.33	44.09
13:00	10	20	34.76	66.76	47.48	15.26	57.23	39.56
14:00	10	20	20.91	45.78	49.74	17.24	52.14	36.17
15:00	10	20	28.26	73.12	48.61	18.65	48.32	39.56
16:00	10	20	46.06	76.94	40.69	20.91	38.79	39.56
17:00	10	20	27.41	71.22	70.08	18.93	33.06	36.17
Average			33.93	60.41	61.82	17.63	45.05	43.74
Standard Deviation			8.07	15.94	22.04	1.80	8.21	7.43
Standard Error			0.62	1.23	1.70	0.14	0.63	0.57
Minimum			20.91	30.52	35.04	14.98	33.06	36.17

Maximum	47.48	85.20	105.13	20.91	57.23	61.04

NB: Min= Minimum ventilation required; Rec=Recommended ventilation; D100, D150 & D200 = 100, 150 and 200 mm diameter vent pipes respectively

Appendix 6-5: Model Data

Observation	D	H	SPT	SCR	Tpipe	Vwind	Temp	Hum	Pabs	Q	lnQ
1	100	250	0	0	23.50	1.7	22.17	49.33	101.6	15.83	2.76
2	100	250	0	0	23.40	0.7	22.20	41.67	101.8	14.41	2.67
3	100	250	0	0	24.90	1.9	24.17	31.00	101.8	18.65	2.93
4	100	250	0	0	26.60	3.4	26.93	15.67	101.8	25.43	3.24
5	100	250	0	0	28.10	2.3	29.03	15.33	101.7	20.06	3.00
6	100	250	0	0	31.50	3.1	33.10	10.67	101.5	19.78	2.98
7	100	250	0	0	32.40	2.4	31.93	23.33	101.2	20.35	3.01
8	100	250	0	1	24.80	0.7	24.20	73.00	101.5	13.85	2.63
9	100	250	0	1	24.40	1.6	23.67	73.00	101.6	17.24	2.85
10	100	250	0	1	25.40	2.0	24.63	67.67	101.7	17.80	2.88
11	100	250	0	1	32.90	1.3	32.50	51.67	101.3	14.98	2.71
12	100	250	0	1	29.20	3.5	29.23	54.33	101.2	26.56	3.28
13	100	250	1	0	24.10	1.7	23.27	62.33	101.5	21.76	3.08
14	100	250	1	0	24.00	2.3	22.70	62.33	101.7	26.28	3.27
15	100	250	1	0	25.20	1.2	24.57	51.67	101.8	18.65	2.93
16	100	250	1	0	26.60	3.9	27.43	24.33	101.8	30.52	3.42
17	100	250	1	0	28.30	2.4	29.00	22.67	101.7	24.30	3.19
18	100	250	1	0	32.00	2.6	33.33	12.00	101.5	22.04	3.09

19	100	250	1	0	31.30	4.6	31.23	22.33	101.4	39.28	3.67
20	100	250	1	0	31.70	3.9	31.20	27.00	101.3	25.72	3.25
21	100	250	1	0	31.90	2.4	31.43	31.33	101.2	22.61	3.12
22	100	250	1	0	28.40	2.9	28.40	49.67	101.3	21.20	3.05

Observation	D	H	SPT	SCR	Tpipe	Vwind	Temp	Hum	Pabs	Q	lnQ
23	100	250	1	1	23.90	0.9	22.53	68.00	101.4	15.54	2.74
24	100	250	1	1	24.30	1.2	23.07	63.67	101.5	16.96	2.83
25	100	250	1	1	25.80	1.0	25.43	56.00	101.6	14.70	2.69
26	100	250	1	1	27.80	1.0	28.40	50.00	101.6	15.83	2.76
27	100	250	1	1	30.30	0.6	31.93	40.00	101.5	12.72	2.54
28	100	250	1	1	32.30	1.4	33.03	43.00	101.4	18.65	2.93
29	100	250	1	1	32.10	1.8	32.27	42.00	101.2	19.50	2.97
30	100	250	1	1	32.80	1.8	32.77	42.67	101.2	20.06	3.00
31	100	250	1	1	32.60	1.1	32.57	45.67	101.1	14.98	2.71
32	100	250	1	1	28.90	1.0	29.47	62.33	101.2	10.46	2.35
33	100	500	0	0	25.60	1.3	25.33	92.00	101.0	23.17	3.14
34	100	500	0	0	25.80	1.4	25.31	91.67	101.1	25.43	3.24
35	100	500	0	0	26.10	2.5	25.93	90.67	101.0	42.11	3.74
36	100	500	0	0	25.40	0.9	25.00	89.00	101.3	21.20	3.05
37	100	500	0	0	25.60	1.4	25.32	91.56	101.2	24.87	3.21
38	100	500	0	0	26.00	2.8	25.73	91.00	101.0	52.56	3.96
39	100	500	0	0	26.40	2.2	27.35	82.50	101.1	39.28	3.67

40	100	500	0	0	26.70	2.0	27.69	81.30	101.2	36.46	3.60
41	100	500	0	0	26.60	4.1	27.07	82.33	101.0	58.50	4.07
42	100	500	0	0	26.70	1.6	27.10	81.33	101.3	25.72	3.25
43	100	500	0	0	28.40	2.4	29.60	72.00	101.1	49.74	3.91
44	100	500	0	0	28.40	2.7	30.12	69.00	101.2	42.67	3.75
45	100	500	0	0	28.10	3.7	29.27	73.00	101.0	78.00	4.36
46	100	500	0	0	28.40	1.6	30.43	67.67	101.4	31.65	3.45

Observation	D	H	SPT	SCR	Tpipe	Vwind	Temp	Hum	Pabs	Q	lnQ
47	100	500	0	0	30.20	2.8	31.10	64.00	101.1	48.04	3.87
48	100	500	0	0	30.60	3.1	31.86	63.00	101.2	42.11	3.74
49	100	500	0	0	30.20	3.1	31.57	61.67	101.0	63.02	4.14
50	100	500	0	0	30.30	1.5	32.30	58.33	101.4	24.87	3.21
51	100	500	0	0	32.40	2.1	33.68	59.00	101.1	31.93	3.46
52	100	500	0	0	32.00	1.6	33.50	57.80	101.1	25.43	3.24
53	100	500	0	0	32.20	3.4	32.63	63.00	101.0	60.76	4.11
54	100	500	0	0	31.30	1.6	33.07	57.67	101.3	23.74	3.17
55	100	500	0	0	32.40	2.9	33.32	59.40	101.1	40.13	3.69
56	100	500	0	0	31.80	4.9	32.07	65.33	101.0	71.22	4.27
57	100	500	0	0	31.80	1.5	32.83	59.67	101.3	28.54	3.35
58	100	500	0	0	34.30	1.8	33.98	57.75	101.0	32.22	3.47
59	100	500	0	0	35.10	1.7	34.68	52.80	101.0	22.04	3.09
60	100	500	0	0	33.10	4.0	32.53	64.33	100.9	70.37	4.25

61	100	500	0	0	34.40	1.7	34.03	55.33	101.2	38.15	3.64
62	100	500	0	0	37.50	1.5	34.90	55.00	100.9	20.06	3.00
63	100	500	0	0	36.80	2.3	34.72	53.40	100.9	29.96	3.40
64	100	500	0	0	33.70	4.8	32.27	66.67	100.8	76.30	4.33
65	100	500	0	0	35.90	1.9	34.23	54.67	101.1	44.37	3.79
66	100	500	0	0	38.10	1.8	34.43	56.00	100.9	22.04	3.09
67	100	500	0	0	36.20	3.2	33.76	57.60	100.8	47.76	3.87
68	100	500	0	0	34.10	4.1	32.00	68.00	100.7	79.13	4.37
69	100	500	0	0	36.70	2.0	33.90	56.67	101.0	35.61	3.57
70	100	500	0	0	34.60	1.9	32.45	63.50	100.9	35.04	3.56

Observation	D	H	SPT	SCR	Tpipe	Vwind	Temp	Hum	Pabs	Q	lnQ
71	100	500	0	0	32.90	3.4	31.94	65.00	100.8	58.22	4.06
72	100	500	0	0	33.10	4.9	31.23	70.00	100.7	76.30	4.33
73	100	500	0	0	36.10	1.8	33.57	57.33	101.0	35.61	3.57
74	100	500	0	0	29.90	3.5	29.44	76.20	100.9	53.41	3.98
75	100	500	0	0	31.70	5.5	30.33	74.00	100.7	74.04	4.30
76	100	500	0	0	35.30	0.9	33.07	58.33	101.0	23.46	3.16
77	100	500	0	0	31.80	1.4	30.73	66.00	100.9	31.09	3.44
78	100	500	0	0	28.90	2.6	28.54	81.00	100.9	47.76	3.87
79	100	500	0	0	29.10	5.2	28.77	81.00	100.8	74.89	4.32
80	100	500	0	0	31.10	1.5	30.53	69.67	101.0	33.35	3.51
81	100	500	0	1	26.00	1.0	25.57	91.00	101.2	23.17	3.14

82	100	500	0	1	26.80	1.8	27.77	81.67	101.2	38.15	3.64
83	100	500	0	1	28.50	2.6	30.07	69.33	101.3	47.48	3.86
84	100	500	0	1	30.60	2.6	32.17	59.33	101.3	33.91	3.52
85	100	500	0	1	32.10	1.5	34.30	54.00	101.3	31.09	3.44
86	100	500	0	1	36.40	1.8	34.93	53.33	101.1	34.76	3.55
87	100	500	0	1	39.00	1.4	35.13	53.67	101.0	20.91	3.04
88	100	500	0	1	37.80	2.0	34.23	56.33	100.9	28.26	3.34
89	100	500	0	1	31.30	1.4	30.57	71.33	101.0	27.41	3.31
90	100	500	1	0	25.70	1.5	25.30	86.00	101.1	21.48	3.07
91	100	500	1	0	26.20	1.0	25.87	91.00	101.2	14.41	2.67
92	100	500	1	0	25.70	1.3	25.50	91.00	101.2	17.52	2.86
93	100	500	1	0	26.10	3.3	25.97	84.33	101.2	37.87	3.63
94	100	500	1	0	26.70	2.4	27.33	82.33	101.3	21.48	3.07

Observation	D	H	SPT	SCR	Tpipe	Vwind	Temp	Hum	Pabs	Q	lnQ
95	100	500	1	0	28.40	2.6	30.18	70.40	101.2	28.26	3.34
96	100	500	1	0	26.80	3.4	26.57	80.00	101.4	29.96	3.40
97	100	500	1	0	28.70	2.7	30.53	68.00	101.3	22.04	3.09
98	100	500	1	0	30.00	2.3	31.72	63.40	101.2	28.26	3.34
99	100	500	1	0	27.90	2.8	27.70	72.00	101.3	26.56	3.28
100	100	500	1	0	29.90	2.5	31.23	65.00	101.3	24.02	3.18
101	100	500	1	0	30.90	3.0	32.00	63.00	101.2	30.24	3.41
102	100	500	1	0	28.90	3.1	28.27	69.67	101.3	31.37	3.45

103	100	500	1	0	31.70	1.9	33.53	59.33	101.3	25.15	3.22
104	100	500	1	0	32.10	2.4	33.20	59.00	101.2	29.67	3.39
105	100	500	1	0	34.60	2.4	33.95	58.25	101.1	22.61	3.12
106	100	500	1	0	31.90	3.5	31.27	60.33	101.1	26.56	3.28
107	100	500	1	0	33.90	2.1	33.43	59.33	101.2	29.39	3.38
108	100	500	1	0	36.30	1.6	33.74	59.20	101.0	24.87	3.21
109	100	500	1	0	33.30	1.6	31.80	64.67	101.0	23.46	3.16
110	100	500	1	0	35.70	3.1	34.20	57.33	101.1	31.09	3.44
111	100	500	1	0	37.30	2.1	33.72	59.60	101.0	27.69	3.32
112	100	500	1	0	32.90	1.6	31.60	65.00	100.9	28.54	3.35
113	100	500	1	0	36.90	2.4	33.70	60.67	101.0	32.78	3.49
114	100	500	1	0	37.60	2.2	33.94	59.20	100.9	26.56	3.28
115	100	500	1	0	34.70	3.2	32.33	61.67	100.9	31.65	3.45
116	100	500	1	0	37.20	1.4	33.87	59.00	101.0	29.67	3.39
117	100	500	1	0	36.50	1.4	33.36	59.60	100.9	27.13	3.30
118	100	500	1	0	34.90	2.0	32.20	64.67	101.0	29.96	3.40

Observation	D	H	SPT	SCR	Tpipe	Vwind	Temp	Hum	Pabs	Q	lnQ
119	100	500	1	0	33.70	1.3	31.24	67.00	100.9	21.76	3.08
120	100	500	1	0	28.30	0.8	27.93	76.67	101.1	18.93	2.94
121	100	500	1	1	26.30	1.5	25.23	92.00	101.2	18.37	2.91
122	100	500	1	1	26.50	1.5	26.70	84.33	101.3	18.93	2.94
123	100	500	1	1	28.70	1.5	30.50	68.67	101.4	19.50	2.97

124	100	500	1	1	29.90	1.5	32.07	62.00	101.4	17.52	2.86
125	100	500	1	1	31.60	1.2	33.20	57.67	101.4	16.96	2.83
126	100	500	1	1	35.40	1.1	35.30	51.33	101.2	15.26	2.73
127	100	500	1	1	38.30	1.3	35.80	51.00	101.1	15.26	2.73
128	100	500	1	1	39.60	1.2	36.03	50.00	101.0	17.24	2.85
129	100	500	1	1	39.50	1.1	35.10	52.33	101.0	18.65	2.93
130	100	500	1	1	33.80	0.9	31.77	64.67	101.0	18.93	2.94
131	100	750	0	0	26.70	0.8	25.50	92.00	101.0	19.50	2.97
132	100	750	0	0	28.40	1.7	30.57	71.33	101.2	37.02	3.61
133	100	750	0	0	29.90	1.8	31.97	64.33	101.2	31.93	3.46
134	100	750	0	0	31.90	1.4	33.83	58.67	101.2	22.89	3.13
135	100	750	0	1	26.20	1.6	26.13	90.00	101.1	28.83	3.36
136	100	750	0	1	26.80	2.6	27.53	84.00	101.1	36.74	3.60
137	100	750	0	1	28.60	3.3	30.13	71.67	101.2	39.85	3.69
138	100	750	0	1	31.30	3.1	32.03	63.00	101.2	50.87	3.93
139	100	750	0	1	32.30	3.5	32.57	64.33	101.1	48.32	3.88
140	100	750	0	1	32.10	4.5	31.93	67.33	101.0	68.67	4.23
141	100	750	0	1	34.90	2.3	33.80	62.33	101.0	41.26	3.72
142	100	750	0	1	34.60	3.3	33.23	63.33	100.8	54.54	4.00

Observation	**D**	**H**	**SPT**	**SCR**	**Tpipe**	**Vwind**	**Temp**	**Hum**	**Pabs**	**Q**	**lnQ**
143	100	750	0	1	35.70	1.9	33.63	61.67	100.8	33.91	3.52
144	100	750	0	1	30.00	3.0	29.43	79.33	100.9	44.93	3.81

145	100	750	1	0	26.90	0.9	25.40	92.00	101.2	14.70	2.69
146	100	750	1	0	27.10	1.4	27.77	81.67	101.3	17.24	2.85
147	100	750	1	0	28.70	2.4	30.60	70.00	101.3	22.33	3.11
148	100	750	1	0	30.00	2.5	31.73	61.67	101.4	29.11	3.37
149	100	750	1	0	30.90	4.2	31.80	62.00	101.3	31.65	3.45
150	100	750	1	0	32.40	3.4	32.33	61.67	101.2	35.89	3.58
151	100	750	1	0	34.40	2.1	33.57	58.33	101.1	30.24	3.41
152	100	750	1	0	34.00	2.8	32.27	60.67	101.0	37.30	3.62
153	100	750	1	0	35.00	3.7	32.50	59.67	100.9	34.76	3.55
154	100	750	1	0	31.30	2.4	30.07	71.00	101.0	24.02	3.18
155	100	750	1	1	26.10	1.3	25.83	91.00	101.0	14.41	2.67
156	100	750	1	1	28.30	2.8	30.03	71.00	101.1	26.56	3.28
157	100	750	1	1	30.30	3.2	32.30	59.67	101.1	25.15	3.22
158	100	750	1	1	31.40	3.7	32.33	63.67	101.1	31.65	3.45
159	100	750	1	1	33.20	2.7	33.03	62.33	101.0	29.96	3.40
160	100	750	1	1	33.80	4.0	33.17	62.67	100.9	32.50	3.48
161	100	750	1	1	34.90	3.5	33.47	62.33	100.8	31.93	3.46
162	100	750	1	1	33.90	4.1	31.50	71.67	100.8	37.30	3.62
163	100	750	1	1	30.00	2.8	29.60	78.67	100.9	31.65	3.45
164	100	1000	0	0	27.70	1.4	26.90	87.67	101.3	26.85	3.29
165	100	1000	0	0	28.80	2.1	29.67	76.33	101.3	33.63	3.52
166	100	1000	0	0	30.70	1.4	31.40	69.00	101.4	31.37	3.45

Observation	D	H	SPT	SCR	Tpipe	Vwind	Temp	Hum	Pabs	Q	lnQ
167	100	1000	0	0	31.70	2.3	32.60	64.00	101.3	36.74	3.60
168	100	1000	0	0	32.80	1.7	33.30	63.33	101.2	27.98	3.33
169	100	1000	0	0	32.80	2.8	32.83	64.00	101.1	39.00	3.66
170	100	1000	0	0	32.50	4.0	31.97	67.33	101.0	51.43	3.94
171	100	1000	0	0	33.10	2.5	32.33	66.67	100.9	43.80	3.78
172	100	1000	0	0	30.60	2.3	29.70	80.33	101.0	38.72	3.66
173	100	1000	0	1	26.40	1.6	26.10	91.00	101.3	33.35	3.51
174	100	1000	0	1	26.70	2.0	26.43	88.67	101.3	34.48	3.54
175	100	1000	0	1	27.90	3.1	28.47	79.00	101.4	47.48	3.86
176	100	1000	0	1	29.20	3.3	29.73	71.00	101.4	51.15	3.93
177	100	1000	0	1	31.30	2.7	31.73	60.00	101.3	44.37	3.79
178	100	1000	0	1	33.60	2.0	33.73	61.67	101.2	35.61	3.57
179	100	1000	0	1	34.30	2.1	33.30	62.33	101.1	40.69	3.71
180	100	1000	0	1	33.70	3.3	32.27	67.33	101.0	44.09	3.79
181	100	1000	0	1	33.00	3.5	31.77	70.00	101.0	52.56	3.96
182	100	1000	0	1	29.50	3.7	29.03	81.00	101.1	41.82	3.73
183	100	1000	1	0	27.10	1.5	25.50	93.00	101.2	20.06	3.00
184	100	1000	1	0	27.10	1.2	26.40	88.00	101.2	17.80	2.88
185	100	1000	1	0	28.20	2.2	28.83	75.67	101.3	22.89	3.13
186	100	1000	1	0	29.70	1.9	31.83	60.33	101.3	20.91	3.04
187	100	1000	1	0	32.10	1.0	33.63	56.33	101.3	16.39	2.80
188	100	1000	1	0	33.90	1.5	35.00	50.33	101.2	16.67	2.81

189	100	1000	1	0	35.10	1.3	34.90	50.33	101.1	16.67	2.81
190	100	1000	1	0	35.10	1.3	34.77	52.33	101.0	22.61	3.12

Observation	D	H	SPT	SCR	Tpipe	Vwind	Temp	Hum	Pabs	Q	lnQ
191	100	1000	1	0	35.20	1.1	33.63	58.00	101.0	21.20	3.05
192	100	1000	1	0	31.90	0.9	30.33	71.67	101.0	18.65	2.93
193	100	1000	1	1	28.60	0.8	29.53	77.33	101.4	16.11	2.78
194	100	1000	1	1	30.30	1.9	31.03	69.33	101.4	23.46	3.16
195	100	1000	1	1	30.90	2.9	31.80	65.33	101.4	26.85	3.29
196	100	1000	1	1	32.90	1.9	33.80	60.00	101.1	20.63	3.03
197	100	1000	1	1	34.00	1.5	34.10	60.33	101.0	19.22	2.96
198	100	1000	1	1	34.40	1.5	33.90	61.67	100.9	21.48	3.07
199	100	1000	1	1	34.30	1.7	32.57	66.33	100.9	24.87	3.21
200	100	1000	1	1	30.80	1.7	29.73	76.67	101.0	22.04	3.09
201	150	250	0	0	22.40	1.4	20.80	69.00	101.4	27.98	3.33
202	150	250	0	0	22.00	1.2	20.43	71.00	101.6	28.61	3.35
203	150	250	0	0	25.00	1.7	25.90	27.00	101.6	32.43	3.48
204	150	250	0	0	27.00	2.5	28.53	18.33	101.5	41.33	3.72
205	150	250	0	0	28.30	3.1	30.43	15.33	101.5	39.42	3.67
206	150	250	0	0	31.70	1.8	33.53	11.67	101.3	36.88	3.61
207	150	250	0	0	31.50	3.6	31.97	22.67	101.1	40.69	3.71
208	150	250	0	1	23.70	1.8	21.83	70.67	101.3	34.97	3.55
209	150	250	0	1	23.60	2.2	21.73	73.00	101.5	39.42	3.67

210	150	250	0	1	26.40	2.6	26.50	62.00	101.6	38.79	3.66
211	150	250	0	1	28.50	1.9	30.40	27.33	101.5	34.97	3.55
212	150	250	0	1	31.60	1.4	33.63	16.00	101.4	24.16	3.18
213	150	250	0	1	31.20	2.6	32.23	28.33	101.2	32.43	3.48
214	150	250	0	1	28.40	2.7	28.67	54.00	101.1	38.79	3.66

Observation	D	H	SPT	SCR	Tpipe	Vwind	Temp	Hum	Pabs	Q	lnQ
215	150	250	1	0	24.40	1.3	23.13	52.00	101.3	32.43	3.48
216	150	250	1	0	27.00	4.1	28.47	19.00	101.6	61.68	4.12
217	150	250	1	0	28.50	3.5	30.80	12.33	101.5	49.60	3.90
218	150	250	1	0	31.20	2.0	34.70	13.33	101.2	33.06	3.50
219	150	250	1	0	30.80	1.8	31.73	35.00	101.1	31.79	3.46
220	150	250	1	0	31.40	2.0	32.17	37.00	101.0	36.88	3.61
221	150	250	1	0	27.80	2.9	27.80	52.67	101.1	43.24	3.77
222	150	250	1	1	28.60	1.2	30.87	28.67	101.5	29.25	3.38
223	150	250	1	1	31.70	2.3	32.57	27.33	101.1	31.79	3.46
224	150	250	1	1	32.00	1.6	33.20	32.33	101.1	29.88	3.40
225	150	250	1	1	29.10	0.9	29.83	45.33	101.1	25.43	3.24
226	150	500	0	0	26.70	0.6	25.50	86.33	101.2	45.78	3.82
227	150	500	0	0	26.80	2.0	26.67	82.00	101.3	72.49	4.28
228	150	500	0	0	28.40	2.2	29.93	72.00	101.3	78.85	4.37
229	150	500	0	0	29.70	3.6	30.97	69.67	101.3	105.55	4.66
230	150	500	0	0	31.00	3.0	32.27	65.33	101.2	96.01	4.56

Observation	D	H	SPT	SCR	Tpipe	Vwind	Temp	Hum	Pabs	Q	lnQ
231	150	500	0	0	33.50	2.3	34.30	58.50	101.1	62.31	4.13
232	150	500	0	0	35.00	2.1	34.20	59.67	101.0	59.13	4.08
233	150	500	0	0	34.40	2.4	33.83	61.33	100.9	72.49	4.28
234	150	500	0	0	33.50	1.6	32.53	65.67	100.9	57.23	4.05
235	150	500	0	0	29.70	3.2	29.40	75.67	101.0	106.82	4.67
236	150	500	0	1	27.00	0.8	25.50	91.00	101.2	38.79	3.66
237	150	500	0	1	27.30	1.6	27.40	82.00	101.3	55.95	4.02
238	150	500	0	1	28.50	1.6	30.30	70.33	101.4	59.77	4.09
239	150	500	0	1	29.70	2.6	31.60	64.00	101.4	85.20	4.45
240	150	500	0	1	31.60	2.2	34.10	55.00	101.4	61.04	4.11
241	150	500	0	1	34.10	1.6	34.77	55.00	101.2	30.52	3.42
242	150	500	0	1	33.80	2.1	34.27	58.67	101.1	66.76	4.20
243	150	500	0	1	35.00	1.6	34.57	57.33	101.0	45.78	3.82
244	150	500	0	1	31.60	1.8	31.50	66.00	101.0	71.22	4.27
245	150	500	1	0	26.60	1.3	25.70	91.00	101.1	34.97	3.55
246	150	500	1	0	27.20	1.7	27.27	84.00	101.2	45.78	3.82
247	150	500	1	0	28.40	2.6	29.87	71.67	101.2	57.86	4.06
248	150	500	1	0	30.50	2.3	31.83	64.33	101.2	48.96	3.89
249	150	500	1	0	31.20	3.0	32.20	64.00	101.2	49.60	3.90
250	150	500	1	0	33.50	2.5	34.20	56.00	101.0	47.69	3.86
251	150	500	1	0	33.60	2.7	33.07	61.00	100.9	58.50	4.07

252	150	500	1	0	34.60	2.5	34.00	58.67	100.9	59.13	4.08
253	150	500	1	0	34.90	1.8	33.77	60.33	100.8	45.15	3.81
254	150	500	1	0	30.70	2.1	30.17	71.67	101.0	46.42	3.84
255	150	500	1	1	27.50	1.1	26.60	89.00	101.2	33.70	3.52
256	150	500	1	1	27.70	1.1	27.40	84.33	101.3	38.79	3.66
257	150	500	1	1	28.60	2.4	29.03	76.67	101.3	51.50	3.94
258	150	500	1	1	29.80	2.2	30.50	69.33	101.3	48.32	3.88
259	150	500	1	1	32.00	2.1	33.10	62.00	101.2	49.60	3.90
260	150	500	1	1	34.10	1.7	35.07	54.00	101.1	41.33	3.72
261	150	500	1	1	34.70	2.4	34.57	55.00	101.0	57.23	4.05
262	150	500	1	1	33.70	2.3	33.40	61.67	101.0	52.14	3.95

Observation	D	H	SPT	SCR	Tpipe	Vwind	Temp	Hum	Pabs	Q	lnQ
263	150	500	1	1	31.50	2.3	30.70	72.67	101.0	48.32	3.88
264	150	500	1	1	30.10	1.1	29.73	78.67	101.0	33.06	3.50
265	150	750	0	0	26.60	0.6	25.73	91.00	101.1	44.51	3.80
266	150	750	0	0	27.00	1.4	27.77	81.33	101.2	59.77	4.09
267	150	750	0	0	28.70	3.0	30.70	70.67	101.2	80.75	4.39
268	150	750	0	0	30.20	3.1	31.53	65.33	101.2	99.83	4.60
269	150	750	0	0	30.80	4.1	32.03	63.00	101.2	111.91	4.72
270	150	750	0	0	31.70	4.4	32.43	63.00	101.0	137.98	4.93
271	150	750	0	0	33.30	4.1	33.07	62.67	100.9	124.63	4.83
272	150	750	0	0	32.70	5.0	31.87	68.67	100.9	152.60	5.03

Observation	D	H	SPT	SCR	Tpipe	Vwind	Temp	Hum	Pabs	Q	lnQ
273	150	750	0	0	32.50	4.3	31.73	70.00	100.8	141.16	4.95
274	150	750	0	0	30.10	3.7	29.93	75.00	100.9	112.55	4.72
275	150	750	0	1	26.40	2.0	25.70	91.00	101.1	64.22	4.16
276	150	750	0	1	26.80	2.8	26.97	83.33	101.2	80.12	4.38
277	150	750	0	1	28.20	2.8	29.50	72.00	101.3	93.47	4.54
278	150	750	0	1	29.60	3.3	31.03	64.33	101.3	95.38	4.56
279	150	750	0	1	31.40	3.5	33.17	56.67	101.2	83.93	4.43
280	150	750	0	1	31.40	4.7	32.10	63.33	101.1	140.52	4.95
281	150	750	0	1	31.80	4.4	32.23	63.33	101.0	127.81	4.85
282	150	750	0	1	32.60	3.7	32.80	65.00	100.9	122.72	4.81
283	150	750	0	1	32.60	3.2	32.07	68.00	100.9	86.48	4.46
284	150	750	0	1	29.80	2.4	29.70	77.67	100.9	87.75	4.47
285	150	750	1	0	26.90	1.8	26.47	89.00	101.1	42.60	3.75
286	150	750	1	0	27.20	2.0	27.00	83.00	101.1	47.05	3.85
287	150	750	1	0	28.00	2.9	28.10	80.00	101.2	52.78	3.97
288	150	750	1	0	30.10	3.6	31.30	64.67	101.2	62.95	4.14
289	150	750	1	0	30.90	3.5	31.47	63.00	101.1	63.59	4.15
290	150	750	1	0	32.80	3.4	34.17	52.67	100.9	59.77	4.09
291	150	750	1	0	32.60	3.7	32.13	67.33	100.8	70.58	4.26
292	150	750	1	0	33.20	3.2	32.60	65.33	100.7	59.13	4.08
293	150	750	1	0	33.10	3.8	31.80	69.00	100.7	73.12	4.29

Observation	D	H	SPT	SCR	Tpipe	Vwind	Temp	Hum	Pabs	Q	lnQ
294	150	750	1	0	30.30	2.1	29.97	79.67	100.8	48.32	3.88
295	150	750	1	1	27.00	1.3	25.90	92.00	101.1	34.34	3.54
296	150	750	1	1	27.30	2.0	27.13	84.33	101.2	47.05	3.85
297	150	750	1	1	28.30	3.1	29.73	71.67	101.2	54.05	3.99
298	150	750	1	1	29.40	3.6	31.00	62.67	101.2	66.76	4.20
299	150	750	1	1	31.10	3.6	32.57	60.00	101.1	66.13	4.19
300	150	750	1	1	32.10	2.7	33.43	61.67	101.0	56.59	4.04
301	150	750	1	1	31.90	2.7	32.57	64.33	101.0	64.22	4.16
302	150	750	1	1	32.30	2.4	32.73	65.33	100.9	65.49	4.18
303	150	750	1	1	32.60	2.4	32.37	67.00	100.8	60.41	4.10
304	150	750	1	1	30.20	3.9	29.80	78.00	100.9	62.95	4.14
305	150	1000	0	0	27.40	1.3	25.90	92.00	101.2	51.50	3.94
306	150	1000	0	0	27.50	1.4	26.77	88.67	101.3	50.23	3.92
307	150	1000	0	0	28.40	1.8	29.70	75.33	101.4	61.68	4.12
308	150	1000	0	0	30.30	2.5	31.50	65.67	101.4	98.56	4.59
309	150	1000	0	0	32.80	1.8	34.50	54.00	101.2	54.05	3.99
310	150	1000	0	0	33.70	1.5	35.03	51.67	101.1	31.79	3.46
311	150	1000	0	0	33.40	2.0	33.93	56.67	101.0	59.13	4.08
312	150	1000	0	0	33.80	1.6	33.50	59.67	101.0	43.87	3.78
313	150	1000	0	0	29.30	1.6	29.47	75.00	101.1	38.79	3.66
314	150	1000	0	1	27.40	1.6	26.30	88.67	101.0	55.32	4.01

315	150	1000	0	1	27.60	1.6	26.93	85.33	101.1	61.04	4.11
316	150	1000	0	1	29.10	1.8	29.67	72.67	101.2	68.04	4.22
317	150	1000	0	1	31.80	0.9	33.90	54.00	101.2	29.25	3.38
318	150	1000	0	1	33.20	1.4	33.40	60.67	101.1	34.34	3.54
319	150	1000	0	1	32.40	2.3	34.10	57.33	101.0	68.67	4.23
320	150	1000	0	1	33.50	2.2	33.73	59.00	100.9	64.86	4.17
321	150	1000	0	1	34.60	1.9	34.07	57.67	100.8	42.60	3.75
322	150	1000	0	1	31.60	1.2	30.33	72.67	100.9	33.06	3.50
323	150	1000	0	1	30.10	1.8	29.10	77.00	100.9	43.87	3.78
324	150	1000	1	0	27.70	0.3	26.13	89.33	101.2	30.52	3.42
325	150	1000	1	0	27.70	1.7	27.07	86.00	101.3	38.15	3.64
326	150	1000	1	0	28.50	2.0	29.53	75.33	101.4	51.50	3.94
327	150	1000	1	0	30.00	3.7	31.40	65.33	101.4	51.50	3.94
328	150	1000	1	0	31.60	1.9	33.00	61.33	101.4	39.42	3.67
329	150	1000	1	0	32.30	1.8	33.80	58.33	101.2	43.24	3.77
330	150	1000	1	0	32.80	1.5	34.13	57.67	101.1	33.06	3.50
331	150	1000	1	0	32.80	2.0	33.50	61.67	101.0	40.69	3.71
332	150	1000	1	0	33.00	1.4	33.20	63.33	101.0	37.52	3.62
333	150	1000	1	0	30.70	1.7	29.97	78.67	101.0	41.97	3.74
334	150	1000	1	1	26.80	0.1	25.30	91.00	101.1	30.52	3.42

Observation	**D**	**H**	**SPT**	**SCR**	**Tpipe**	**Vwind**	**Temp**	**Hum**	**Pabs**	**Q**	**lnQ**
335	150	1000	1	1	26.90	0.9	26.70	87.33	101.3	34.34	3.54

336	150	1000	1	1	28.30	0.8	29.83	72.33	101.3	27.34	3.31
337	150	1000	1	1	30.30	0.4	33.47	55.00	101.3	24.80	3.21
338	150	1000	1	1	32.50	1.1	33.87	54.33	101.3	27.98	3.33
339	150	1000	1	1	34.10	1.7	34.30	56.00	101.1	36.88	3.61
340	150	1000	1	1	34.20	2.6	33.70	59.00	101.1	33.06	3.50
341	150	1000	1	1	33.70	1.3	33.47	56.67	101.0	29.88	3.40
342	150	1000	1	1	34.60	1.6	34.10	56.67	101.0	34.97	3.55
343	150	1000	1	1	30.10	3.6	29.33	78.33	101.0	63.59	4.15
344	200	250	0	0	23.10	0.9	21.50	60.00	101.3	62.17	4.13
345	200	250	0	0	23.40	0.3	22.40	48.00	101.4	50.87	3.93
346	200	250	0	0	24.80	0.9	25.37	41.00	101.4	39.56	3.68
347	200	250	0	0	27.80	0.1	30.47	30.67	101.4	29.39	3.38
348	200	250	0	1	24.60	1.8	21.60	88.00	101.5	64.43	4.17
349	200	250	0	1	25.70	0.9	25.83	38.00	101.7	58.78	4.07
350	200	250	0	1	27.10	2.3	29.60	15.33	101.7	65.56	4.18
351	200	250	0	1	28.20	2.5	31.30	13.00	101.6	67.82	4.22
352	200	250	0	1	30.30	2.7	34.40	11.33	101.4	55.39	4.01
353	200	250	0	1	31.20	1.8	35.57	10.00	101.3	61.04	4.11
354	200	250	0	1	30.90	3.4	32.90	22.33	101.2	91.56	4.52
355	200	250	0	1	30.70	3.3	32.10	26.00	101.2	79.13	4.37
356	200	250	0	1	28.90	2.9	29.43	42.67	101.2	66.69	4.20
357	200	250	1	0	23.70	0.7	21.10	67.00	101.3	48.61	3.88
358	200	250	1	0	23.70	1.4	21.57	65.00	101.4	54.26	3.99

Observation	D	H	SPT	SCR	Tpipe	Vwind	Temp	Hum	Pabs	Q	lnQ
359	200	250	1	0	24.20	2.2	23.00	63.50	101.5	67.82	4.22
360	200	250	1	0	25.90	2.7	26.87	50.67	101.5	73.48	4.30
361	200	250	1	0	27.40	2.0	29.90	45.33	101.4	53.13	3.97
362	200	250	1	0	28.70	1.8	32.67	27.67	101.4	44.09	3.79
363	200	250	1	0	29.20	2.3	32.17	27.00	101.3	64.43	4.17
364	200	250	1	0	30.10	1.8	32.87	32.67	101.2	44.09	3.79
365	200	250	1	0	30.90	1.4	33.73	33.00	101.1	39.56	3.68
366	200	250	1	0	30.50	1.6	32.33	40.00	101.0	50.87	3.93
367	200	250	1	0	28.10	1.4	28.60	56.67	101.1	44.09	3.79
368	200	250	1	1	26.00	1.9	23.50	88.00	101.4	70.08	4.25
369	200	250	1	1	26.30	2.7	25.33	74.00	101.7	91.56	4.52
370	200	250	1	1	28.40	2.7	31.20	31.33	101.6	68.95	4.23
371	200	250	1	1	29.60	3.5	32.27	39.00	101.3	107.39	4.68
372	200	250	1	1	30.80	1.9	33.70	40.67	101.2	64.43	4.17
373	200	250	1	1	30.80	2.0	33.57	41.00	101.2	75.74	4.33
374	200	250	1	1	29.40	1.5	30.17	59.67	101.2	49.74	3.91
375	200	500	0	0	26.50	0.3	25.90	90.00	101.1	92.69	4.53
376	200	500	0	0	26.80	0.8	26.47	86.67	101.2	89.30	4.49
377	200	500	0	0	27.20	1.2	27.13	83.00	101.3	111.91	4.72
378	200	500	0	0	28.90	1.7	29.10	74.67	101.3	141.30	4.95
379	200	500	0	0	30.30	4.1	31.47	62.00	101.2	171.82	5.15

380	200	500	0	0	31.00	3.2	31.30	65.67	101.0	176.34	5.17
381	200	500	0	0	33.00	3.4	33.17	60.67	100.9	160.52	5.08
382	200	500	0	0	30.80	2.3	30.30	72.67	100.9	150.34	5.01

Observation	D	H	SPT	SCR	Tpipe	Vwind	Temp	Hum	Pabs	Q	lnQ
383	200	500	0	0	29.00	3.0	28.57	81.00	101.0	144.69	4.97
384	200	500	0	1	27.40	1.6	25.67	91.00	101.2	78.00	4.36
385	200	500	0	1	27.50	0.9	26.80	86.00	101.4	64.43	4.17
386	200	500	0	1	28.10	1.0	29.73	74.00	101.4	105.13	4.66
387	200	500	0	1	29.50	1.7	32.57	61.00	101.4	101.74	4.62
388	200	500	0	1	31.00	1.4	30.70	71.67	101.1	70.08	4.25
389	200	500	1	0	26.30	0.7	25.40	87.00	101.1	52.00	3.95
390	200	500	1	0	27.10	1.1	27.93	75.67	101.2	67.82	4.22
391	200	500	1	0	28.30	2.5	29.87	69.00	101.2	75.74	4.33
392	200	500	1	0	29.70	2.7	31.00	65.00	101.2	88.17	4.48
393	200	500	1	0	33.10	2.5	33.43	58.33	101.1	76.87	4.34
394	200	500	1	0	35.40	2.6	34.30	55.33	101.0	67.82	4.22
395	200	500	1	0	35.10	2.5	33.33	61.00	100.9	81.39	4.40
396	200	500	1	0	35.10	2.4	33.53	61.67	100.9	81.39	4.40
397	200	500	1	0	31.30	2.6	30.57	70.00	101.0	75.74	4.33
398	200	500	1	1	27.40	1.0	25.50	93.00	101.4	78.00	4.36
399	200	500	1	1	27.50	0.5	26.53	90.67	101.4	64.43	4.17
400	200	500	1	1	31.20	1.0	34.83	53.00	101.4	44.09	3.79

401	200	500	1	1	33.00	1.2	35.43	53.00	101.2	47.48	3.86
402	200	500	1	1	33.30	1.6	35.13	53.33	101.1	49.74	3.91
403	200	500	1	1	33.40	1.4	34.00	60.33	101.0	48.61	3.88
404	200	500	1	1	31.00	0.8	30.70	67.67	101.1	70.08	4.25
405	200	750	0	0	27.60	2.4	27.27	88.00	100.9	139.04	4.93
406	200	750	0	0	27.40	2.3	27.70	83.67	101.0	134.52	4.90

Observation	D	H	SPT	SCR	Tpipe	Vwind	Temp	Hum	Pabs	Q	lnQ
407	200	750	0	0	28.60	1.9	29.43	75.67	101.1	130.00	4.87
408	200	750	0	0	30.30	2.8	32.07	65.00	101.1	117.56	4.77
409	200	750	0	0	30.20	4.2	31.37	68.67	101.1	224.95	5.42
410	200	750	0	0	32.20	2.2	33.43	64.00	101.0	140.17	4.94
411	200	750	0	0	31.90	3.6	32.47	67.67	100.9	192.17	5.26
412	200	750	0	0	33.50	2.3	33.30	64.00	100.8	148.08	5.00
413	200	750	0	0	32.10	3.3	32.17	68.00	100.8	189.91	5.25
414	200	750	0	0	30.10	2.8	29.90	78.00	100.9	145.82	4.98
415	200	750	0	1	27.50	0.1	26.57	88.00	101.1	65.56	4.18
416	200	750	0	1	27.80	0.8	27.30	85.00	101.3	58.78	4.07
417	200	750	0	1	29.30	2.3	31.13	64.00	101.3	88.17	4.48
418	200	750	0	1	30.60	1.8	33.33	60.00	101.3	87.04	4.47
419	200	750	0	1	30.60	1.8	32.70	62.33	101.3	96.08	4.57
420	200	750	1	0	27.40	1.9	26.97	87.33	101.0	61.04	4.11
421	200	750	1	0	27.50	1.0	27.33	84.67	101.2	46.35	3.84

422	200	750	1	0	29.20	2.0	31.03	69.67	101.2	64.43	4.17
423	200	750	1	0	30.20	2.5	31.77	66.00	101.2	79.13	4.37
424	200	750	1	0	30.90	2.7	32.43	64.33	101.2	87.04	4.47
425	200	750	1	0	32.30	1.9	34.13	59.33	101.1	65.56	4.18
426	200	750	1	0	33.30	2.0	34.10	60.33	101.0	66.69	4.20
427	200	750	1	0	32.90	3.0	33.33	62.00	100.9	89.30	4.49
428	200	750	1	0	33.60	2.3	33.33	63.00	100.9	80.26	4.39
429	200	750	1	0	30.10	2.0	29.67	77.67	101.0	76.87	4.34
430	200	750	1	1	27.20	0.4	25.50	91.00	101.1	49.74	3.91

Observation	**D**	**H**	**SPT**	**SCR**	**Tpipe**	**Vwind**	**Temp**	**Hum**	**Pabs**	**Q**	**lnQ**
431	200	750	1	1	27.50	1.4	26.50	86.67	101.2	74.61	4.31
432	200	750	1	1	28.00	2.0	27.73	80.67	101.3	84.78	4.44
433	200	750	1	1	29.20	1.8	29.97	71.33	101.3	75.74	4.33
434	200	750	1	1	30.50	3.0	31.83	63.67	101.3	82.52	4.41
435	200	750	1	1	31.70	2.1	33.10	61.00	101.1	67.82	4.22
436	200	750	1	1	32.70	2.4	34.23	56.67	101.0	67.82	4.22
437	200	750	1	1	32.60	2.4	33.47	61.00	101.0	76.87	4.34
438	200	750	1	1	32.40	2.6	32.47	63.33	100.9	74.61	4.31
439	200	1000	0	0	27.80	0.7	26.63	84.67	101.2	88.17	4.48
440	200	1000	0	0	27.80	0.6	27.10	83.67	101.3	87.04	4.47
441	200	1000	0	0	28.40	1.2	28.63	78.67	101.4	123.21	4.81
442	200	1000	0	0	29.40	2.7	30.57	67.00	101.4	152.60	5.03

443	200	1000	0	0	30.00	3.3	32.43	58.67	101.4	171.82	5.15
444	200	1000	0	0	31.10	2.6	33.23	61.00	101.2	139.04	4.93
445	200	1000	0	0	32.20	2.4	33.73	59.67	101.1	109.65	4.70
446	200	1000	0	0	33.70	2.3	34.93	55.67	101.0	83.65	4.43
447	200	1000	0	0	30.00	3.1	29.70	77.00	101.0	169.56	5.13
448	200	1000	0	0	29.50	2.5	28.87	83.67	101.0	148.08	5.00
449	200	1000	0	1	27.00	1.0	26.27	90.00	101.1	105.13	4.66
450	200	1000	0	1	27.50	1.2	28.37	82.00	101.2	120.95	4.80
451	200	1000	0	1	28.40	3.8	29.77	74.67	101.2	178.60	5.19
452	200	1000	0	1	29.70	3.2	30.83	71.33	101.3	176.34	5.17
453	200	1000	0	1	30.30	4.4	31.23	66.67	101.2	209.12	5.34
454	200	1000	0	1	31.40	3.3	32.83	64.67	101.1	189.91	5.25

Observation	D	H	SPT	SCR	Tpipe	Vwind	Temp	Hum	Pabs	Q	lnQ
455	200	1000	0	1	32.30	2.8	32.13	68.67	101.0	120.95	4.80
456	200	1000	0	1	33.20	2.3	32.93	67.33	100.9	107.39	4.68
457	200	1000	0	1	33.60	2.1	32.87	64.67	100.8	110.78	4.71
458	200	1000	0	1	28.80	3.7	28.47	84.00	100.9	143.56	4.97
459	200	1000	1	0	27.40	0.5	25.70	90.00	101.2	70.08	4.25
460	200	1000	1	0	27.50	1.0	26.70	85.00	101.3	81.39	4.40
461	200	1000	1	0	28.30	1.8	29.73	73.33	101.3	75.74	4.33
462	200	1000	1	0	29.30	2.1	30.90	68.67	101.3	65.56	4.18
463	200	1000	1	0	29.90	3.7	31.30	67.00	101.3	90.43	4.50

464	200	1000	1	0	31.40	1.8	33.47	61.33	101.1	58.78	4.07
465	200	1000	1	0	32.00	1.9	33.70	61.67	101.0	68.95	4.23
466	200	1000	1	0	31.90	2.6	32.73	63.00	101.0	85.91	4.45
467	200	1000	1	0	31.50	1.5	32.00	66.67	101.0	67.82	4.22
468	200	1000	1	0	30.20	0.1	29.33	77.33	101.1	33.91	3.52
469	200	1000	1	1	27.50	0.4	26.53	90.33	101.0	57.65	4.05
470	200	1000	1	1	27.80	0.6	28.40	80.67	101.1	59.91	4.09
471	200	1000	1	1	28.50	2.0	29.83	74.00	101.1	72.35	4.28
472	200	1000	1	1	30.30	1.3	32.50	63.67	101.1	58.78	4.07
473	200	1000	1	1	31.00	2.3	31.93	65.33	101.1	62.17	4.13
474	200	1000	1	1	33.20	1.7	34.37	57.33	101.0	64.43	4.17
475	200	1000	1	1	31.30	2.1	31.13	70.00	100.9	80.26	4.39
476	200	1000	1	1	31.70	3.2	31.33	69.33	100.8	87.04	4.47
477	200	1000	1	1	33.60	1.6	33.77	61.67	100.8	61.04	4.11
478	200	1000	1	1	31.70	0.8	31.17	71.00	100.9	47.48	3.86

Appendix 6-6: Model Validation Output

Observation	D	H	SPT	SCR	Vwind	Temp	Hum	Predicted Q	SE	CLIM1	CLIM2	PLIM1	PLIM2	Observed Q	Remark
1	100	250	0	0	0.6	22.93	32.67	12.43	1.04	11.53	13.41	8.71	17.75	14.41	PL
2	100	250	0	0	1.3	31.60	11.00	15.92	1.03	14.90	17.00	11.17	22.69	18.65	PL
3	100	250	0	1	0.7	24.00	75.67	19.01	1.03	18.06	20.01	13.37	27.02	12.43	PL
4	100	250	0	1	2.6	33.07	40.00	29.90	1.02	28.68	31.17	21.06	42.45	16.39	PL
5	100	250	1	0	2.2	22.40	65.00	19.41	1.03	18.35	20.53	13.64	27.61	24.59	PL
6	100	250	1	0	2.6	31.90	15.67	17.50	1.03	16.53	18.51	12.30	24.89	22.04	PL

7	100	250	1	1	0.9	22.57	65.33	12.73	1.03	12.00	13.50	8.95	18.12	13.85	PL
8	100	250	1	1	0.9	32.97	39.67	13.18	1.02	12.58	13.82	9.28	18.73	13.85	PL
9	100	500	0	0	1.2	25.23	92.00	28.87	1.02	27.61	30.19	20.33	41.01	28.26	CL
10	100	500	0	0	2.5	33.13	60.00	37.52	1.02	36.28	38.80	26.45	53.23	44.93	PL
11	100	500	0	1	2.0	32.77	62.33	31.55	1.02	30.41	32.73	22.24	44.77	46.06	>PL
12	100	500	0	1	2.2	34.23	54.33	31.41	1.02	30.19	32.67	22.13	44.58	39.56	PL
13	100	500	1	0	3.1	25.70	82.00	32.80	1.02	31.32	34.34	23.09	46.59	27.98	PL
14	100	500	1	0	3.3	29.70	66.33	33.52	1.02	32.29	34.79	23.62	47.56	29.96	PL
15	100	500	1	1	0.9	25.20	92.00	17.93	1.03	17.08	18.82	12.62	25.48	16.67	PL
16	100	500	1	1	1.7	34.27	55.00	20.22	1.02	19.44	21.03	14.25	28.70	14.98	PL
17	100	750	0	0	0.9	25.40	92.00	26.86	1.02	25.65	28.13	18.91	38.16	15.54	PL
18	100	750	0	0	2.4	33.37	60.00	37.10	1.02	35.85	38.40	26.15	52.64	35.04	PL
19	100	750	0	1	1.4	26.00	90.00	28.36	1.02	27.13	29.65	19.97	40.28	23.74	PL
20	100	750	0	1	3.4	33.13	63.00	47.47	1.02	45.60	49.40	33.44	67.38	43.80	PL
21	100	750	1	0	1.1	25.10	93.00	20.65	1.02	19.73	21.62	14.54	29.34	16.67	PL

Observation	**D**	**H**	**SPT**	**SCR**	**Vwind**	**Temp**	**Hum**	**Predicted Q**	**SE**	**CLIM1**	**CLIM2**	**PLIM1**	**PLIM2**	**Observed Q**	**Remark**
22	100	750	1	0	3.9	32.07	62.00	40.45	1.02	38.81	42.16	28.49	57.43	33.91	PL
23	100	750	1	1	1.6	25.87	92.00	22.31	1.02	21.30	23.36	15.70	31.69	16.11	PL
24	100	750	1	1	3.2	32.60	63.33	31.69	1.02	30.45	32.98	22.33	44.99	27.69	PL
25	100	1000	0	0	1.2	26.03	90.67	29.46	1.02	28.22	30.75	20.74	41.83	25.15	PL
26	100	1000	0	0	2.5	33.13	63.00	39.22	1.02	37.91	40.58	27.65	55.64	37.59	PL
27	100	1000	0	1	2.2	25.90	92.00	36.28	1.02	34.69	37.94	25.54	51.53	31.37	PL

28	100	1000	0	1	2.2	33.13	59.00	31.91	1.02	30.76	33.12	22.49	45.29	35.89	PL
29	100	1000	1	0	1.4	25.40	92.00	22.04	1.02	21.08	23.04	15.52	31.30	18.65	PL
30	100	1000	1	0	1.0	32.87	61.00	17.95	1.02	17.24	18.68	12.64	25.48	18.37	CL
31	100	1000	1	1	1.7	33.63	59.67	20.65	1.02	19.88	21.45	14.55	29.31	18.93	PL
32	100	1000	1	1	1.9	32.13	68.00	22.83	1.02	22.02	23.66	16.09	32.39	22.33	CL
33	150	250	0	0	1.8	20.70	70.67	43.50	1.03	41.10	46.04	30.57	61.89	31.16	PL
34	150	250	0	0	1.8	32.20	11.00	32.99	1.03	31.05	35.06	23.17	46.98	34.97	CL
35	150	250	0	1	1.3	21.60	79.00	38.86	1.03	36.84	40.99	27.33	55.26	31.16	PL
36	150	250	0	1	2.4	31.73	19.00	38.81	1.03	36.74	40.99	27.28	55.20	33.70	PL
37	150	250	1	0	2.0	22.67	63.00	32.93	1.03	31.25	34.70	23.16	46.83	38.15	PL
38	150	250	1	0	3.7	32.43	10.00	41.41	1.03	38.90	44.09	29.08	58.98	47.05	PL
39	150	250	1	1	0.7	22.13	48.67	17.89	1.03	16.75	19.11	12.56	25.50	31.16	>PL
40	150	250	1	1	1.1	32.23	35.33	23.57	1.02	22.58	24.61	16.60	33.47	23.53	CL
41	150	500	0	0	1.9	31.63	66.33	58.81	1.02	57.07	60.60	41.47	83.40	89.02	>PL
42	150	500	0	0	1.9	33.60	60.33	58.52	1.02	56.53	60.57	41.25	83.02	66.13	PL
43	150	500	0	1	1.3	25.50	91.00	48.94	1.02	46.95	51.01	34.47	69.48	48.96	CL
44	150	500	0	1	2.0	34.20	56.00	54.41	1.02	52.49	56.39	38.34	77.20	71.22	PL

Observation	**D**	**H**	**SPT**	**SCR**	**Vwind**	**Temp**	**Hum**	**Predicted Q**	**SE**	**CLIM1**	**CLIM2**	**PLIM1**	**PLIM2**	**Observed Q**	**Remark**
45	150	500	1	0	0.9	25.53	91.00	34.20	1.02	32.80	35.66	24.09	48.56	31.79	PL
46	150	500	1	0	1.9	32.77	63.00	42.51	1.02	41.26	43.79	29.98	60.28	42.60	CL
47	150	500	1	1	1.6	26.60	88.00	39.03	1.02	37.55	40.56	27.50	55.39	37.52	PL
48	150	500	1	1	3.0	33.50	62.33	54.43	1.02	52.54	56.39	38.37	77.23	55.32	CL

Observation	D	H	SPT	SCR	Vwind	Temp	Hum	Predicted Q	SE	CLIM1	CLIM2	PLIM1	PLIM2	Observed Q	Remark
49	150	750	0	0	1.0	25.70	91.00	49.26	1.02	47.26	51.34	34.70	69.94	54.05	PL
50	150	750	0	0	4.7	32.07	62.00	127.34	1.02	121.48	133.48	89.62	180.92	127.81	CL
51	150	750	0	1	1.5	25.43	91.00	52.21	1.02	50.11	54.39	36.77	74.12	63.59	PL
52	150	750	0	1	2.8	33.30	60.33	70.41	1.02	68.09	72.81	49.63	99.88	92.20	PL
53	150	750	0	1	3.2	30.90	73.33	82.54	1.02	79.69	85.50	58.18	117.11	108.73	PL
54	150	750	1	0	1.6	26.40	86.67	40.96	1.02	39.50	42.48	28.87	58.12	38.15	PL
55	150	750	1	0	3.5	32.27	60.00	63.94	1.02	61.73	66.23	45.07	90.72	61.04	PL
56	150	750	1	1	2.3	25.90	92.00	48.25	1.02	46.19	50.41	33.98	68.52	45.78	PL
57	150	750	1	1	3.7	32.10	65.00	66.86	1.02	64.10	69.75	47.09	94.94	64.22	CL
58	150	1000	0	0	0.2	25.70	93.00	39.98	1.03	38.06	41.99	28.13	56.82	35.61	PL
59	150	1000	0	0	2.7	32.00	62.33	71.95	1.01	69.92	74.04	50.74	102.02	101.74	PL
60	150	1000	0	1	1.6	26.30	88.00	53.45	1.02	51.45	55.53	37.66	75.86	62.31	PL
61	150	1000	1	0	1.1	26.23	89.00	36.54	1.02	35.14	37.99	25.74	51.86	36.24	CL
62	150	1000	1	0	1.8	33.43	59.33	40.54	1.02	39.29	41.84	28.59	57.50	41.97	PL
63	150	1000	1	1	1.8	33.93	56.33	37.29	1.02	36.08	38.54	26.29	52.90	35.61	PL
64	150	1000	1	1	1.3	31.93	64.00	32.37	1.02	31.35	33.42	22.82	45.91	39.42	PL
65	200	250	0	0	0.8	21.73	51.33	49.33	1.03	46.15	52.73	34.61	70.31	58.78	PL
66	200	250	0	0	1.7	32.77	35.00	73.94	1.02	70.49	77.56	52.04	105.07	31.65	PL
67	200	250	0	1	2.0	21.47	83.00	89.68	1.03	84.66	94.99	63.02	127.61	59.91	PL
68	200	250	0	1	2.5	32.43	11.33	68.03	1.03	63.82	72.51	47.75	96.91	66.69	CL
69	200	250	1	0	1.5	20.80	66.67	49.56	1.03	46.55	52.77	34.80	70.59	56.52	PL

70	200	250	1	0	1.3	30.97	47.67	51.00	1.02	48.98	53.12	35.93	72.41	36.17	PL
71	200	250	1	1	2.0	23.03	87.33	70.88	1.03	67.17	74.79	49.84	100.80	71.22	CL
72	200	250	1	1	1.4	33.20	33.67	45.41	1.02	43.35	47.58	31.97	64.52	61.04	PL
73	200	500	0	0	0.8	26.00	89.00	81.27	1.02	77.51	85.21	57.20	115.47	92.69	PL
74	200	500	0	0	1.7	33.93	56.33	94.71	1.02	90.65	98.94	66.69	134.50	70.08	PL
75	200	500	0	1	0.7	25.50	91.67	74.12	1.03	70.61	77.81	52.16	105.34	61.04	PL
76	200	500	0	1	1.6	35.30	50.67	84.40	1.02	80.55	88.43	59.40	119.90	57.65	PL
77	200	500	1	0	0.7	25.40	86.00	54.08	1.02	51.61	56.66	38.06	76.83	57.65	PL
78	200	500	1	0	3.8	32.87	58.67	125.98	1.02	120.29	131.94	88.68	178.97	101.74	PL
79	200	500	1	1	1.6	25.30	93.00	70.58	1.02	67.33	73.98	49.68	100.28	61.04	PL
80	200	500	1	1	1.5	35.03	52.67	60.09	1.02	57.59	62.70	42.32	85.33	57.65	CL
81	200	750	0	0	0.6	26.40	90.00	77.67	1.03	73.93	81.60	54.65	110.39	92.69	PL
82	200	750	0	0	2.5	32.43	65.67	124.38	1.02	119.69	129.26	87.64	176.54	143.56	PL
83	200	750	0	1	0.5	26.50	88.00	69.30	1.02	66.05	72.71	48.77	98.47	50.87	PL
84	200	750	0	1	1.4	33.73	57.33	80.79	1.02	77.35	84.39	56.89	114.74	56.52	PL
85	200	750	1	0	1.6	26.80	89.00	75.06	1.02	71.91	78.34	52.86	106.58	52.00	PL
86	200	750	1	0	1.5	30.63	71.00	67.75	1.02	65.28	70.31	47.74	96.14	66.69	CL
87	200	750	1	1	0.7	26.17	89.00	53.23	1.02	50.85	55.73	37.48	75.62	53.13	CL
88	200	750	1	1	1.7	32.87	59.67	64.32	1.02	61.99	66.73	45.32	91.27	68.95	PL
89	200	1000	0	0	0.3	26.50	87.00	70.15	1.03	66.68	73.80	49.35	99.72	101.74	>PL
90	200	1000	0	0	3.3	29.30	81.00	169.29	1.02	162.12	176.77	119.21	240.40	160.52	PL
Observation	**D**	**H**	**SPT**	**SCR**	**Vwind**	**Temp**	**Hum**	**Predicted Q**	**SE**	**CLIM1**	**CLIM2**	**PLIM1**	**PLIM2**	**Observed Q**	**Remark**

91	200	1000	0	1	4.4	31.70	66.67	202.81	1.03	192.26	213.95	142.62	288.42	205.73	CL
92	200	1000	0	1	3.2	29.30	80.00	152.14	1.02	145.61	158.96	107.13	216.06	151.47	CL
93	200	1000	1	0	0.7	25.50	90.00	56.46	1.02	53.83	59.21	39.73	80.22	67.82	PL
94	200	1000	1	0	2.1	33.07	62.33	80.55	1.02	77.57	83.64	56.76	114.31	67.82	PL
95	200	1000	1	1	2.4	33.10	62.00	80.28	1.02	77.31	83.36	56.57	113.93	78.00	CL
96	200	1000	1	1	0.9	32.23	66.00	53.56	1.02	51.44	55.76	37.73	76.03	48.61	PL