FACULTY OF TECHNOLOGY
DEPARTMENT OF CIVIL ENGINEERING

FINAL YEAR PROJECT REPORT

TITLE: DESIGN OF A DRY TOILET VENTILATION SYSTEM TO ACCELERATE DRYING

Submitted in partial Fulfillment of the requirements for the award of the degree of Bachelor of Science in Civil Engineering of Makerere University

CANDIDATE:

....

NTABADDE MARTHA KIWUWA

REG NUMBER**:** 00/U/141

MAIN-SUPERVISOR: *CO-SUPERVISOR*

....

MR.CHARLES NIWAGABA *ASSOC. PROG. G. NGIRANE- KATASHAYA*

DEDICATION

To my dear mum and Dad for all the sacrifices made to get me this far and for the vision of life instilled in me

ACKNOWLEDGEMENTS

I am grateful, first of all to the Almighty God for all for all the graces He has showered me to enable me safely reach this far in my academic carrier.

Special thanks go to my lead supervisor; Mr. Niwagaba Charles for all the patience, sacrifice and assistance rendered to me during the course of this project, without which I couldn’t have gotten this far.

To My Co-supervisor Assoc Prof. G. Ngirane-Katashaya; for your patience and the helping hand whenever I needed it, is greatly appreciated

Thanks go to the Management and staff of the Directorate of Water Development, for their co-operation and financial assistance without which the research couldn’t have been equally enjoyable.

Thanks to Brothers, sisters and my parents for all the sacrifices you’ve made to bring us this far, thank God it has all come to an end. Thanks to my sister Peggy and Eng. Kalegga. I am grateful for each and every little thing – you took up the role of my parents

To my buddies- my friends and my classmates; Naka, Sheila, Jose, Dimple, Martin, Henry, Harry, Justin, Mike, Richie, e.t.c (Kikoko crew), Josephine Mugala, Clare, Jane; without you guys life would not have been the same at campus.

ABSTRACT

Ecological Sanitation systems have been recently developed to help ameliorate the problems of pollution, excess usage of water and wastage of nutrients, which were characterising the historical ‘drop and store’ and the ‘flush and discharge’ systems. Despite the added advantages of ecological sanitation systems, the systems have inherent problems in their design and operation, among which is the performance of the ventilation system as far as accelerating drying of faecal matter is concerned

The objective of the study was to develop a modified system that would accelerate drying. Accelerating drying would be useful in shortening the retention period required before faecal matter can be rendered safe for handling, resulting in smaller units and reduced overall costs.

Field visits were made to the South Western Towns Water and Sanitation Project area, specifically Kabale and Kisoro. Other Ecosan and similar kind of toilets were visited in Mbarara and around Kampala. A total of 25 sites were visited and 20 people interviewed. Data was collected by use of checklists and questionnaires and from the Meteorological Department. The data was analysed and basing on the results, an appropriate design to accelerate drying was produced, costed and design drawings produced.

From the analysis of the data, the Ecosan systems were found to be employing natural ventilation, but often with a number of loopholes hence they were not effective. Inadequacies included small vent pipe diameters, improper and weak materials, inadequate height above the roof, e.t.c.

After all considerations, it was found that a minimum vent pipe diameter of 150mm is required for efficient ventilation. In addition much better results are obtained when a rotary vent turbine is incorporated to further increase the rate of extraction of water evaporated from the vaults. Another method of increasing the rate of drying in the vaults was the use of one-way glass for the vault covers and Insulating the walls to allow in as much direct sunlight as possible and at the same time reduce on the amount of heat lost through the vaults walls. These conditions are very important, if accelerated drying is to be realised.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE: INTRODUCTION

1.1 Background

The sanitation technologies that are promoted in the world today fall under two main categories namely: 'flush-and-discharge' or 'drop-and-store.' The drop and store facilities are based on containment and indefinite storage of human excreta. Over the past 100 years, flush -and - discharge has been regarded as the ideal technology, particularly for urban areas

Most urban centres in the third world cannot afford the necessary resources in terms of water, money and institutional capacity to provide a flush and discharge system. Many of these will face extreme water shortages by the year 2010, threatening the life and health of inhabitants (UNDP, 1996)

In the prevalent conditions of food insecurity, scarcity of water, decrease in soil fertility and escalating prices of fertilisers on the world market, there is a need to utilise the nutrients, especially in human urine for agricultural purposes thereby increasing productivity and reducing the need for artificial fertilisers. (Esrey *et al,* 1998). This challenge presents a need to raise the status of sanitation and the need for new techniques, methods and approaches to sanitation management.

The Ecological Sanitation (Ecosan) systems are a relatively new concept, which enable the complete recovery of all nutrients from faeces, urine and grey water to the benefit of agriculture (sanitise and recycle). The systems also minimise water pollution, while at the same time ensuring that water is used economically and is reused to the greatest possible extent, particularly for irrigation purposes (Esrey *et al*, 2001). Ecological sanitation systems have been looked at as an ideal sanitation system and have been adopted in both developing and developed countries.

Pathogen destruction in Ecosan systems is achieved by two main processes: decomposition and dehydration (Esrey *et al,* 1998). Decomposition or composting involves bacteria, worms and other organisms under controlled conditions, breaking down organic substance to humus, which is free from pathogens, if the right conditions are achieved. Under dehydration, the contents of the vaults are dried with the help of heat, ventilation and addition of drying material (Esrey *et al,* 1998). In a dehydration system, the moisture content should be brought down to below 25%, at which moisture content there is rapid pathogen destruction, no smell and no fly breeding. According to Esrey *et al,* 1998, dehydration methods are said to kill pathogens more effectively than other methods.

Despite the enormous benefits of ecological sanitation (Ecosan) systems, the system still has a number of constraints, which restrict its optimum performance. Among these is the low rate at which the faeces in the dehydrating vaults dry up. There is thus need to design a system with an improved ventilation system to accelerate the rate of evaporation in the system and hence the rate of drying. The increase in the rate of drying is expected to be brought about not only by the ventilation system, but also proper design of other components like the processing vaults.

1.2 Problem Statement

In an attempt to promote the concept of ecological sanitation in Uganda, pilot units were constructed in 1997 in Kisoro and Kabale districts by the Directorate of Water Development (DWD)'s the South western Towns Water and Sanitation (SWTWS) Project. SWTWS has since built over 500 Ecosan units. In addition, Kampala City Council is in its advanced stages of embarking on the construction of a number of units in the peri-urban areas of the city.

These units have not been operating optimally because they don't dry faeces as fast as required and to the moisture levels expected. The low rate at which faeces in the processing chambers dry-up and the resulting odour in the system is a serious negative to heir popularity. One of the reasons for this is inappropriate design of the ventilation systems.

Thus there is need to design an appropriate ventilation system which will accelerate drying in the processing chambers and at the same time increase air movement that will help to reduce odours in the system.

1.3 Justification

Accelerating the rate of drying in a dry toilet can be of great significance. Increasing the rate of drying potentially increases the rate at which pathogens are destroyed. Thus the required retention period will be reduced since with an increased rate of drying, the faecal matter will be sanitised (free from pathogens-safe for handling) faster than normal. With a decreased retention period, the required sizes of vaults will also be reduced and hence reduced cost of construction.

In rural areas where people have been sensitised, when demand for sanitised faecal matter increases beyond the rate at which it is produced (sanitised), there will be need to shorten the retention period to satisfy the demand without the users handling unsanitised faecal matter. This necessitates an improved rate of drying and hence the rate pathogen destruction.

In Urban and peri-urban areas, for example, in Kampala City Council the pilot Ecosan units are to be constructed for public and communal use. With the relatively high number of anticipated users in such areas and the limited space available for use, this may imply a faster rate at which the processing chambers get filled up. This too necessitates accelerated drying to shorten the required retention period, without rendering the faecal matter unsafe for handling and subsequent use.

Therefore, the design of an improved ventilation system for accelerated drying will result in a more efficient and convenient use of Ecosan toilets.

1.4 Objectives

1.4.1 Main Objective

The main objective is to design an innovative dry toilet ventilation system to accelerate drying.

1.4.2 Specific Objectives

- To study the Ecosan ventilation systems available, their performance and operation.
- To identify loopholes in the design and operation of the current systems
- To produce adequate modifications to accelerate drying, depending on the findings and describe how the modified system is expected to work
- To come up with a model of the modified system
- To produce design drawings of the modified system with the aid of a CAD software
- To estimate the cost of construction of the modified Ecosan toilet

1.5 Scope of Study

The study was focused on ventilation system as a means of accelerating drying. Other conditions necessary to accelerate drying were also looked at.

The performance of the ventilation systems of Implemented or Installed systems in Kabale, Kisoro and around Kampala was assessed.

1.6 Expected Output

If the rate of drying is increased, it is expected that this will result in reduced retention periods and hence smaller sizes of vaults being required.

CHAPTER TWO: LITERATURE REVIEW

2.1 Some Definitions

Domestic Waste; water borne or other waste generated from household including sewage and solid waste (Agrawal, 1999).

Domestic Sewage; Is composed of human body waste (faeces) and sullage (Agrawal, 1999).

Ecology; The science study of the relationship between living organisms and their environment, that is, it is the study of the interactions that determine the distribution, abundance and characteristics of organisms (Chapman *et al*, 1992)

Ecosystem; Ecological system formed by the interaction of coacting organisms and their environment. (Agrawal, 1999)

Energy; The physical quantity which can manifest itself as heat, as mechanical work, as motion and in the binding of matter by nuclear or chemical forces (Sharma, 1995).

Environment; Collective term for the conditions in which an organism lives, for example, temperature, light, water, e.t.c (Kumar, 1992)

Sanitation; A general program of environmental health to provide a safe source and distribution of portable water and proper collection of wastewater and solid waste treatment and disposal (Kumar, 1992).

Ecological Sanitation; Is a safe method of recovering nutrients from human excreta, then recycling them back into the environment and productive systems (Esrey *et al,* 1998)

Turbine; A mechanical device consisting of fan-like bodies mounted on a shaft, when water, steam or air rushes past the blades, the shaft turns and thus mechanical energy is produced (Agrawal, 1999).

Vent Pipe; A pipe which provides a safe outlet into the atmosphere for the foul gases in a drain, latrine or sewer (Birdie *et al*, 1998).

Waste; Any solid, liquid or gaseous emission as a result of human activity, for which no use can be found by the organisms or system that produces it and for which a method of disposal must be devised (Agrawal, 1999).

Waste treatment; Physical, chemical and biological processes employed to remove dissolved and suspended solid from wastewater (Kumar, 1992)

Wind; moving air (Sharma, 1995)

Wind Power; The Kinetic Energy of the wind (Sharma, 1995)

2.2 On-Site Sanitation Systems

2.2.1 Introduction

The single most important criterion of all sanitation systems is that they form a barrier against the spread of diseases caused by pathogens in human excreta. Sanitation has had transformations from indiscriminate open defecation to simple basic on-site facilities like pit latrines. The traditional pit latrine however had problems of smell/odour and fly nuisance associated with it. In an effort to overcome these problems, improved types were developed.

In 1973, the ventilated Improved Pit (VIP) latrine was developed at the Institute of Blair Research (IBR) in Zimbabwe. This innovation brought about major improvements in on-site Sanitation as it greatly controlled odours and flies with the help of a vent pipe with a fly screen. Other improved Pit latrine types incorporating a vent pipe work closely on the same principle as a VIP latrine.

On-site sanitation systems are those in which the safe disposal of excreta takes place on or near the site of waste production. There are two basic human waste disposal systems under on-site sanitation; Water-borne (wet) and Non-water borne systems (Dry-systems)

2.2.2 Water-borne Sanitation Systems

In such a system, water is used for the collection of excreta. It comprises of water closets, Cistern flush, septic tanks, aqua privies, vaults, e.t.c. In water-borne sanitation systems, the vent pipes provided in some of the systems are mainly to control problems of odour by removing the gases produced from the anaerobic digestion e.g. Hydrogen Sulphide, methane, etc, in most of the systems.

2.2.3 Non-Water Borne (Dry) Sanitation Systems

Human excreta in such systems is collected in pit latrines, trenches bucket latrines and other conservancy systems.

2.2.2.1 Pit Latrines

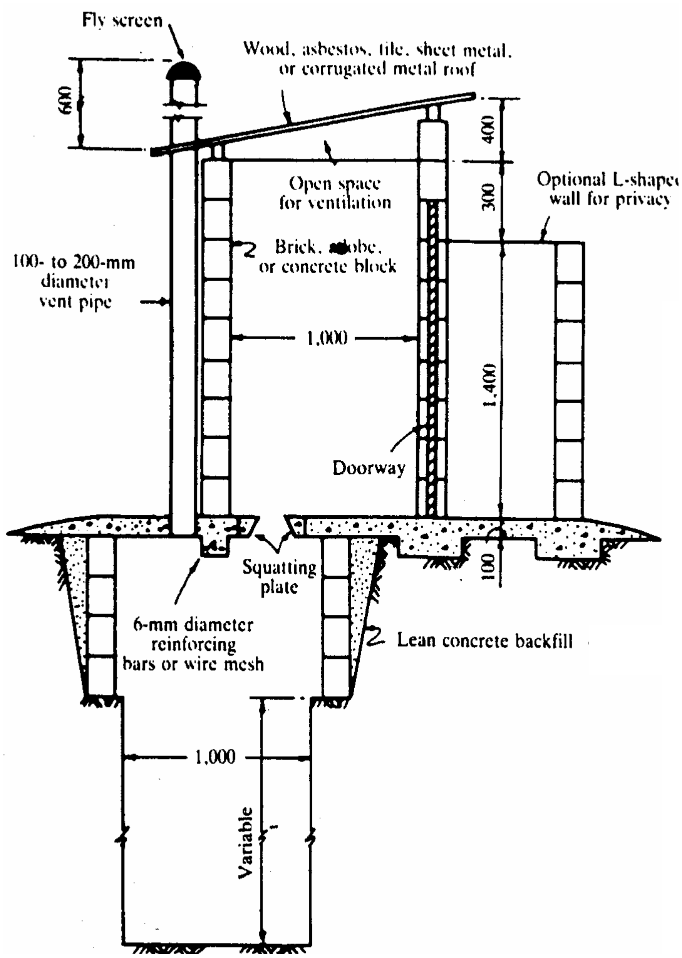
These are the simplest on-site disposal systems in rural areas. A pit latrine comprises of; a base, a floor, a mould of excavated soil and a superstructure A pit latrine collects excreta in a pit dug in the ground beneath the toilet structure. However, the traditional design of pit latrines without a vent pipe has a problem of odour/smell (due to lack of proper aeration and air circulation) and flies, associated with it.

Modified Pit Latrines

a. The Ventilated Improved Pit (VIP) Latrine

This is a modified pit latrine, which incorporates a vent pipe with a fly screen and the superstructure is kept reasonably dark to control both flies and odour nuisance. When the solar radiation heats the black vent pipe, the air in the pipe is warmed up and rises upwards out of the pipe. A downward draught of cooler air flows through the squat hole to replace the warm air, thus keeping the latrine ventilated (Feachem et al, 1988). In addition, the air passing out of the pipe creates a negative pressure, therefore establishing a suction phenomenon. The light through the vent pipe attracts flies, so they fly towards it but they are prevented from leaving by the screen. To prevent the passage of flies and mosquitoes, the mesh aperture should not be larger than 1.2 by 1.5mm.Smaller apertures may reduce ventilation rate due to friction losses.

The main aim of the vent pipe on a VIP latrine Is therefore not to accelerate drying, but rather to improve aeration and circulation to control the problem of odours and control flies with the aid of a fly screen.



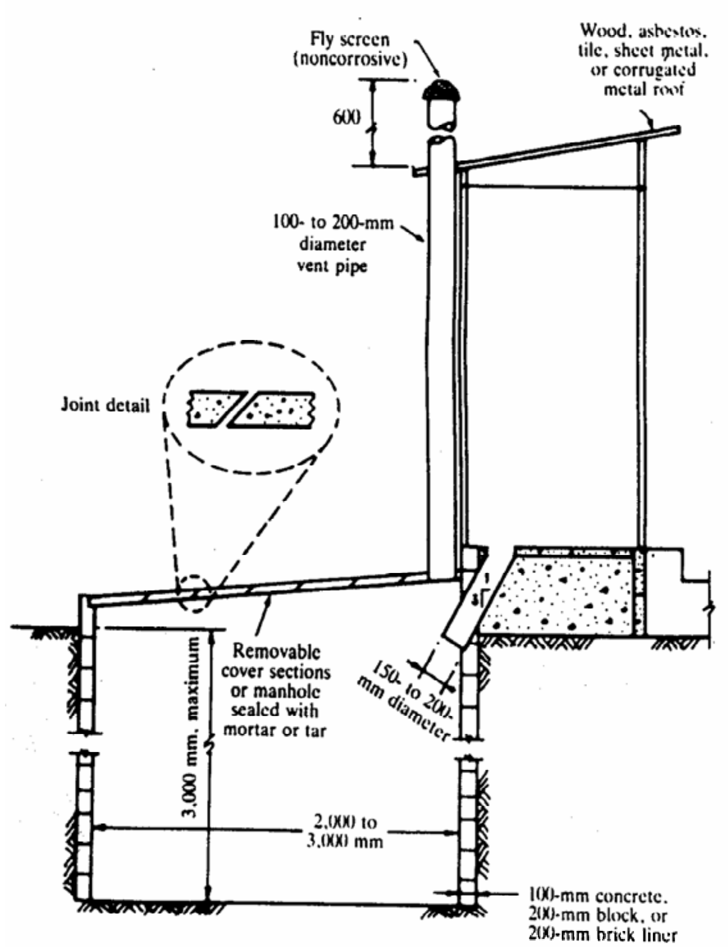


Figure 2.1a. A VIP Latrine

Figure 2.1b.An ROEC Toilet

(Adapted from Feachem *et al,* 1988)

b. The Reed Odourless Earth Closet (ROEC)

This is an offset pit latrine provided with a vent pipe to control odour and fly nuisance (Figure 2.5b). The latrine is provided with a pedestal seat with a curved chute substituting the squatting plate in pit latrine (Feachem *et al,* 1988).

It is claimed that the chute in conjunction with the ventilation stack encourages vigorous air circulation down the latrine, thereby removing odour and discouraging flies. The design and operation principles of an ROEC toilet are the same as for a VIP latrine, except the ROEC is a composting pit latrine.

c. The Composting Toilet

Instead of indefinite storage, the compost from human excreta and other materials added is used as a fertiliser. The most common types of composting toilets may be divided into two categories: Single vault or multrum type and double vault or batch composter type. The vaults are constructed well above the ground water table and are provided with a removable cover for removal of the compost.

Ventilation in a composting toilet not only controls odours, moisture and eliminate flies, but also provides oxygen for the aerobic decomposition processes. Oxygen is required because composting is an aerobic process and many of the microbes responsible for composting require oxygen.

Most cases, the processing chambers are provided with perforations (e.g. using perforated pipes) to bring in air into the pile and the foul gases and moisture are expelled through the vent pipe.

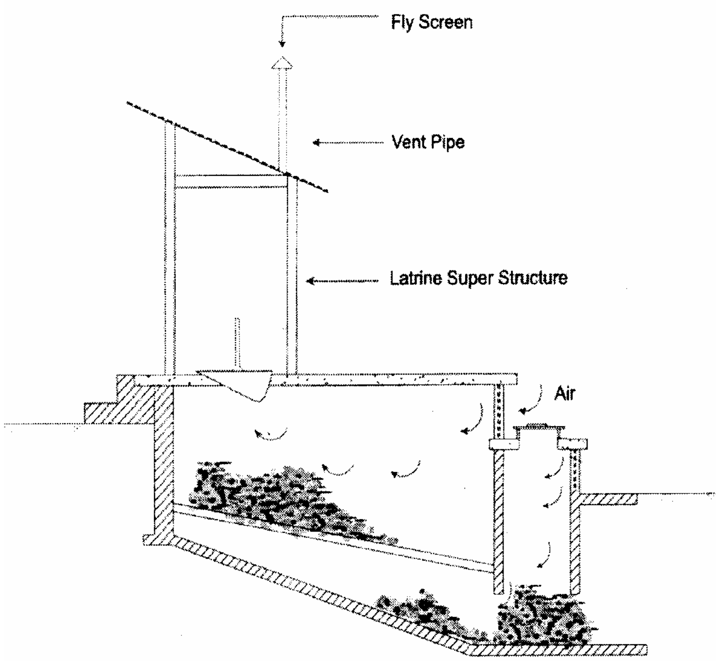


Fig. 2.2: A multrum type compost latrine

2.2.4 Ecological Sanitation Systems

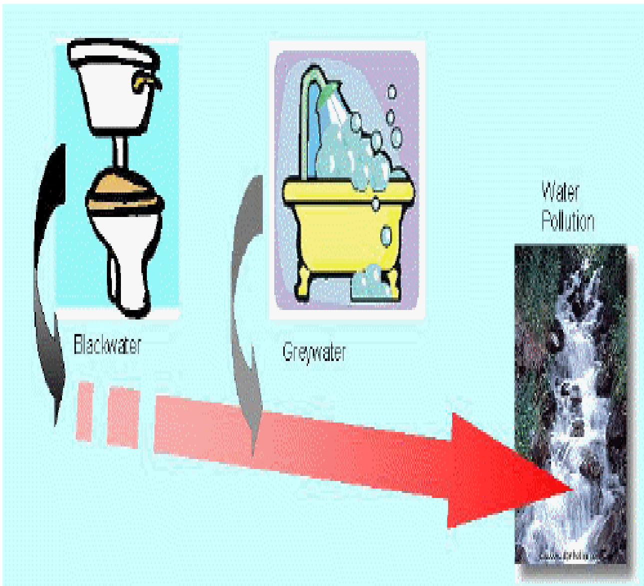
2.2.4.1 Introduction

Ecological Sanitation is a cycle or closed loop system which treats human excreta as a resource (Esrey *et al,* 1998). In this system, excreta are processed on site until they are free of pathogenic organisms. Thereafter, the sanitized excreta are recycled by using them for agricultural purposes. The system aims at recycling nutrients back into the environment and into productive systems (UNDP, 2003).

The sanitation technologies that are being promoted in the world today fall under two categories; 'Flush and discharge' and 'drop and store'. The drop and store is based on containment and indefinite storage of human excreta (Esrey *et al,* 1998) whereas the 'flush and discharge' systems were designed and built on the premises that human excreta are a waste suitable only for disposal and that the environment is capable of assimilating this waste (UNDP, 2003).

Over the past 100 years, flush and discharge has been regarded as the ideal technology, particularly for urban areas. (Esrey *et al,* 1998). However Conventional sewage systems based on flush-toilets, have failed to solve the sanitation needs for developing countries. Over 95% of sewage in developing countries is today discharged untreated, polluting rivers, lakes and coastal areas (UNDP, 2003). With increasing food insecurity, scarcity of water, decrease in soil fertility and escalating prices for fertilizers on the world market, the challenge presents a need to raise the status of sanitation and the need for new approaches, techniques and methods (Esrey *et al,* 1998).

Ecosan systems, which are a relatively new approach to sanitation, have been looked at as ideal systems and have been adopted as an alternative sanitation practice. Ecosan systems enable the complete recovery of nutrients from faeces, urine and grey water to the benefit of agriculture. The systems also minimise water pollution, while at the same time ensuring that water is used economically and is reused to the greatest possible extent.



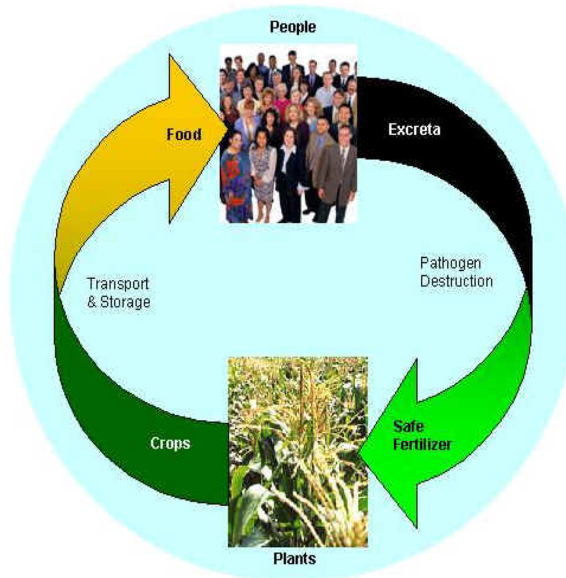


Figure 2.3a. Linear flow systems Figure 2.3b Circular flow systems.

(Adapted from Esrey *et al*, 2003)

2.2.4.2 Circular Flow systems

Whereas linear flow systems ('drop and store', 'flush and discharge') lead to waste of nutrients and organic matter, circular flow systems (Ecological sanitation) aim at safe recovery of nutrients from human excreta, then recycling them back into the environment and productive systems. However before the material is recycled, it should be free from pathogens. One of the ways this can be achieved is by increasing temperature and lowering the moisture (drying).

If separated, urine can easily serve as a fertiliser after it has been diluted with water. After faeces have been desiccated (dried-out), they are free from pathogens, diseases and odour (Esrey *et al,* 2001).

They can then serve as a soil conditioner for agriculture, returning a significant part of the nutrients to the soil.

One of the ways by which desiccation is achieved in dry toilets is through ventilation. However, ventilation on its own cannot do much to effect drying. The main contribution of ventilation towards drying is by lowering the relative humidity in the surrounding of the faecal matter, by withdrawing the moisture evaporated. Increasing the relative humidity increases the rate of evaporation, hence drying.

2.2.4.3 Pathogens and how they are destroyed

2.2.4.3.1 Introduction

The first and most important criteria/ principle of ecological sanitation and all sanitation practices is that the system forms a barrier against the spread of diseases caused by harmful living organisms (pathogens) in human excreta.

In fresh faeces, there are four main groups of organisms of concern to humans: bacteria, viruses, protozoa and helminths. These organisms once excreted they may be immediately infectious; bacteria and viruses, require some period of time outside of the body to become infectious; protozoa excreted as cysts and eggs of helminths or may require an intermediate host before becoming infectious; bilhazia. (Esrey *et al,* 1998).

2.2.4.3.2 How Pathogens die

A large number of pathogens or parasite's eggs after they are excreted in the faeces into the environment, they eventually die or become incapable of causing disease. The time it takes for all organisms of the same type to die, referred to as the die-off rate varies with each pathogen and its influenced by a number of conditions (Esrey *et al,* 1998). The major conditions considered to be important are shown In Table 2.1. Among these conditions, those directly related to drying are temperature and moisture.

Table 2.1 Environmental Conditions speeding up the death of pathogens

Environmental Factor	**How**
Temperature	Increase in temperature
Moisture	Decrease in moisture
Nutrients (organic matter)	Decrease in nutrients
Micro-organisms (including other pathogens)	Decrease in organisms
Sunlight	Increase in sunlight
pH	Increase in pH

Source: Esrey *et al*, 1998

It is generally assumed that if pathogens most resistant to destruction are destroyed effectively, then all other pathogens will also be destroyed. Two pathogens that are very resistant are *Ascaris lumbricoides* (Roundworm) and *Cryptosporidium parvum* (parasite that causes diarrhea). Dehydration destroys *C. parvum* and studies conducted on Ascaris eggs have shown that the most effective methods for destroying *Ascaris* eggs are drying and heating (Esrey *et al,* 1998)

Thus, in conclusion the combination of low moisture, low mount of organic matter/nutrients and high pH make for the most rapid destruction. According to Esrey *et al,* 1998, the most effective method of pathogen destruction seems to be dehydration (Esrey *et al,* 1998)

2.2.4.4 Case Study: Longitudinal study of Double vault urine diverting and Solar toilets in El Salvador

In a one year study of double vault toilets (with vaults directly below the superstructure) and solar toilets (with vaults extending slightly beyond the superstructure with slanting metal covers to absorb sunlight) in El Salvador in Central America, repeated measures of physical, chemical and microbiological properties of biosolids were done on 156 Ecosans with different designs, use and maintenance patterns. This was intended to measure the effectiveness of the two designs. The outcomes of the study are given below.

For solar toilets where the peak temperature could reach 44°C, temperature was found to be the strongest predictor of Ascaris die-off. Temperature is closely related to drying since, the higher it is, the higher the evaporation rate hence drying.

In Solar toilets (with black metal covers), high peak temperature, pH and storage time were found to be the most critical factors affecting microbial inactivation. In both Double vault urine diverting and solar toilets, pH was the most important single factor determining the inactivation of the bacterial indicators. The most rapid inactivation of faecal coliforms occurred when pH was greater than 11 and peak temperature was greater than 36°C. To achieve these conditions, there was need to orient the metal covers for the vaults painted black, toward the sun to receive maximum sunlight and additives added to raise pH levels in the toilet.

The most notable difference between the two designs was the shorter average storage time of biosolids in solar toilet (26 days vs. 306 days) due to the smaller vault design of the solar toilets. Solar toilets were also were slightly drier and reached higher peak temperature than Double vault urine diverting toilets.

2.2.4.5 Processes by which Pathogens are destroyed

Ecological sanitation systems employ two main processes to achieve pathogen destruction (Esrey *et al,* 1998); dehydration or decomposition/composting

i. Composting

Composting is a biological process in which, under controlled conditions, bacteria, worms and other types of organisms break down organic substances to make humus, an excellent soil conditioner in which roots thrive.

In a composting Ecosan toilet, human excreta along with additional bulking agents such as vegetable scraps, straw, wood shavings, are deposited into a processing chamber where soil based micro organisms decompose the solids. Temperature, airflow and other factors are controlled to varying degrees to promote optimal conditions for composting. The humus produced is free from pathogens if the right conditions are achieved and if adequate retention time is achieved.

Sufficient oxygen should be able to penetrate the compost heap to maintain aerobic conditions. The material in the composting vault should have; moisture content of 50-60%, the carbon: Nitrogen balance (C: N ratio) within the range 15:1 to 30:1 and the temperature of the composting vault above 15°.

Most examples of composting toilets collect urine and faeces together, but in order to create conditions that promote composting, they usually rely on various design strategies to separate the faeces and urine after they have been mixed together in the processing vault.

The most challenging operational problem of a composting toilet is maintaining the required conditions in the vaults. This has forced many people to opt for the dehydrating type.

ii. Dehydration

In a dehydrating toilet, the contents of the processing vault are dried with the help of heat, ventilation addition of dry material like ash. The moisture content is brought down as quickly as possible to below 25% (Esrey *et al,* 1998). At this level, there is rapid pathogen destruction, no smell and no fly breeding.

The use of specialised collection devices (squatting pans or seat risers) which divert urine for storage in a separate container, allows the faeces to be dehydrated fairly easily. It becomes hard to dehydrate excreta without urine diversion. Since urine contains most of the nutrients but generally no pathogens, it may be used directly as a fertiliser, after dilution, without the need for further processing.

2.3 Ventilation and Aeration

2.3.1 Introduction

Ventilation is the process by which fresh air is introduced and ventilated air is removed from an occupied space. Ventilation serves several purposes; preserve the qualities of air (removing odours), it dries out the contents and in composting toilets, provides oxygen for the decomposition (Esrey *et al,* 1998). Ventilation may also be used to lower the temperature inside an occupied area (Arch-hku, 2001)

2.3.2 Natural ventilation

2.3.2.1 Introduction

Natural ventilation is the process of supplying and removing air by means of purpose-provided aperture (such as openable windows, ventilators and shafts) and the natural forces of wind and temperature-difference pressures.

Natural ventilation may be divided into two categories:

- ***Controlled natural ventilation*** is intentional displacement of air through specified openings such as windows, doors, and ventilations by using natural forces (usually by pressures from wind and/or indoor-outdoor temperature differences).

- ***Infiltration*** is the uncontrolled random flow of air through unintentional openings driven by wind, temperature-difference pressures and/or appliance-induced pressures across the building envelope. In dry toilets and other pit latrines, infiltration is one of the causes for inefficiency of the systems especially as regards to control of odours and extracting moisture to accelerate dying. This is because with unintentional openings in the superstructure and the vaults, the flow of air current usually takes a reverse direction (of lower resistance) to that intended to control odours and extract moisture.

2.3.2.2 Principles of Natural Ventilation

For air to move into and out of a building, a pressure difference between the inside and outside of the building is required. The resistance to flow of air through the building or vent pipe will affect the actual air flow rate and pattern. For example in cases where there is more friction resistance in the vent pipe (especially small ones), air has been found to flow out of the squat hole because of less resistance in this direction than in the intended reverse direction of flow.
In general, controlled natural ventilation and infiltration are driven by pressure difference across the building envelope. The pressure difference is caused by:

- Wind (or wind effect);
- Difference in air density due to temperature difference between indoor and outdoor air (stack or chimney effect); or
- Combination of both wind and stack effects.

An extremely important factor in maintaining good ventilation is the inertia of moving air. Air in motion acquires a momentum similar to any moving object, which tends to keep it moving in the same direction. A correctly designed ventilation system keeps air moving in the same direction (HVAC Field Manual, 1998)). This makes inertia of air work to maintain a constant air flow. In effect, provides more ventilation with less wind. Therefore the vent pipe in a toilet should be kept as straight as possible.

Wind effect

The force of the wind blowing against the side or end of a house or vent pipe creates a positive pressure area at the point of contact. It then flares out, jumping in a vertical or horizontal direction or both, depending on the configuration of the point of impact (HVAC Field Manual, 1988). Within this jump area, a negative pressure is created and thus establishing a suction phenomenon; for example in case of a vent pipe, the air inside the pipe rushes out to occupy the vacuum space created.

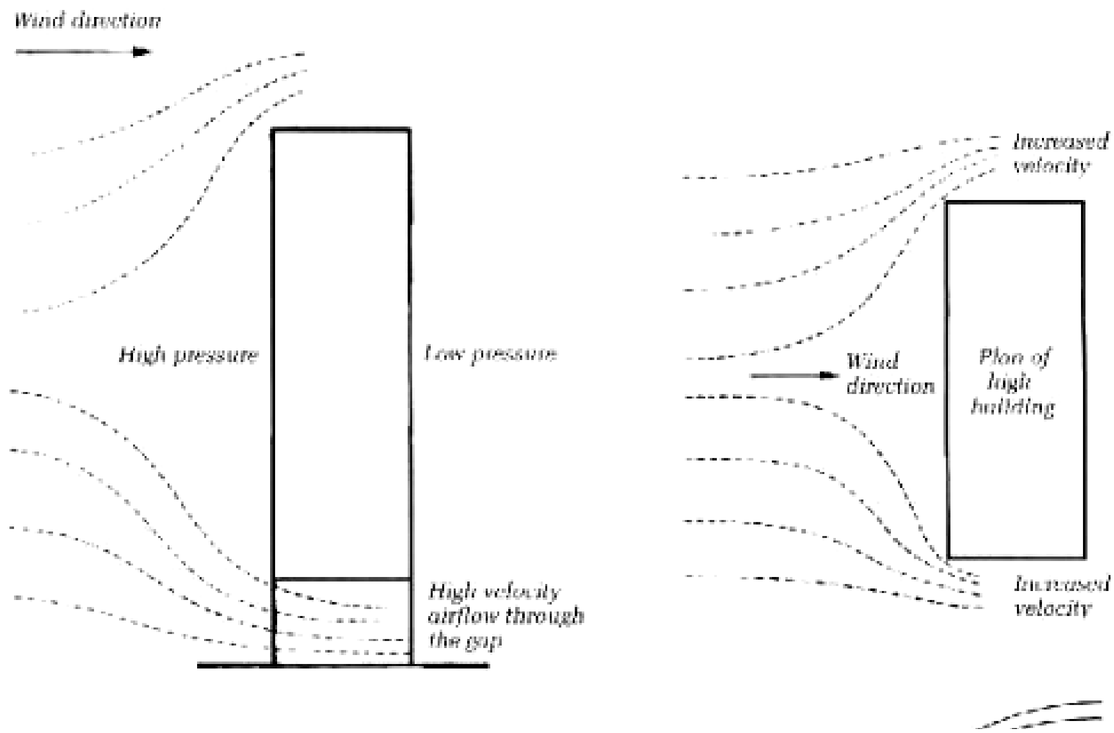


Figure.2.4: Airflow around a building

Stack Effect

Stack effect is due to temperature difference causing density differentials, and therefore pressure differences , that drive the air to move. In a dry toilet or pit latrine with a vent pipe, the following happens:

- Vent pipe temperature is heated higher than the temperature of the superstructure and surroundings;
- the warmer air in the vent pipe then rises up;
- the upward air movement produces negative indoor pressure at the bottom of the vent pipe;
- positive pressure is created at the top of the vent pipe;
- warmer air flows out of the vent pipe at the top;
- and the air is replaced by colder outside air that enters the toilet through the ventilators (or other opening) and the squat hole.

The rate of ventilation is directly proportional to the size of the openings and the height difference between inlet and outlet. Therefore the height of the vent pipe affects the rate of ventilation.

Combined effect of wind and temperature difference

In most cases, natural ventilation depends on a combined force of wind and stack effects. The pressure patterns for actual buildings continually change with the relative magnitude of thermal and wind forces. However, according to HVAC field Manual (1988), thermal /stack effect is not a major force in natural ventilation systems. The wind effect is said to be much greater. Liddament,1996 also comments that wind-driven ventilation is normally more dominant than thermally driven ventilation.

2.3.2.3 Design for Natural Ventilation

The design of controlled natural ventilation systems requires identification of the prevailing wind direction, the strategic orientations and positions of openings on the building envelope (Arch-hku, 2001). These openings include windows, doors, roof ventilators, skylights, vent pipes, and so forth.

2.3.2.3.1 Ventilation rates

When designing a ventilation system, the ventilation rates are required to determine the sizes of fans, openings, and air ducts (Arch-hku, 2001). The methods that can be used to determine the ventilation rates include:

a) Heat generation

The ventilation rate required to remove heat from an occupied space is given by:

$$Q = \frac{H}{c_p \cdot \rho \cdot (T_i - T_o)} \quad (1)$$

where H = heat generation inside the space (W)
Q = ventilation rate (l/s)
c_p = specific heat capacity of air (J/kg.K)
ρ = density of air (kg/m^3)
T_i = indoor air temperature (K)
T_o = outdoor air temperature (K)

(b) Air change rates

Most related professional institutes and authorities have set up recommended ventilation rates, expressed in air change per hour, for various situations. Table 2.2 gives some recommended air change rates for typical spaces.

The ventilation rate is related to the air change rate by the following equation:

$$Q = \frac{V \cdot ACH}{3600} \cdot 1000 \quad (2)$$

where Q = ventilation rate (l/s)
V = concentration of contaminants in outdoor air
ACH = air change per hour

Table 2.2 Recommended air change rates

Space	Air change rates per hour
Carparks	6
Kitchen	20 - 60
Lavatory	15
Bathrooms	6
Boiler rooms	15 - 30

Data source: ASHRAE Standard 62-1989, Ventilation for Acceptable Indoor Air Quality.

2.3.2.3.2 Flow caused by wind

Major factors affecting ventilation wind forces include:

- average wind speed;
- prevailing wind direction;
- seasonal and daily variation in wind speed and direction;
- local obstructing objects, such as nearby buildings and trees; and
- position and characteristics of openings through which air flows.

Natural ventilation systems are often designed for wind speeds of half the average seasonal velocity because from climatic analysis there are very few places where wind speed falls below half the average velocity for many hours in a year (Arch-hku, 2001).

The following equation shows the airflow rate through ventilation inlet opening forced by wind (Arch-hku, 2001):

$$Q = C_v \cdot A \cdot v \qquad (3)$$

where Q = air flow rate (m^3/s)

A = free area of inlet openings (m^2)

v = wind velocity (m/s)

C_v = effectiveness of the openings (assumed to be 0.5 to 0.6 for perpendicular winds and 0.25 to 0.36 for diagonal winds)

2.3.2.3.3 Flow caused by thermal forces

If the building's internal resistance is not significant, the flow caused by stack effect may be estimated by(Arch-hku, 2001):

$$Q = K \cdot A \cdot \sqrt{2 \cdot g \cdot \Delta h \cdot \frac{T_i - T_o}{T_i}} \quad \text{if } T_i > T_o$$
$$Q = K \cdot A \cdot \sqrt{2 \cdot g \cdot \Delta h \cdot \frac{T_o - T_i}{T_o}} \quad \text{if } T_o > T_i \qquad (4)$$

where Q = air flow rate (m^3/s)

K = discharge coefficient for the opening (usually assumed to be 0.65)

A = free area of inlet openings (m^2)

Δh = height from inlet (lower) opening to outlet level (m)

T_i = indoor air temperature (K)

T_o = outdoor air temperature (K)

2.3.3 Mechanical ventilation;

2.3.3.1 Introduction

Mechanical ventilation is the process of supplying and removing air by means of mechanical devices, such as fans. It may be arranged to provide supply, extract or balanced ventilation for an occupied

2.3.3.2 Principle of mechanical ventilation

The air pressure difference, created by fans and other mechanical ventilators, between the inside and the outside of a structure the reason why air is exchanged in a mechanically ventilated facility. For example exhaust fans create a slight negative pressure or vacuum in a structure which causes air to enter the structure through designed inlets for example louvers and the squat hole in a latrine.

2.3.3.3 Turbine Vents

A turbine vent consists of a turbine wheel mounted on top of a roof vent or a vent pipe (e.g. the enviro loo) to help exhaust air from the attic or toilet respectively (HVAC Field Manual, 1998). The rotating wheel consists of a series of specially shaped vanes that turn wind force into rotary motion. As the spinning vanes gain velocity, they create an area of negative pressure, which in turn pulls air from the attic or toilet.

However according to the Wind Engineering Journal (10-12 April 2003), very little is known about the complex flow field (aerodynamics) associated with the operation of this device. However, it has been established to work efficiently in the various tests carried out using the wind tunnel test.

2.3.4 Vent Pipe Design

A wide variety of materials can be used for vent pipes including Polyvinyl Chloride, Polyethylene, asbestos cement, cast iron pipes, bricks, etc. The material used should be durable, locally available, economic and easy to construct.

The pipe should be at least 0.5m above the highest point of the roof. The internal diameter of the pipe depends on the venting velocity necessary to achieve the recommended ventilation rate of $20m^3$/hr (Lecture notes, 2003) According to Esrey *et al (*1998), a vent pipe should have a diameter of 10-15cm. In humid climates with large amount of liquid to be evaporated, the diameter could be larger, up to 25cm. The pipe should be as straight as possible and reach 30-90cm above the roof (Esrey *et al,* 1998).

The ventilation rate depends on: -

- Internal surface roughness of the pipe
- Length of the pipe
- Head loss through the fly screen and squat hole
- The direction of the wind

minimum internal sizes of the vent pipes that are recommended are shown in Table 2.3

Table 2.3: Recommended Vent pipe diameter (in mm)

Material	**Wind speed < 3 m/s**	**Wind speed > 3 m/s**
Asbestos cement	150	100
Polyvinyl Chloride	150	100
Brick	230	200
Cement-rendered, reed or hessian	230	200
All other rural type e.g. bamboo	230	200

Source: CE325 Lecture Notes, .2003

2.3.5 The Enviro Loo

The 'enviro loo' is a waterless dehydration /evaporation, zero discharge Ecosan toilet system that is driven by radiant heat ant wind power. The system is one of the most efficient dry sanitation systems in South Africa and other parts of Africa. (La Trobe *et al,* 2003). Despite being a non urine-diverting toilet, the enviro loo successfully achieves dehydration of the faeces and evaporation of all the urine separated from faeces after being mixed. One of the most distinguishing feature of this toilet is its ventilation system whose operation is based on a combination of natural and forced (mechanical) ventilation.

Radiant heat contributes to the operation of the system. The radiations heat up the low-density polyethylene (LDPE) forming the manhole covers and the vent pipe. The vent pipe and manhole covers then act as black bodies and heat the air in turn, causing a convection current, thereby positive ventilation extraction through the system (La Trobe *et al,* 2003).

When the ventilation extractor (vent turbine) rotates with the aid of wind, it creates a negative pressure within the container and pipe, and hence the suction phenomena. Cooler air rushes into the negative pressure space to maintain equilibrium conditions. The ventilation in the system is such that during the period that the waste moves down the drying plate it is constantly subjected to a large airflow. For example with a relatively low wind speed of4km/hr, airflow of approximately 100-to150 m^3/hr is approximated through the system. The continual airflow is said to have the following effects on the waste

- A reduction in volume through evaporation of the high moisture content;
- Devitalization of pathogens by the oxygen;
- De-odourising of the waste by the oxygen..

Low Density Polyethylene plastic was chosen for use on the manhole covers and the vent pipe. This was after various prototypes were tested and evaluated over a four-year period. Based on the initial positive tests results of the process and after researching various manufacturing materials, LDPE plastic was found to offer the best structural properties with regard to strength, flexibility, material lifespan and its inert properties (La Trobe *et al,* 2003).

2.3.6 Solar Chimney

2.3.6.1 Design concepts

A solar Chimney can be constructed from A solar chimney can be constructed from conventional building materials. The difference between the conventional chimney and the solar chimney lies in the implicit use of solar radiation to elevate the temperature of the air inside the chimney to increase the pressure difference and give an increased airflow (Lowndes, 2000).

Typically the south facing wall of a solar chimney is replaced with glazing and the interior of the other walls are blackened in order to increase the solar heat absorption. The walls of the chimney are insulated in order to store the heat absorbed from solar radiation through the glazing. The principle aim is to maximise the air temperature within the chimney, thereby minimising air density and pressure differential to that of the room air in order to drive the "stack effect" air flow.

A number of theoretical steady-state mathematical models that have been developed by researchers that try to quantify the effect of solar energy absorption and the resulting ventilation performance of the solar chimney. One of the simplest developed is by Aboul Naga et al (Lowndes, 2000). They cite an equation for the energy balance per unit area of solar absorber plate (chimney) from the form:

$$(\alpha\zeta)\, \acute{S}(t) = h_f\,(T_p - \check{T}_f) + (T_p - T_a) \qquad (5)$$

Equation 5 highlights the principle parameters that are at work in the solar absorption process, namely;

- Solar absorpativity 'α': a coefficient that represents how well the walls of the chimney absorb the solar radiation.
- Transmittance 'ζ': a coefficient that represents how well the glass transmits the incident solar radiation.
- The amount of incident solar radiation 'Ś(t)' falling on the chimney (W/m^2).
- The convective heat transfer coefficient 'h_f' ($W/m^2\ ^oC$). This coefficient accounts for the fact that most of the temperature drop occurs in a relatively stagnant boundary layer adhering to the absorber surface, relying on the thermal conductivity of the fluid and that away from this convection heat transfer dominates.
- The temperature difference between the absorbing surface and the air in the chimney 'T_p - $\check{T}_f$' (^oC) and that of the ambient temperature 'T_p – $\check{T}_a$' (^oC). The higher these temperature differences, the higher the heat transfer.

It can be seen from equation 5, that for a given amount of solar radiation falling upon the solar chimney, the greater the values of chimney surface absorpativity and glass solar radiation transmittance; the greater the differentials between the absorbing surface, chimney air and ambient air temperature will be (assuming steady state fixed heat transfer coefficient).

This would imply that the surface area of materials that are designed to transmit solar radiation (glass) and absorb it (chimney wall) should be maximised to create the biggest temperature differentials, maximising air flow.

2.3.6.2 Optimising the Solar Chimney Effect

The theory explored so far suggests that to maximise the air flow through a ventilation chimney, the stack height should be optimised to increase pressure gradient 'ΔP' since $\Delta P = \rho g \Delta h$. This is also a function of temperature difference, which governs air density and can be optimised by increasing the chimney air temperature, from exposure to both direct and absorbed solar radiation (equation 5).

The results of the solar chimney mathematical model created by Aboul Naga et al are shown that increasing the solar chimney height increases the ventilating capacity. A solar chimney height of three and a half metres achieves a ventilating capacity approximately five times that of a two-metre high chimney (Lowndes, 2000).

2.3.6.3 Conclusion

If the theoretical performance of a solar chimney is to be realised in practice, a number of issues must be addressed. In particular, the utilisation of materials that not only admit the optimum direct solar radiation but also materials that limit heat loss, to avoid down draught and break down of the stack effect. Simple parameters like thermal insulation of walls, inclination of collection glass towards the sun should be optimised to optimise ventilation

2.3.7 Wall Insulation

2.3.7.1 Keys to Effective Wall Insulation

Insulation has the ability to store heat, which slows down the amount of time it takes heat to move through the wall (Balthazar *et al,* 1992). Walls are the most complex components of the building envelope to insulate, air seal and control moisture (Habitat for Humanity International, 1999). The keys to effective wall insulation are:

- Air tight construction –- all air leaks sealed in the wall during construction
- Moisture Control – exterior rain drainage system, continuous air barrier, vapour barrier on the appropriate side of the wall
- Complete insulation coverage – Optimum value engineered framing to maximise insulation coverage

Air Sealing

Air sealing reduces convective heat flow and prevents water vapour in he air entering the wall. In a 100-square foot wall, one cup of water will diffuse through a dry wall without a vapour barrier in a year, but 50 cups will enter through a half-inch diameter hole (Habitat for Humanity International, 1999). Thus sealing air leaks is about 50 times as important as installing a vapour barrier

Moisture Control

Moisture control makes insulation more effective. Most moisture enters walls either a fluid capillary action or as water vapour through air leaks. Controlling moisture in walls involves installing a polythene ground cover (Damp proof membrane) to prevent moisture moving upwards by capillary action and installing a vapour barrier in the wall itself

2.3.7.2 Insulating properties of Building Materials.

The insulation value of the wall materials and their thickness determine the heat flow in the wall. The insulating properties of a material is measured in R-Values, which is a measure of resistance to heat flow. The higher the R-Value, the more of a barrier a material is to heat penetration. The total R-Value for a wall can be found by adding the R-Value of each type material used in the wall. Even a thin film of air on the interior and exterior of the wall has some insulation value. Table 2.4 below lists some building materials and their R-values for a one-inch thickness.

Table 2.4 Building Materials and their R-Values for a One-Inch Thickness.

Material	R-Value/inch
Foams (rigid boards)	3.6 - 7.5
Cellulose (loose blown)	2.8 - 3.8-
High Density Fiberglass (batts)	3.2 – 3.5
Fiberglass (batts or blown)	2.2 – 3.3
Vermiculite	2.4 – 3.0
Plywood	1.25
Softwoods	1.25
Wood Siding	0.79
Concrete Blocks	0.58
Gypsum Board - 1/2"	0.45
Brick	0.20
Concrete	0.08
1/4" Wood Panelling	0.31

Source: Balthazar *et al,* 1992

2.3.8 Conclusion

Basing on the literature reviewed, the design to be developed will use a combination of natural ventilation; due to stack and wind effect and mechanical ventilation using a rotary vent turbine (wind driven).

In order to allow in as much sunlight and heat as possible into the vaults and retain as most of the heat, the vault doors will be made from a one-way glass, slanting at an appropriate angle. For effective insulation, the vaults will have a double wall with a readily available insulating material in the middle and air leakage especially through the vaults will be minimised.

CHAPTER THREE: METHODOLOGY AND ACTIVITIES

3.1 Introduction

The methodology adopted in this study was for the purpose of obtaining relevant information and data necessary to come up with an improved ventilation system that would accelerate the drying process in the vaults of dry toilets. The methods adapted to accomplish this are: literature review, Data collection through site visits, Data analysis, design of the ventilation system and a recommendation of materials and costing

3.2 Literature Review

Literature was successfully reviewed about dry toilets with emphasis on the ventilation systems. However since much of the literature obtained was not discussing ventilation of dry toilets specifically, reference was made to heating and ventilation in general and to ventilation systems used in other sanitation systems from which the ventilation in a dry toilet was adopted. The required literature on ventilation was hardly available in available textbooks, so most of it was obtained from the internet. The literature obtained gave information on the:

- Ventilation employed for common sanitation systems,
- Ecological sanitation systems and how drying and ventilation are achieved,
- Importance of drying (evaporation) as regards to die-off of pathogens and other conditions necessary for death of pathogens,
- 'Enviro Loo' a unique zero discharge dehydration system with a unique ventilation system,
- Experiences regarding different designs of Ecosan toilets with particular interest in comparative performance of the different designs as regards to drying excreta material in the vaults,
- Types of ventilation and what affects the performance of a given type of ventilation,
- Ways to achieve effective wall insulation and insulation values of different building materials.

3.3 Data Collection

3.3.1 Site Visits

Site visits were made to the South-western Towns Water and Sanitation (SWTWS) project area and other areas around Kampala in order to get acquainted with Ecosan toilets and to establish Information about the different types of ventilation systems available, their performance, and attitude of the users and cost of construction of different ecological sanitation toilet units. The sites visited were mostly in Kabale and Kisoro, where the Ecosan toilets have been operational for the longest period since 1997. Other sites visited included the Enviro loo in Makerere Kivulu and in Luzira, the dry toilet at the directorate of water development and another in Mukono.

The required technical and non-technical information was obtained by use of questionnaires or oral interviews and use of checklists.

3.3.1.1 Sampling

Since the population of ecological sanitation was too large for the researcher to attempt to survey all of its members. A small, but carefully chosen sample was used to represent the population. The sample reflects the characteristics of the population from which it was drawn.

The method of sampling used was random sampling is the purest form of probability sampling (where each member of the population has an equal and known chance of being selected). A random sample of twenty ecological sanitation toilets was selected from different areas in Kisoro and Kabale.

3.3.1.2 Questionnaires/ Oral Interviews

Questionnaires were used mainly to establish the general attitude of the Ecological Sanitation toilet users, seek their views on how the system could be improved, establish the time taken to fill one vault and the average cost of construction for the different units. (Sample in Appendix A)

3.3.1.3 Checklists

Checklists were used for more technical information such as the height of pipe above the roof, location of the vent pipe, diameter of vent pipe, number of vent pipes per stance, presence of vent cover, material of vent pipe, obstructions to wind flow. The information was obtained by taking measurements and by personal observation. (Sample in Appendix A)

In order to assure quality of the results, the measurement of the diameter of the diameter was repeated three times at different locations and the average of these values was taken. Since the height of the pipe above the roof could not be accessed for direct measurement, the value was averaged from four close values, independently estimated by myself and other colleagues.

3.4 Selection of Materials and sizing Components

3.4.1 Selection of material for the pipe

The material for the vent pipe was selected using the following procedure:

- Data collected from the field was analysed to establish the type of materials being used for the vent pipes.
- The available materials on market were compared to establish those with a higher absorpativity (to optimise ventilation due to the stack effect) than the currently predominantly used Polyvinyl Chloride (PVC)
- The material with a higher absorpativity but with a comparable cost to the PVC being used, was selected
- A mild steel pipe of thickness of 1.2mm was selected or alternatively; the pipe could be welded from plain steel plates 1.2mm thick.
- The problem of rust could be checked by painting the pipe with black oil paint which in turn would improve on the absorpativity of the pipe.
-

3.4.2 Selection of materials for the vaults

The materials for the vault walls and doors were selected using the following procedure:

- The materials being used in the field were established
- Literature was reviewed to establish conditions that would effect optimum temperatures in the vaults
- Basing on the literature, a material with a high transmittance for the vault doors and for the walls materials were selected so as to have maximum insulation and absorpativity.
- One-way glass was selected for the vault doors because it allows in direct sunlight in one direction-into the vault.
- A double wall was selected for the vaults with a space between the two walls to accommodate any form of insulating material available

3.4.3 Selection of pipe Diameter

The pipe diameter was selected using the following criteria:

- The sizes of vent pipes being used in the field were established, that is, predominantly 100mm and an exceptional case with 75mm.
- The larger size of 100mm was checked, using acquired equations, to find out if it meets the recommended ventilation rate of $20m^3/hr$ according to ASHRAE (American Society of Heating, Refrigeration and Air-Conditioning Engineers) standards. The ventilation rate was checked for both stack and wind effect, assuming at one point they would be working independently.
- The recommended size from tables (Table 2.3) was checked to establish if the size can achieve the recommended ventilation rate of $20m^3/s$. The size used from tables was 150mm since the average wind velocity calculated was found to be less than 3m/s.

- The ventilation rate due to wind effect was calculated using equation 3 below.

$$Q = C_v \cdot A \cdot v \tag{3}$$

where Q = air flow rate (m^3/s)
A = free cross-sectional area of inlet openings (m^2)
v = wind velocity (m/s)
C_v = effectiveness of the openings (assumed to be 0.5 to 0.6 for perpendicular winds and 0.25 to 0.36 for diagonal winds)

For design purposes, as recommended from literature, the wind velocity used was half the average seasonal wind velocity calculated. The average wind velocity was calculated from data for wind velocities averaged over 30 years for 9 districts all over Uganda. The Data was obtained from the meteorological Department Kampala.

- The ventilation rate due to stack effect was calculated using equation 4

Since the temperature of air in the vent pipe had not been measured for the data obtained for dry toilets, the temperature measured at a point 1.8m vertically above the squat hole was averaged and used (it was assumed to be close to the temperature of the air in the PVC plastic vent pipe).However, for the Enviro loo in Mbarara Rwebikoona market, the actual temperature values of air in the vent pipe, measured three times a day for three days were averaged and used in the calculations.

The temperature values used for analysis were obtained from measurements by Felix Groth an Austrian student who was carrying out a similar research on dry toilets

$$Q = K \cdot A \cdot \sqrt{2 \cdot g \cdot \Delta h \cdot \frac{T_i - T_o}{T_i}} \quad \text{if } T_i > T_o$$
$$Q = K \cdot A \cdot \sqrt{2 \cdot g \cdot \Delta h \cdot \frac{T_o - T_i}{T_o}} \quad \text{if } T_o > T_i \tag{4}$$

where Q = air flow rate (m^3/s)

K = discharge coefficient for the opening (usually assumed to be 0.65)

A = free cross-sectional area of vent pipe (m^2)

Δh = height of vent pipe (m)

T_i = vent pipe air temperature (K)

T_o = outdoor air temperature (K)

- A pipe diameter was selected such that the recommended ventilation rate could be achieved under the effect of either wind or stack.

3.4.4 Sizing of the vaults

The vaults were sized for an average household of eight. The following assumptions were made

- Volume of solid excreta per person per year = 50l
- Volume of urine per person per year = 500l
- Volume of dry material (ash) added per person per year = 50l
- Retention time = 6 months
- Duration taken to fill one vault = 10 months
- Ash added is equal to the faeces and 1 litre is equivalent to 1Kg (that is, Density = 1kg/l)

Volume of each vault, V in m^3 is calculated from:

$$V = N * n(F + A + U)/1000$$

where N = Number of users

n = Period taken to fill one vault (years)

F = Volume of faeces produced per person per year in litres

A = Volume of ash per added per person per year in litres

U = Volume of urine per person per year in litres

Since for a dehydrating (dry) toilet the urine is diverted, no urine enters the vault, therefore $U = 0$. The vault was also assumed to be filled to 0.8 of the total height of the vault.

3.4.5 Selection of a Vent Turbine

Since from the review of literature, ventilation systems operating purely on natural ventilation have been found not to be very effective especially when poorly designed, a mechanical wind-driven turbine vent was opted for. Wind was selected as a source of power because it is readily available

The engineering design procedure for a rotary turbine vent was not carried out since the information for its design was not readily available.

The size of the rotary turbine vent was established basing on the size of the vent pipe on which the vent turbine was to be installed and considering specifications given for turbine vents on market.

Aluminium was chosen as the material for the blades of the vent turbine because it is a light materal (can be easily rotated by wind), free from rust and more durable than plastics.

3.5 Construction of a Model

A model of the designed Ecosan toilet was constructed at a scale of 1:4. The walls of the vaults and the superstructure were constructed using 9mm thick plywood since it was the most convenient material available on market, to use. The inside of the vault walls was painted black to increase the amount of heat absorbed. The vault doors were made of one-way glass, allowing direct sunlight into the vaults and not in the reverse direction. The vent pipe was fabricated from a mild steel pipe of diameter 3.75mm and gauge 1.2mm. The rotary turbine vent air extractor with 14 blades was constructed from Aluminium.

3.6 Data Analysis Methods

The data obtained from checklists and questionnaires was summarised in a table using Microsoft excel.

Percentage values of different results obtained from the checklists and questionnaires were calculated and the results were plotted on bar graphs using Microsoft Excel.

The average seasonal wind velocity was obtained by calculating the annual wind speed for each of the nine districts. An average seasonal wind speed was calculated from the average values of each district with the exception of Arua district whose results were incomplete. The wind speed value used for design was half overall average value calculated

The ambient temperature value used for design was an average of the values recorded in Kabale and Kisoro. These were thought to be sufficient, though they were not representative of the whole country, because this part of the country experiences the lowest temperatures. Therefore the design obtained could work sufficiently for the lowest temperature values and even better for other parts of the country with higher temperatures.

CHAPTER FOUR: RESULTS, ANALYSIS AND DISCUSSION

In this chapter is presented field results, analysis, design and discussion of the results.

4.1 Field results

The information obtained from questionnaires and checklists used in Kabale and Kisoro is summarised in Table 4.1a and 4.1b below. The data given is for the twenty randomly selected Ecosan units visited in Kabale and Kisoro. Some of this information is further summarised in Table 4.2 and Graphs (Figure 4.1a – 4.1b) were generated from these results

Table 4.2 : Summary of Results

Height of vent pipe above roof (m)	**< 0.5**	**0.5 - 0.7**	**> 0.7**
Number	8	8	4
Percentage	40	40	20
Orientation of vault doors	**Vertical**	**Slanting**	**Horizontal**
Number	6	12	2
Percentage	30	60	10
Number and location of vent - pipes per stance	**1, centre of 2 vaults**	**2, centre of each vault**	**2, side of each vault**
Number	11	7	2
Percentage	55	35	10
Vent Covers	**With**	**without**	
Number	13	7	
Percentage	65	35	
Pipe material	**PVC**		
Number	20		
Percentage	100		

Table 4.1a: -. Summary of Field Observation Results

No.	Item	Vent pipe diameter (mm)	height above roof (m)	Pipe material	Number and location of vents per stance	Vent pipe alignment	Vent-caps (covers)	Material of vault doors	Vault door orientation	No. of stances
1	Mahoro Mauda-K'le	100	0.3	PVC	2. Side of @ vault	straight	None	Pre-cast concrete	horizontal*	1
2	Kikungiri Prim. Sch.-K'le	100	0.4	PVC**	1. Between 2 vaults	straight	Yes	Steel plate**	slanting	5
3	Faustine Male- K'le	100	1.0	PVC	1. Between 2 vaults	straight	Yes	Steel plate**	slanting	1
4	Semei Kwarinkunda-K'le	100	0.6	PVC	1. Between 2 vaults	straight	None	Steel plate**	slanting	1
5	St Mary's Rushoroza-K'le	100	0.5	PVC*	1. Between 2 vaults	straight	Yes	Steel plate**	slanting	6
6	Mwesigwa Emma -K'le	100	0.6	PVC	1. Between 2 vaults	straight	Yes	Steel plate**	slanting	1
7	Mwesigwa Jude- K'le	100	0.6	PVC	1. Between 2 vaults	straight	Yes	Steel plate**	slanting	1
8	Ndorwa Prim. Sch.	100	0.9	PVC	1. Between 2 vaults	straight	None	Steel plate**	slanting	2
9	Rutenga-Katuna Rd-K'le	100	0.6	PVC	1. Between 2 vaults	straight	Yes	Steel plate**	slanting	1
10	Pre-Read Pri. Sch.-K'ro	100	0.5	PVC	2. Centre of @ vault	straight	Yes	Steel plate**	slanting	3
11	Kisoro Mosque	100	0.3	PVC	1. Between 2 vaults	straight	None	Steel plate*	vertical	1
12	Aunt Phina Nursery Sch-K'ro	100	0.4	PVC	2. Centre of @ vault	straight	None	Pre-cast concrete	horizontal*	2
13	Shalom Foundation Sch-K'ro	100	0.4	PVC	1. Between 2 vaults	straight	Yes	Steel plate*	vertical	2
14	Kisoro Town Council	100	1.0	PVC	2. Centre of @ vault	straight	Yes	Steel plate*	vertical	6
15	Kisoro New Market	100	0.8	PVC	2. Side of @ vault	straight	Yes	Steel plate**	slanting	4
16	St Cosmas Clinic-K'ro	100	0.05	PVC	2. Centre of @ vault	straight	Yes	Steel plate*	vertical	2
17	Mr. Turyamureeba-K'ro	100	0.6	PVC	2. Centre of @ vault	straight	None	Steel plate**	slanting	1
18	Nyirabimana -K'ro	100	0.4	PVC	2. Centre of @ vault	straight	None	Steel plate*	slanting	1
19	Mgahinga Gorilla Office-K'ro	100	0.3	PVC	2. Side of @ vault	straight	Yes	Steel plate*	vertical	2
20	Henry Hashakimana-K'ro	100	0.5	PVC	2. Centre of @ vault	straight	Yes	Steel plate*	vertical	1

horizontal* - Composting toilet
Steel plate* - painted black
Steel plate** - gauge 1.2mm, painted black
PVC* - pipe painted black
PVC** - pipe rough-cast and painted black

Table 4.1b: Summary of Field Observation Results

No.	Item	No. of users	Duration to fill# (months)	Retention Period	Contruction Cost	Attitude and Reason	Problems encountered during operation
1	Mahoro Mauda-K'le	6	18	–	800,000/=*	Indifferent	Covers are too heavy
2	Kikungiri Prim. Sch.-K'le	500	8	–	7,000,000/=*	Positive-High water table	Blockage of urine diversion
3	Faustine Male- K'le	12	6	6 months	400,000/=	Positive-Source ofmanure	Scarcity of ash
4	Semei Kwarinkunda-K'le	5	(not filled)		800,000/=*	Positive-no smell, no flies	None
5	St Mary's Rushoroza-K'le		(not in use)	–	7,000,000/=*	Positive-Rocky ground	Not applicable
6	Mwesigwa Emma -K'le	6	8	6 months	800,000/=*	Positive-High water table+manure	None
7	Mwesigwa Jude- K'le	2	(not filled)	–	800,000/=*	Positive-High water table	None
8	Ndorwa Prim. Sch.	15	(not filled)	–		Positive-High water table	No washer facility provided
9	Rutenga-Katuna Rd-K'le	8	12	–	800,000/=*	Positive-High water table	None
10	Pre-Read Pri. Sch.-K'ro	150	3	6 months	400,000/=	Positive-Rocky ground	Misuse by the Kids
11	Kisoro Mosque	–	12	–	–	Negative-No provision for washers	No provision for washers
12	Aunt Phina Nursery Sch-K'ro	130	7	–	–	Positive-Economy of space	Misuse of facility by kids
13	Shalom Foundation Sch-K'ro	80	12	4 months	–	Positive-Rocky ground	Misuse of facility by kids
14	Kisoro Town Council	–	24	–	12,000,000/=	Positive-rocky ground+manure	–
15	Kisoro New Market	30	24	6 months	30,000,000/=*	Negatie-Lack of sensitisation	Missuse
16	St Cosmas Clinic-K'ro	20	8	–	–	Positive-No smell, space economy	Scarcity of ash + insects
17	Mr. Turyamureeba-K'ro	8	12	6 months	800,000/=*	Positive- Source of manure	Water enters above door
18	Nyirabimana -K'ro	6	18	6 months	200,000/=	Positive-manure,no smell, no flies	–
19	Mgahinga Gorilla Office-K'ro	15	8	–	–	Positive-Rocky ground*, less smell	Small flying Insects
20	Henry Hashakimana-K'ro	6	12	6 months	–	Positive-Rocky ground*	None

800,000/=* - Funded by DWD through SWWSP with a contribution of 30,000/= from the users
7,000,000/=*, 30,000,000/=* - Funded by DWD through SWWSP
- Duration to fill one vault
– Not given or not applicable

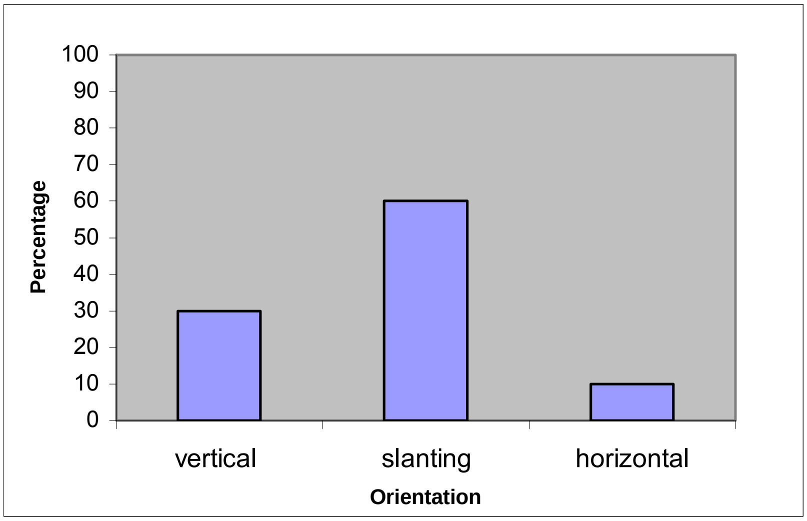


Figure 4.1a: Vault Door orientation

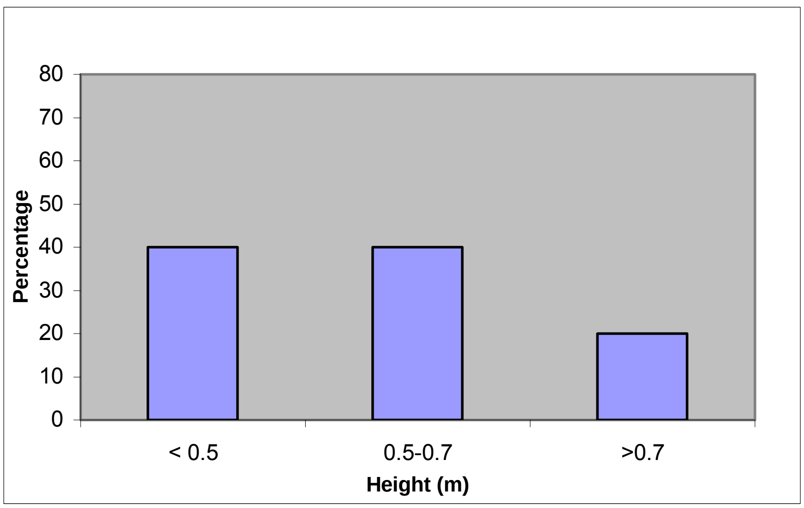
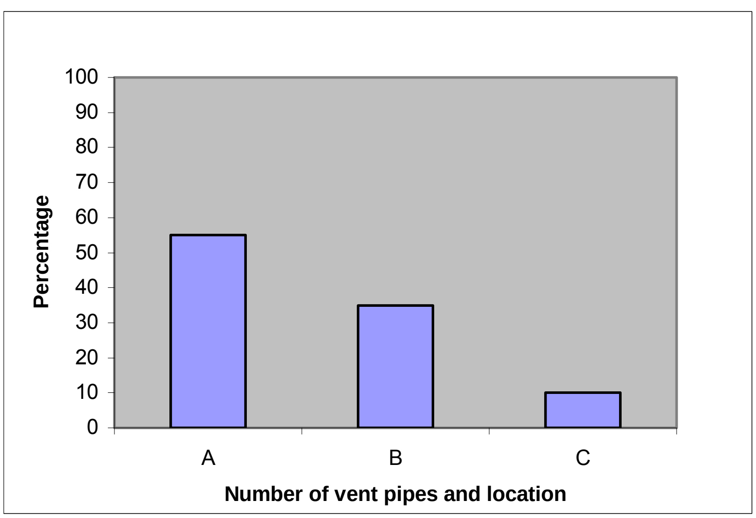


Figure 4.1b: Height of Vent Pipes above Roof



A-1,center of 2 vaults

B-2, center of each vault

C- 2, side of each vault

Figure 4.1c: Number and location of vent Pipes per stance

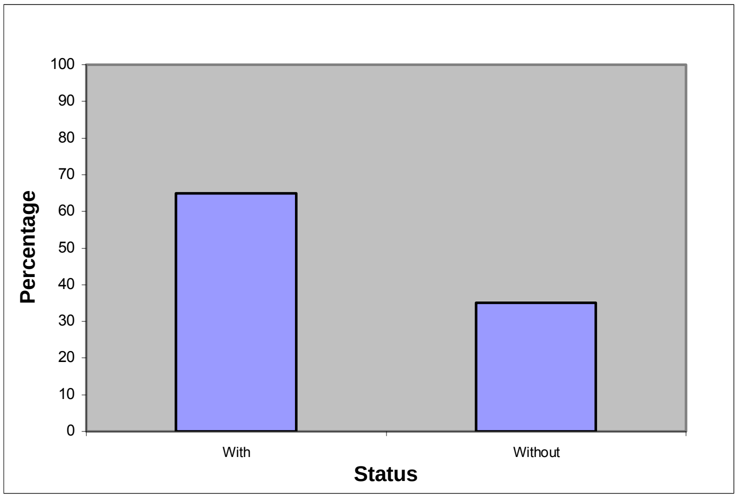


Figure 4.1d: Vent Caps or Rain stoppers

From Figure 4.1a, thirty percent of the selected toilets had vertical vault doors, that is, the vaults were not being directly heated by the sun. These were all old designs produced before the significance of solar heating in enhancing the death of pathogens was appreciated. However, the biggest percentage (60%) and all the new designs had slanting metallic doors painted black (Figure 4.2a) . Drier faecal matter was observed in such units than that in units with vertical doors (Figure 4.2b), because such units received maximum heat, which was absorbed by the steel doors painted black (solar panels), facing the sun. The two units with horizontal precast concrete covers were for composting toilets.

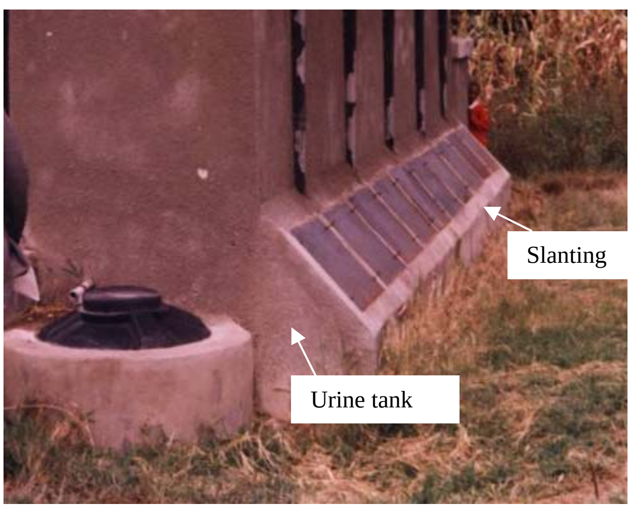


Figure 4.2a: Plate showing vaults of a solar dry toilet

Figure4.2b: Plate showing vaults of a non-solar dry toilet

From figure 4.1b, twenty percent of the vent pipes achieved the ideal recommended vent height above the roof, that is, at least 0.5m above the highest point of the roof (about 0.8m above the roof). However 40% had a height above the roof that was still acceptable (at least 0.5m above the roof). 40% had vent heights below that acceptable (< 0.5m). Some vents barely went above the roof some times the outlet of the vet pipe was completely covered by the vent cap (Figure 4.3), which completely interfered with airflow (ventilation)

Figure 4.3: Plate showing Vent Pipes barely extending above the Roof

From Figure 4.1c, about sixty percent of the units visited had one vent pipe serving two vaults. A hole is made in the partitioning wall between the vaults as shown in Figure 4.4. This approach is not effective as far as ventilation is concerned. The free flow of air into the vent pipe from the vaults is greatly hindered since the effective area of entry is reduced. Therefore the rate of ventilation achieved will in turn be much less than if the pipe was in the open, at the centre of each vault. Figure 4.2a also shows the arrangement of vent pipes positioned between two vaults, as seen from the outside.

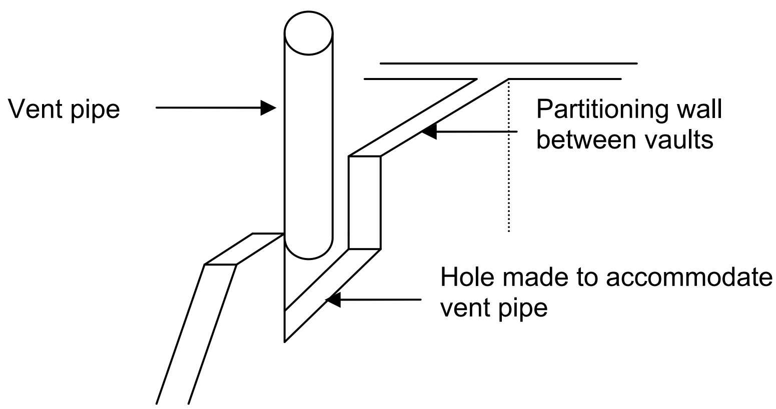


Figure 4.4 Use of one vent pipe to Aerate two vaults

Thirty five percent of the units were without vent caps to cover the top of the top vent (Figure 4.5b). This implied that water would find its way to the vaults through the vent pipes whenever it would rain, thus increasing amount moisture in the vault, which is not needed in a dry toilet.

The entire sample selected had Polyvinyl Chloride (PVC) vent pipes and only two of these were painted black. The grade of PVC pipes being used was so weak such that the pipes were easily broken (Figure 4.5a and 4.5b) Plastics, hence PVC, act as insulators and do not allow as much heat to penetrate through them to heat the air inside the vent pipe, as metallic ones. Thus the ventilation rate due to stack (heat) effect is retarded, especially during the day.

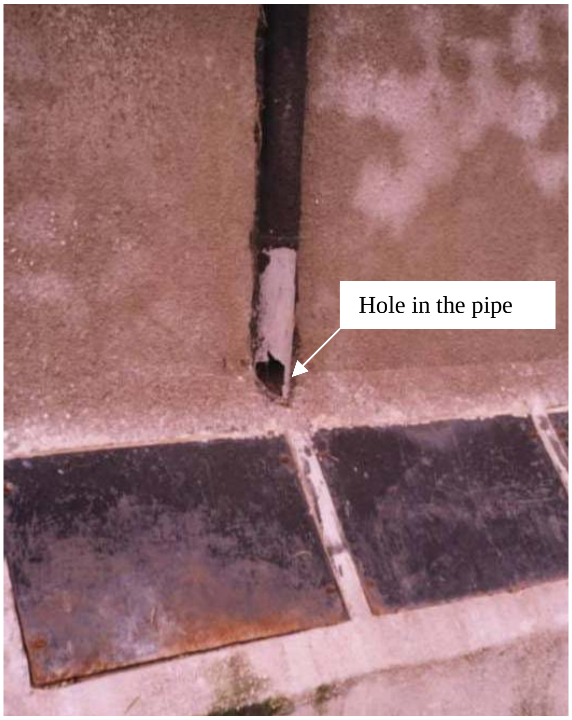


Figure 4.5a. A Solar dry-Toilet with a broken vent pipe

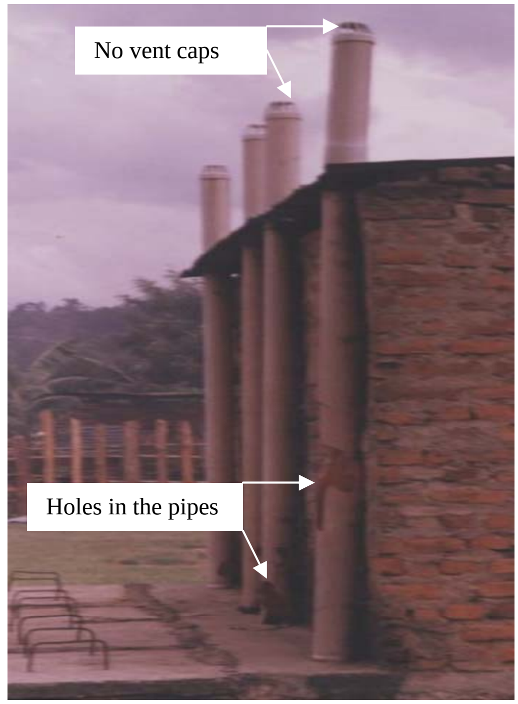


Figure 4.5b. A Composting Toilet with broken PVC pipes

The majority of the people had a positive attitude towards Ecological sanitation toilets mainly because of the prevalent geological and hydrological conditions in Kisoro and Kabale respectively. Rocky grounds in Kisoro had rendered the construction of pit latrines very expensive while in Kabale, the high water table led to the collapse of pit latrines almost during every wet season. Thus in either case pit latrines were expensive to construct.

Some of the people were also using the sanitised faecal matter for agricultural purposes. An example is a lady who was using the manure from the Ecosan toilet for small scale horticulture and floriculture (Figure 4.6a).

Figure 4.6a. Horticulture using Manure from Ecosan toilet.

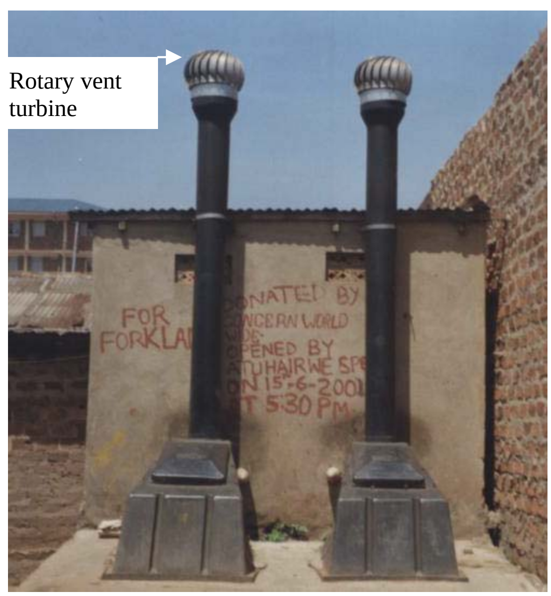


Figure 4.6b. An Enviro Loo in Makerere Kivulu

Apart from the Ecological Sanitation units in Kisoro and Kabale, an Enviro loo was Ecosan toilet in Makerere Kivulu and a sample Eko loo, a plastic Ecosan manufactured by Crest Tanks, were also visited.

The Enviro loo had a sufficient vent pipe diameter of 250mm, however since the Enviro loo is a non-urine diverting toilet sometimes the system failed to work as anticipated. Despite employing a rotary vent turbine which greatly increases the rate of evaporation, the system sometimes failed to evaporate all the urine. The result is that the system would smell a lot and would produce maggots and flies, for example the enviro loo in Mbarara, Rwebikoona market.

The Crest tank Eko Loo had a very small vent pipe of diameter 75mm.This is too small a size and it needs to be increased. Since the smaller the pipe, the higher the resistance to air flow (air takes the path of least resistance), such a vent pipe size would hardly have air flowing through it. If at all the air flows, it would not be enough to meet the required ventilation rate

4.2 Design of the ventilation System

4.2.1 Sizing the Vent pipe

The adequacy of ventilation using a 150mm diameter pipe was checked using equations 3 and 4 for both ventilation due to thermal effect and ventilation due to wind.

The wind velocity used for design in equation 3 was averaged from the results given in Table 4.3.

Table 4.3 Mean Long term wind speed in Knots for over 30 years (Source: Meteorological Department)

STATION	TIME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual speed	Wind drxn (Annual)
KABALE	6:00Z	3	3	3	3	3	3	3	3	3	4	3	3	3	S-W
	12:00Z	9	9	8	9	9	9	10	11	9	9	7	7	9	E-S
ENTEBBE	6:00Z	5	3	5	5	6	4	6	5	6	5	5	3	5	N-NW
	12:00Z	8	8	9	9	9	10	9	11	10	10	10	9	9	SE-SW
ARUA	6:00Z	3	3	3	3	2	—	2	2	2	3	2	2	—	—
	12:00Z	—	—	—	—	—	—	—	—	—	—	—	—	—	—
JINJA	6:00Z	5	4	6	5	4	3	2	3	3	3	3	2	4	W-N
	12:00Z	7	7	8	8	7	8	8	7	6	8	6	8	7	SE-SW
KASESE	6:00Z	1	2	2	3	3	2	1	2	2	4	3	2	2	E
	12:00Z	5	5	5	6	4	4	4	5	7	6	6	5	5	NE-SE
TORORO	6:00Z	6	5	7	6	2	5	4	4	4	3	3	5	5	E-SE
	12:00Z	9	7	9	9	5	7	7	7	7	8	6	7	7	SW-NW
GULU	6:00Z	7	6	6	6	5	5	5	6	6	7	7	6	6	E-S
	12:00Z	8	7	7	6	5	5	6	6	7	7	7	8	7	E-SE
MBARARA	6:00Z	1	1	1	1	1	3	2	2	2	2	2	1	2	Calm
	12:00Z	5	8	9	7	12	10	10	9	7	5	4	5	8	E-S
MASINDI	6:00Z	1	1	2	2	2	1	0	1	1	1	2	1	1	Calm
	12:00Z	4	3	4	3	3	3	3	3	3	3	3	3	3	N-E
AVERAGE														5	

Note:

$1ms^{-1}$ = 2 knots

Calm = Indicator Stationary

Z = Greenwich mean time

Wind direction is eight-point campus

Source: Meteorological Department: Ministry of Water, Lands and Environment.

4.2.1.1 Ventilation rate due to wind effect

For a vent pipe of diameter 150mm, the ventilation rate due to wind-effect was calculated from equation 3.

$$Q = C_{v.}Av$$

(3)

Taking $C_v = 0.36$ (for diagonal winds)

$$v = \frac{5}{2} knots = 2.5 knots$$

$$= 1.25 ms^{-1}$$

$$Q = 0.36 x \frac{\pi (0.15)^2}{4} \; (1.25)$$

$$= 7.952 x 10^{-3} \; m^3/s$$

$$= 7.952 x 10^{-3} \; x 3600 \; m^3/hr$$

$$= 28.62 m^3/hr \qquad > 20m^3/hr$$

For a vent pipe of diameter of 100mm (0.1m),

$$Q = 12.72 m^3/hr \qquad < 20m^3/hr$$

4.2.1.2 Ventilation due to Stack (Thermal) Effect

The temperature values substituted in equation 4 were averaged from results in Table 4.4a -4.4c for Kabale and Kisoro and Table 4.4d for Mbarara.

For Kabale and Kisoro

For a vent pipe of diameter 150mm, the ventilation rate due to the thermal effect was calculated from equation 4

$$Q = K \cdot A \sqrt{2 \cdot g \cdot \Delta h \cdot \frac{T_i - T_0}{T_i}} \qquad (4)$$

where

Ambient temperature $T_0 = \frac{20.3 + 20.7 + 19.6}{3}$

$$T_0 = 20.2 \, ^0C$$

$$= 20.2 + 273$$

$$= 293.2 K$$

Vent pipe temperature $T_i = \frac{24.6 + 23.4 + 22.7}{3}$

$$T_i = 23.6 \, ^0C$$

$$= 23.6 + 273$$

$$= 296.6 K$$

$$\Delta h = 3.5m (height \, of \, vent \, pipe)$$

Rate of ventilation;

$$Q = 0.65\,x\,\frac{(0.15)^2\ x\pi}{4}\sqrt{\frac{2\,x9.81\,x3.5\,x\ (296.6-293.2)}{296.6}}$$

$$= 0.010191 m^3/s\ x\,3600\,s/hr$$

$$= 36.7\,m^3/hr \qquad > 20\,m^3/hr$$

For a 100mm diameter vent pipe

$$Q = 4..529\,x10^{-3}\ m^3/s$$

$$= 16.3\,m^3/hr \qquad < 20m^3/hr$$

For Mbarara

$$Q = K \cdot A\sqrt{2 \cdot g \cdot \Delta h \cdot \frac{T_i - T_0}{T_i}}$$

where

$$T_o = 24.6\,^0C$$
$$= 24.6 + 273$$
$$= 297.6\,K$$
$$T_i = 27.7\,^0C$$
$$= 27.7 + 273$$
$$= 300.7\,K$$

$$Q = 0.65\ x\,\frac{(0.15)^2\ x\pi}{4}\sqrt{\frac{2\,x9.81\ x\,3.5\ x\ (300.7-297.6)}{300.7}}$$

$$= 9.664\ x10^{-3}\ m^3/s\ x\,3600\ s/hr$$

$$= 34.8\,m^3/hr \qquad > 20\ m^3/hr$$

For a 100mm diameter vent pipe

$$Q = 4.295\,x10^{-3}\ m^3/s$$

$$= 15.5\,m^3/hr \qquad < 20m^3/hr$$

Though the rates of ventilation due to thermal (stack) effect for temperatures obtained in Kabale/Kisoro and Mbarara were calculated separately, the results obtained in both cases were almost the same.

From the results obtained, the rate of ventilation obtained in a 100mm diameter pipe does not meet the recommended ventilation rate, whereas a 150mm diameter vent pipe was found to be sufficient in all cases.

Table 4.4a:. Temperature values, Wind Direction and Airflow measured in Kabale, Kitumba-Katuna Road

Day		Time	Weather		Temperature (°C)					Air flow
			Wind-direction	Other conditions	A	B1	B2	B3	C	
1st Day	**1. Mst**	09.00	no wind	dull	16.6	19.8	20.8	19.4	20.1	↑
	2. Mst	14.00	E	cloudy	21.6	22.1	24.4	22.7	21.3	↑↓
	3. Mst	19.00	no wind	dull; sun set	19.5	21.2	23.8	22.3	21.1	-
2nd Day	**4. Mst**	09.00	no wind	dull	17.7	19.7	20.2	19.6	19.8	↑
	5. Mst	14.00	no wind	cloudy, sunny	25.1	23.7	25.9	23.1	22.5	-
	6. Mst	19.00	no wind	clear, sun set	16.8	20.4	21.5	20.8	20.4	-
3rd Day	**7. Mst**	09.00	no wind	dull	17.6	19.3	20.2	19.0	19.4	↑
	8. Mst	14.00	E	cloudy	22.2	21.7	24.0	22.4	21.1	↓
	9. Mst	19.00	no wind	dull; sun set	19.2	21.1	23.2	22.0	21.1	-
	Average				**19.6**		**22.7**			

Table 4.4b: Temperature values, Wind Direction and Airflow recorded in Kabale, Nyabikoni-Rutenga

Day		Time	Weather		Temperature (°C)					Air flow
			Wind-direction	Other conditions	A	B1	B2	B3	C	
1st Day	**1. Mst**	09.00	no wind	sunny, cloudy	21.7	20.5	21.2	-	20.0	-
	2. Mst	14.00	SE	sunny, cloudy	25.1	25.4	26.2	-	25.1	↑↓
	3. Mst	19.00	no wind	cloudy, sun set	20.0	24.1	24.6	-	24.1	-
2nd Day	**4. Mst**	09.00	no wind	dull	15.8	20.3	18.2	18.0	20.2	↑
	5. Mst	14.00	S	cloudy, sunny	24.2	25.7	27.2	22.0	24.2	↑↓
	6. Mst	19.00	no wind	Clear, sun set	18.7	23.3	24.6	22.7	23.3	↑
3rd Day	**7. Mst**	09.00	no wind	dull	16.0	19.5	18.7	18.2	19.9	↑
	8. Mst	14.00	no wind	sunny, cloudy	24.7	25.3	24.7	21.9	25.5	↑↓
	9. Mst	19.00	S	clear, sun set	20.3	23.9	24.9	23.4	23.7	↑↓
	Average				**20.7**		**23.4**			

Source: Felix Groth, 2004

Table 4.4c: Temperature values, Wind Direction and Airflow recorded in Kisoro, Karumena Village

Day		Time	Weather		Temperature (°C)					Air flow
			Wind-direction	Other conditions	A	B1	B2	B3	C	
1st Day	**1. Mst**	09.00	E	dull	20.5	18.7	22.5	19.6	18.5	-
	2. Mst	14.00	SE	cloudy	21.9	19.7	25.1	20.7	19.3	↑↓
	3. Mst	19.00	no wind	clear; sun set	17.8	21.0	24.3	21.0	20.3	-
2nd Day	**4. Mst**	09.00	E	cloudy	17.5	18.2	20.4	18.4	18.7	↑↓
	5. Mst	14.00	SE	sunny; cloudy	23.2	21.8	28.3	23.5	21.0	↑↓
	6. Mst	19.00	SE	cloudy, sun set	17.8	22.0	22.8	21.6	21.1	↓
3rd Day	**7. Mst**	09.00	SE	sunny	19.2	18.4	21.9	18.4	18.5	↑↓
	8. Mst	14.00	SE	sunny; cloudy	25.3	23.9	31.0	25.4	22.5	↑↓
	9. Mst	19.00	No wind	cloudy, sun set	19.3	22.5	25.5	22.5	22.3	-
	Average				**20.3**		**24.6**			

Table 4.4d: Temperature values, Wind Direction and Airflow measured for the Enviro loo in Mbarara, Rwebikoona Market

Day		Time	Weather		Temperature (°C)				Air flow
			Wind-direction	Other conditions	A	B1	B2	D	
1st Day	**1. Mst**	09.00	E	sunny	22.1	20.0	20.8	-	↑-
	2. Mst	14.00	SE	sunny	28.3	27.9	29.2	32.3	↓
	3. Mst	19.00	no wind	clear; sun set	24.2	22.3	25.9	23.1	↑
2nd Day	**4. Mst**	09.00	E	sunny	21.8	21.5	23.5	28.2	↓
	5. Mst	14.00	SE	sunny	28.0	27.1	28.1	31.6	↓
	6. Mst	19.00	SE	cloudy, sun set	23.70	24.7	25.5	22.8	↑↓
3rd Day	**7. Mst**	09.00	SE	cloudy	22.7	21.8	22.9	24.3	↓
	8. Mst	14.00	SE	Cloudy, sunny	27.2	27.0	28.5	36.0	↓
	9. Mst	19.00	No wind	cloudy	23.4	22.4	25.8	23.3	↓
	Average				**24.6**		**25.58**	**27.70**	

Legend:

↑ Up, from processing chamber
↓ down, from user chamber to processing chamber
↑↓ Reversing air flow

A – Ambient Temperature
B1 – User Chamber temperature measured directly above squatting pan
B2 – User Chamber temperature measured 1.8m vertically above squatting pan
C – Temperature of air in the vault
D – Temperature of air in the vent pipe

Source: Felix Groth, 2004

4.2.2 Design and Sizing of the Vaults

Volume required for each vault, V in m^3 was calculated from:

$$V = N * n(F + A + U)/1000$$

where N = 8 users

n = 10 months (5/6 years)

F = 50 litres of fresh faeces

A = 50 litres

U = 0 litres (since urine is diverted)

The vault was also assumed to be filled to 0.8 of the total height of the vault.
Initially faeces have moisture content between 60 and 75% (Esrey *et a*l, 2001).
Taking a higher value of 75% and assuming by the time the vault fills at least 20% of the average moisture has been removed due to the modified system, then the final moisture content is 55%.
Volume of each vault, V in m^3 is calculated from:

Then actual Volume of faecal matter at the time of filling the vault =155/175 * 50 = 44l

Therefore V= 8*10/12 *(44 +50+0)/1000= $0.63m^3$

Volume of designed vault = 0.6* (0.8*1)*1.40

= $0.72m^3$ > 0.63m3- Therefore, size is adequate

$$V = N\,x\,n\,(A+F+U)$$

$$F = \frac{155}{175}\,x\,50\ l$$

$$= 44\ l$$

Therefore, the required volume for each of the vaults;

$$V_{required} = 8p\,x\frac{10}{12}yrs\,x\frac{(44+50+0)\ l/p/yr}{1000kg/l}$$
$$= 0.63m^3$$

Volume of designed vault

$$V_{design} = 0.6\,x(0.8\,x1)\,x1.40$$
$$= 0.72m^3 \qquad > V_{required} = 0.63m^3$$

Therefore, the volume of the designed vaults is adequate to meet the demand for a family of 8 people.

4.2.3 Design of Vault Walls

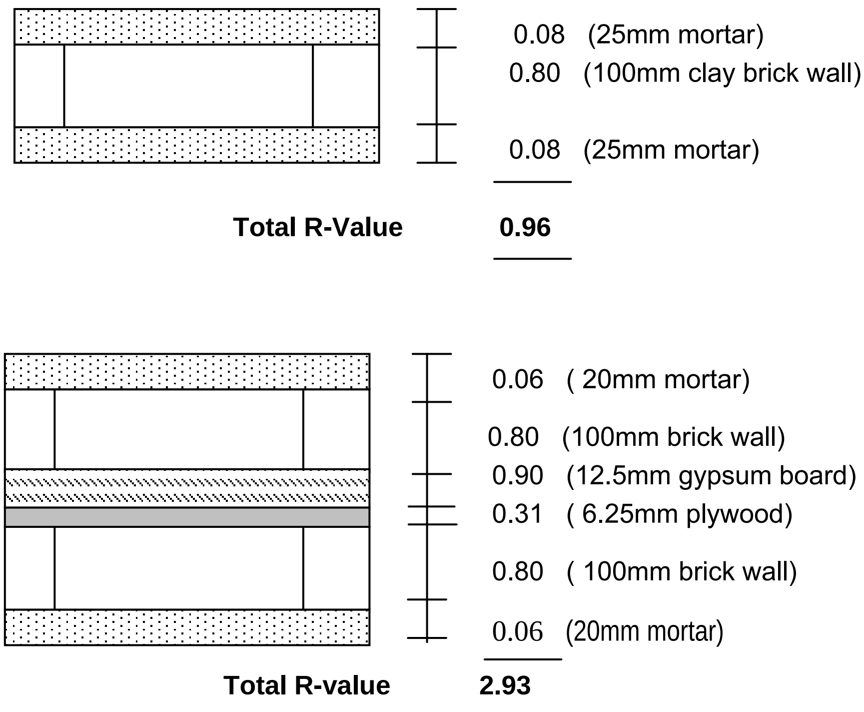


Figure 4.7: Cross-section through the vault walls of the old and new design showing the corresponding R-Values

From the results of R-value calculated above, by using a double vault and incorporating Gypsum board and plywood as insulators, the insulation capacity of the vault walls is tripled. This implies that an amount of heat lost in a given time through the walls of the old design will take three times the time, to be lost through the new design.

It is important to ensure air-tightness of the whole structure, but most importantly the vault walls because this greatly affects air movement through the structure will in turn affect performance of the system , for example as far as controlling odour in the structure is concerned.

The vaults should also be watertight, to minimise water entering into the vaults from outside. Therefore, the materials for the vaults should not be compromised and the covers should be fixed in such a way to ensure that no water will finds its way through the vault openings into the vaults.

4.2.4 Vault Doors

One-way glass was selected for the vault doors, with the glass allowing in sunlight into the vaults and limited quantities in the reverse direction. The material was selected after studying the conditions that would be necessary to maximise the temperature in the vault which were found to be; allowing in as much direct sunlight as possible and preventing the loss of heat.

However it is important to note that glass in such a vulnerable material because it is susceptible to damage. In instances where there are high chances of being vandalised, the glass can be protected by some kind of wire mesh, to shield off potential large damaging objects like stones, but at the same time allowing in sunlight through to the glass.

4.2.5 Rotary Turbine vent

The rotary turbine vent was locally fabricated from Aluminium. The rotary turbine vent 265mm high with a maximum diameter of 340mm, had a throat diameter of 155 mm and 16 blades and rotating on two vertically aligned ball bearings on a stainless steel rod.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

From the study done, the following conclusions were reached

- With the exception of the Enviro-loo, which incorporates some kind of mechanical ventilation, all the Ecological Sanitation units visited were operating purely on Natural Ventilation. However most their ventilation systems were poorly designed and many a time there was no flow recorded in the vent pipe, especially in cases where the vent pipe size was too small. The importance of vent pipe size and control air movement to improve performance, is yet to be appreciated

- After all considerations in this study, it was found necessary to a vent diameter of at least 150mm. Diameters larger than 150mm achieve even better results. Incorporating a rotary vent turbine to will greatly increase the rate of extraction of water evaporated from the vaults.

- Another factor that would accelerate drying was the use of one way glass for the vault doors, to allow in as much direct sunlight as possible into the vault and limited quantities in the reverse direction, while ensuring that the amount of heat lost through the vault walls is reduced by providing insulating material for the external vault walls.

- If optimum accelerated drying is to be realised, the cost implications cannot be overlooked. However depending on the economic status of an individual user or community, the proposed improvements in the design can be carefully selected to achieve an increased rate of drying to some extent, without necessarily having escalated prices.

5.2 Recommendations

- The design should be redone with the temperatures recorded over a period of at least one year, so that sizing of the vent pipe can be done to serve adequately even during the seasons when the lowest ventilation rates would be achieved

- In order to test the applicability of the suggested designs, it should be incorporated in the current ecological sanitation facilities and a prototype be made. Further research should then be carried out to monitor the performance of the improved design and compare with the existing design, considering factors that needed to be improved before this study was initiated.

- The minimum vent pipe diameter size should be 150mm. However if a steel pipe is not used, a plastic material manufactured black for example Poly Ethylene or Polyvinyl Chloride should be used to improve absorpativity. The vent pipe should also be located on the outside of the Ecosan unit to maximise the surface area exposed to the sun

- The rotary vent turbine should be designed using a conventional scientific procedure, putting into consideration the necessary parameters.

REFERENCES

1. Agrawal, K. C, 1993, "Environmental Biology" 1st Edition, Annees Offset Press, New Dehli.
2. Arch-hku-Department of Architecture -University of Hong Kong, Lecture notes on Air Movement and Natural Ventilation. **http://www.arch.hku/teaching/lectures/airvent/sect.03.htm**, created August 2001, accessed 20th March 2004.
3. ASHRAE Standards for Adequate Ventilation Rates and Contamination Levels
4. Balthazar Lorenza *et al,* 1992 "Energy Conservation in Construction and Design: Exterior Wall Insulation, " Louisiana, USA. **http://www.leeric.lsu.edu/bdbb/7/ecep/Constr/b/t/htm**, accessed 11th May 2004.
5. Birdie, G. S. and G.S. Birdie, 1998, "Water Supply and Sanitation Engineering, "6th Edition, Dhanpat Rai Publishing Company, New Dehli.
6. Chapman, J. L., 1992, "Ecology: Principles and Applications," 1st edition, University Press, Cambridge.
7. Esrey Steven *et al*, 1998, "Ecological Sanitation," SIDA, Stockholm.
8. Esrey Steven *et al*, 2001, " Closing the Loop: Ecological Sanitation for Food Security, " SIDA, Stockholm. **http://www.undp.org/water/docs/closing_the_loop.pdf**, accessed 2nd April 2004.
9. Feachem Richard G., J. D. Bradley, H. Garelick and D. Duncan Mara, 1983, "Sanitation and Disease; Health Aspects of Excreta and Wastewater Management, " 1st edition, John Wiley and Sons, New York.
10. Habitat for Humanity, 1999, "Buildings for the 21st Century: Wall Insulation." **http://www.energystar.gov/ia/home_sealing/WallInsulation-DOE.pdf**, created February 2000, accessed 11th May 2004.
11. Kumar, H. D., 1992, "Modern Concepts of Ecology, " 7th Edition, Vikas Publishing House, New Delhi.
12. La Trobe Brian and G. La Trobe, 2003, " An effective Dry sanitation System- the Enviro Loo, " Proceedings, Second International Symposium on Ecological Sanitation Incorporating the first IWA Specialist Group Conference on Sustainable Sanitation, Lübeck, Germany.
13. Liddament Martin W., 1996, "A guide to Energy Efficient Ventilation," 1st edition, AIVC Publications.
14. Lowndes Stephen, 2000 "Optimising Natural Ventilation using a Wind Turbine" **http://www.buildenergy.com/solarchimney.htm**, accessed 21st April 2004.
15. Mann, H. T. and D. Williamson, 1982, "Water Treatment and Sanitation," 3rd edition, Russell Press Ltd, England.
16. Moe Christine and Izurieta Ricardo, 2003, "Longitudinal Study of Double Vault urine Diverting Toilets in El Salvador" proceedings, Second International Symposium on Ecological Sanitation Incorporating the first IWA Specialist Group Conference on Sustainable Sanitation, Lübeck, Germany
17. Niwagaba Charles, 2003, "Public Health Engineering Lecture Notes," Kampala, Uganda
18. Parmley Robert et *al*, 1988, "HVAC Field Manual, " MacGraw-Hill, New York, USA
19. Rashid D. and Ahmed N. A., 2004, "Aerodynamic Forces on a Rotating Wind Turbine," Wind Engineering Journal. Volume 27. **http://www.multi-science.co.uk/windeng.htm** , accessed 24th March, 2004.
20. Sharma, R. S., 1995, "Environmental Energy Resources, "Common Wealth Publishers, New Dehli.
21. UNDP, 2003, "Sustainable Water Management: Ecological Sanitation," **http://www.undp.org/seed/water/ecosannew.htm** , accessed 10th April, 2004

APPENDIX A

- Cost Estimates
- Sample Questionnaire
- Sample Checklist

Cost Estimates for a household ecosan with improved ventilation

Item	Description	Unit	Quantity	Rate	Amount
1	SUBSTRUCTURE				
1.1	Excavation Excavate oversite average depth 150mm to remove the vegetable soil and deposit in heaps 300m away from site in an appropriate place	m^2	5	500/=	2,500/=
1.2	Hardcore Filling Lay, compact and level well approved hardcore bed 200mm thick, blinding with 50mm sand	m^2	5	3,000/=	15,000/=
1.3	Damp proof membrane 500 gauge horizontal polythene sheeting laid with 300mm laps as joints	m^2	5	1500/=	7,500/=
1.4	Plain concrete mix 1:3:6 in 150mm oversite concrete	m^3	0.5	100,000/=	50,000/=
1.5	Brick Wall in cement mortar (1:4) Erect 140mm thick brick wall up to a height of 100m, leaving provisions for solar heaters	m^2	12	5000/=	60,000/=
1.6	External wall Insulation Provide and fix ¼ " plywood sheeting and½ " gypsum board for insulation between the vault walls	Pcs pcs	1.5 1.5	25,000/= 35,000/=	37,500/= 52,500/=
1.7 1.7.1 1.7.2	Sawn formwork to Sides and soffites of slab Sides of foundation	m^2 m^2	4 1	1,000/= 1,000/=	4,000/= 1,000/=
1.8	Vibrated reinforced Concrete grade 20 (1:2:4) in 150mm thick slab, leaving provisions for squat hole.	m^3	0.5	170,000/=	85,000/=
1.9	Reinforcement bars to BS4449 as described in reinforced concrete slab 10mm diameter cold worked square twisted bars at 150 c/c including bends, hooks, binding wire in beam	Kg	25	1,700/=	292,500/=
	Total Carried to Collection				607,000/=
2	SUPERSTRUCTURE				
2.1 2.1.1	Brick Wall in cement mortar (1:4) Erect 140mm thick brick wall up to lintel and the steps	m^2	16	5,000/=	80,000/=
2.1.2	Erect 140mm thick brick wall above lintel	m^2	2	5,000/=	10,000/=
	Fill Fill for steps with murrum, compact fully to receive blinding	m^3	0.4	7,000/=	2,800/=
	Sawn formwork to Sides and soffites of reinforced concrete lintel Sides of steps	m^2	1	1,000/=	1,000/=
	Reinforced concrete 1:2:4 in: 150mm reinforced concrete for the lintel	m^3	0.2	170,000/=	34,000/=
	Reinforcement bars to BS 4449 as described in reinforced concrete lintel 8mm cold worked square twisted high yield steel bars including bends and hooks to approval 6mm mild round steel links at 150 c/c ditto	Kg Kg	4 1	1,700/= 1,700/=	6,800/= 1,700/=
	Total Carried to Collection				136,000/=

Item	Description	Unit	Quantity	Rate	Amount
	ROOF				
	Sawn approved hardwood And Softwood as described 100mm x 50mm Timber purlins 100mm x 50mm Timber rafters 100mm x 75mm wall plate 200mm x 25mm fascia board Hoop Iron Roofing nails	 pcs pcs pcs pcs Kg Kg	 2 2 1.5 2 1 2	 3,500/= 3,500/= 3,500/= 4,000/= 5,000/= 1,500/=	 7,000/= 7,000/= 7,000/= 8,000/= 5,000/= 3,000/=
	Galvanised corrugated iron sheeting as described Roof with GI corrugated sheets gauge 28	 pcs	 3	 15,000/=	 30,000/=
	Total Carried to Collection				37,000/=
	FINISHES				
	Cement Sand (1:4) plaster as described Plaster the internal and external walls of the vaults and the room	m^2	37	2,700/=	99,900/=
	Cement-sand screed (1:3) as described 25mm cement : sand screed 1:3, finish to the floor of room and vault	m^2	7	2,500/=	17,500/=
	Solar Heaters comprising of one-way glass; Provide and fix solar heaters consisting of one-way glass (800x700) 6mm thickness with proper frame, ensuring water tightness	No.	2	75,000/=	140,000/=
	Supply and fix hard timber shutters 800x2000 Match bodied timber door all finished for vanishing the door and a frame	No	1	50,000/=	50,000/=
	Plumbing Provide and fix plastic squatting pans 11/2 " UPVC Blue Plumbing Pipes 11/2 " PVC Tees	 No. m No.	 2 2 2	 30,000/= 5,000/= 2,500/=	 60,000/= 10,000/= 5,000/=
	Provide and fix vent pipes and rotary turbine vents 150mm diameter, install such that it protrudes 25mm below the soffit of the concrete slab and 800mm above roof and apply two coats black bituminous paint to pipes Aluminium Rotary turbine vent, with throat diameter 155mm with frictionless ball bearings	No. No.	2 2	25,000/= 60,000/=	50,000/= 120,000/=
	Total Carried to Collection				552,400/=
	SUMMARY				
	SUBSTRUCTURE				607,000/=
	SUPERSTRUCTURE				136,000/=
	ROOF FINISHES				37,000/= 552,400/=
	Add 8% Contingencies				106,600/=
	GRAND TOTAL				1,439,000/=

RESEARCH QUESTIONNAIRE

The purpose of this research questionnaire is to investigate the performance of the current Ecological Sanitation systems, what affects their performance and establish how the performance can be improved, specifically as regards the ventilation system in achieving accelerated drying. The target groups for this research questionnaire are; the household, institutional and communal Ecosan toilet users.

Accelerating the rate at which faeces in the processing chambers dry up will lead to shorter retention periods of the faecal matter before it can be used for agricultural purposes or disposed off and it would also greatly reduce the odours in the Ecosan systems. A shorter retention period would also imply smaller sizes of the Ecosan units an hence a reduction in the overall cost of ecosan toilets

Therefore your co-operation will be highly appreciated, as the results of the research will be beneficial to the households and the community at large

Household /Institution/location Name

A. Interviewees using communal/Institutional Ecosan toilets

a) Do you like the idea of using Ecosan Communal toilets? ---------------------------------

b) Why did you welcome the system in the first place? ___________________________________

----

c) How man people /families use the ecosan facility? ______________________________________

d) How many people in your family use the facility? ______________________________________

e) Are there alternative sanitation systems being used? ___________________________________

f) If yes, what are they? ____

g) Which of the mentioned systems is used more often?

h) Any idea why? --

B. Interviewees using Household Ecosan toilets

a) Why did you welcome the system in the first place? _____________________________________

----

b) How many people are you in the family? ____

c) How many members use the ecosan facility? ____

d) If not all, why? ____

e) Are there alternative sanitation systems being used?

f) If so, mention these ____

g) Which of the mentioned systems is used more often and why? ____________________________

C. General. For all Interviewees

a) Any operation and maintenance problems associated with Ecosan facilities?
b) **If yes,** what are they?

----
c) What do you suppose are the causes of these problems?

----
d) How can they be solved?
----
e) How long does it take you to fill one vault?
----
f) Do you use the urine and the sanitised faecal matter?
g) **If yes,** i) for what? --

ii) Who is removes it and who uses it? --
----
h) **If no,** what do you do with it?
----
i) How long do you retain the material prior to use? ---------------------------------------
j) Do you consider this retention period long? --
k) How many stances does the ecosan unit have? ---------------------------------------
l) What was the total cost of the ecosan unit?--

CHECKLIST

Checklist for the dimensions of different components of the ventilation, performance indicators and some parameters necessary in the design of a ventilation system

Household/Institution name (if applicable) --

Sex and name of Interviewee --

Area/Zone /Parish --

1. Dimensions of vent pipe, location and Positioning

Diameter of pipe ------------------------------

Height of pipe above roof ------------------------------

Location of vent pipe ------------------------------

2. Materials used in construction

Roof ---

Walls (Superstructure) --

Vent pipe --

Substructure (vault walls) -------------------------------------

Vault Doors (covers) --

3. Operation and operational problems

Urine diverting ---------------- Non-Urine diverting ------------------------------------

Odour in system ---------------------------------

Any obstacle affecting circulation of air? --

Is vent pipe straight or bent? ----------------------

Water-tightness at location of vent pipe in roof --

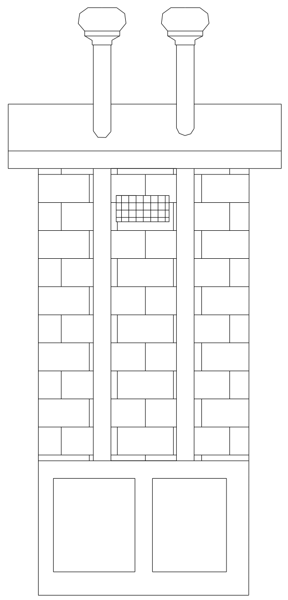
4. Weather

Wind direction ---

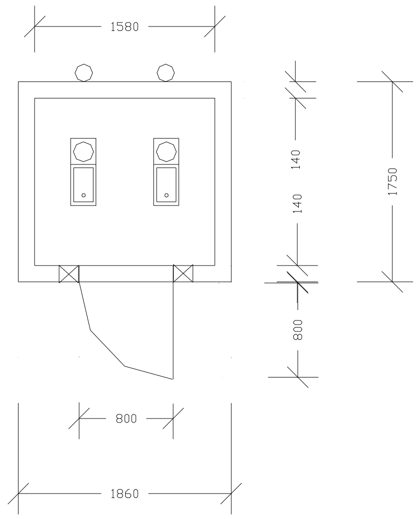
General weather condition ---

APPENDIX B

- Design Drawings
- Drawings for the model



REAR ELEVATION



FLOOR PLAN

General Notes

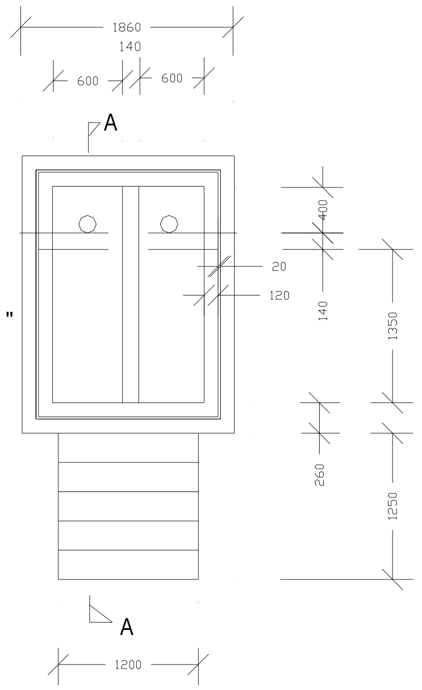
1) All dimensions are in mm
2)Concrete slab reinforced with 10mm diameter bars @150mm c/c
3) Timber match- boarded Door: 800 x 2100
4) Gypsum and plywood may be to a height of 0.85m
5) Rotary turbine vent 150mm throat diameter to manufacturers specifications
6) Prepare and apply two coats black bituminous paint to mild steel vent pipe

Roof Notes

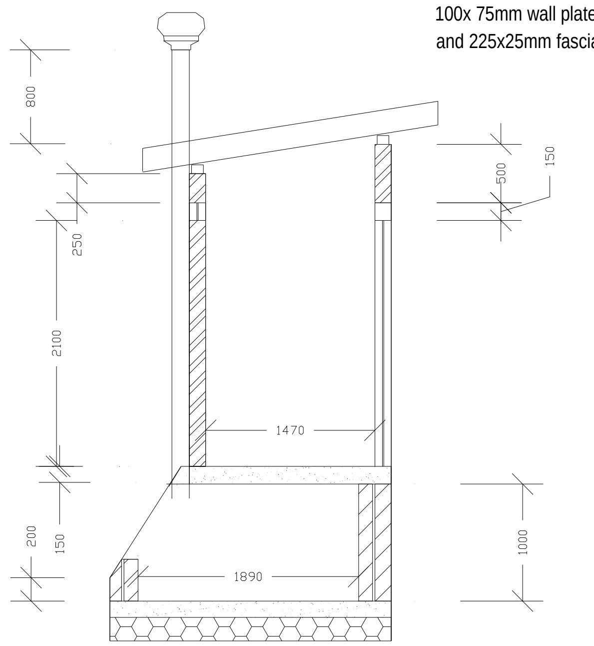
Roof pitch 9.5°
G.I. sheets gauge 28
with matching ridges on
100x50mm Timber purlins on
100x50mm Timber Rafter on
100x 75mm wall plate
and 225x25mm fascia board

150mm mild steel vent pipe
with 150mm-throat aluminium
rotaty turbine vent with 16 blades

$\frac{1}{2}$" gypsum board and $\frac{1}{4}$" plywood between the walls



2No. one-way glass with
watertight frame
(800 x 700)



Foundation Notes

50mm thich cement/sand screed on
100mm site concrete mix (1:3:6) on DPM
50mm blinding on
200mm well compacted hardcore filling on firm ground

SECTION A_A