

SOPAC

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SOPAC Miscellaneous Report 249

DESIGN EXAMPLES OF WATERLESS COMPOSTING TOILETS

"Compost toilets consume no water, pollute no water and allow nutrient recycling; they must have a place in the future". - P.D. Chapman, 1995.

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INTRODUCTION

Some Thoughts on Sanitation and the Environment

"The Western type of toilet system cannot solve the problem of getting rid of excreta in Third World countries. Nor, indeed, has it solved those problems in the developed world.

The Western system is expensive. It uses large amounts of clean water to flush away a small amount of excreta. It dirties streams, lakes and groundwater. For the large majority of people who still have no piped water, such a system is not even something to consider".

Winblad and Kilama, 1985

"..... the conventional approach has primarily meant using water to carry wastes out of sight - through reticulated sewage systems to centralised treatment facilities, into decentralised septic systems and leach fields, or into the ground directly through simple water-sealed toilets."

"About half of the nutrients flowing into the oceans is the result of raw or partially treated sewage discharged directly into coastal waters or carried there indirectly via rivers and streams and through seepage from septic systems and other failing or inadequate land-based treatment methods."

Rapaport, 1996

"..... the disadvantages (of wet systems) mainly stem from the mobility given to the toilet waste by the water. The water might conveniently remove the waste from the toilet room but it is then difficult to contain and can easily spread both nutrients and pathogens to pollute valuable water supplies. It also means that often scarce potable water is wasted in that process".

Bencke, 1996

Some Descriptions of Composting latrines to Give an Idea of How they Work

A composting latrine is a sanitation facility in which suitable conditions for the composting process are carefully induced with the purpose of producing a compost as the end product, which has a good fertiliser value and can be applied on agricultural land, (Dharmabalan, 1988).

Waterless biological toilets, also known as 'composting toilets', use natural aerobic soil organisms to transform human excrement into a harmless residual called humus, inside an enclosed container, (Rapaport, 1996).

In this latrine, excreta fall into a watertight tank to which ash or vegetable matter is added. If the moisture content and chemical balance are controlled, the mixture will decompose to form a good soil conditioner in about four months. Pathogens are killed in the dry alkaline compost, which can be removed for application to the land as fertiliser, (Franceys, R. et al, 1992).

A composting toilet is a sanitation technique that is capable of converting excrement and organic material into a leafy or soil like material that has a pleasant earthy odour, and which can be safely disposed of in the environment after adequate time has passed for composting, (Crenan, 1995).

Some Advantages and Disadvantages

Advantages

Requires little or no water, an advantage in water short and pollution prone small islands.

Composting toilets ... need no sewer hook-up, septic system, or plumbing, (Chaplin, 1993).

Aerobic digestion of wastes using naturally produced heat reduces unpleasant odor and increases pathogen die-off. Aerobic digestion has potential for reduction of nitrogen and reduction in leachate by evaporation.

..... arguably the most environmentally sound treatment technology for human excrement ...,
(Rapaport, 1996).

Groundwater contaminations is prevented if there is no waste water discharge.

Produces a valuable humus - compost/soil conditioner. The value of the fertiliser (N.P.K.) is estimated at US\$10 per person per year.

Research is needed to document the reliability of processes and operational requirements in various situations.

Disadvantages

- Behaviour - some people are :-
- reluctant to use content for agricultural purposes
 - reluctant to touch or convey own faeces to a new site

Careful operation is essential. Ash or vegetable matter has to be added regularly.

Compost could be a health hazard if it is removed before decomposition is complete.

It may be necessary to collect urine separately. The high nitrogen content and zero pathogens make urine a good fertiliser suitable for immediate use.

If it is necessary to construct the toilet collection chamber above ground for good ventilation and easy access to remove compost, the structure may be considered unsightly and obtrusive.

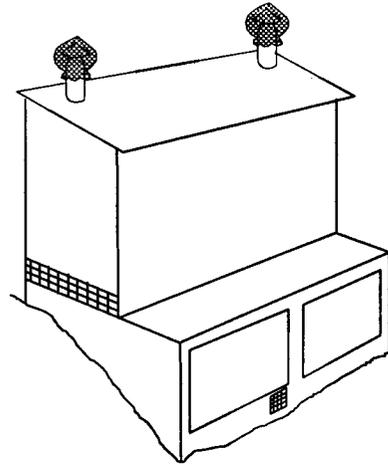
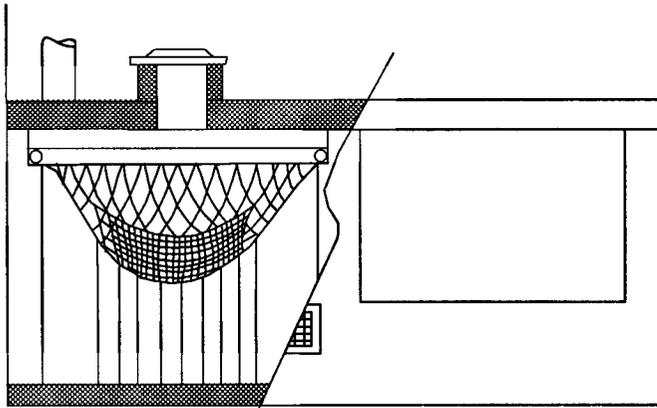
Access, via steps or a ramp, can be a problem for the elderly or disabled.

Insect breeding in the chamber can become a problem if the toilet lid is not kept down and other ventilation and access openings are inadequately sealed against insects.

Some versions of composting toilets may be too expensive for some island people to afford.

SOME EXISTING DESIGNS THAT DEMONSTRATE THE USE OF COMPOSTING TOILETS

The Center for Clean Development, (CCD), Toilet



Source: Rapaport, D. 1996

Rear view of a modified "coffee maker" CCD toilet showing cut-a-way of one digestion chamber. In this version of the design, the net for separating solids hangs from a plastic pipe frame for easy removal when decomposition is complete. In the original design, as shown in Figure 1, the net hangs from hooks and can not be removed as easily.

Rear view of the modified "coffee maker" CCD toilet featuring net suspended from a plastic pipe frame in each digestion chamber for easy removal of composted solids. Note the large surface area on the ventilation exhaust pipes to avoid constricting air-flow.

An aerobic Double Vault Composting Toilet, (DVC), for tropical environments that achieves zero-discharge sanitation with low maintenance requirements.

What distinguishes the CCD toilet from other DVC toilets is that it is designed to promote aerobic conditions in the digestion chambers without the need for manual turning. Excreta falls on a mat woven from coconut palm fronds resting on top of a nylon fishing net suspended inside the chamber, separating liquids from solids. The false floor allows air to penetrate the compost pile from all sides.

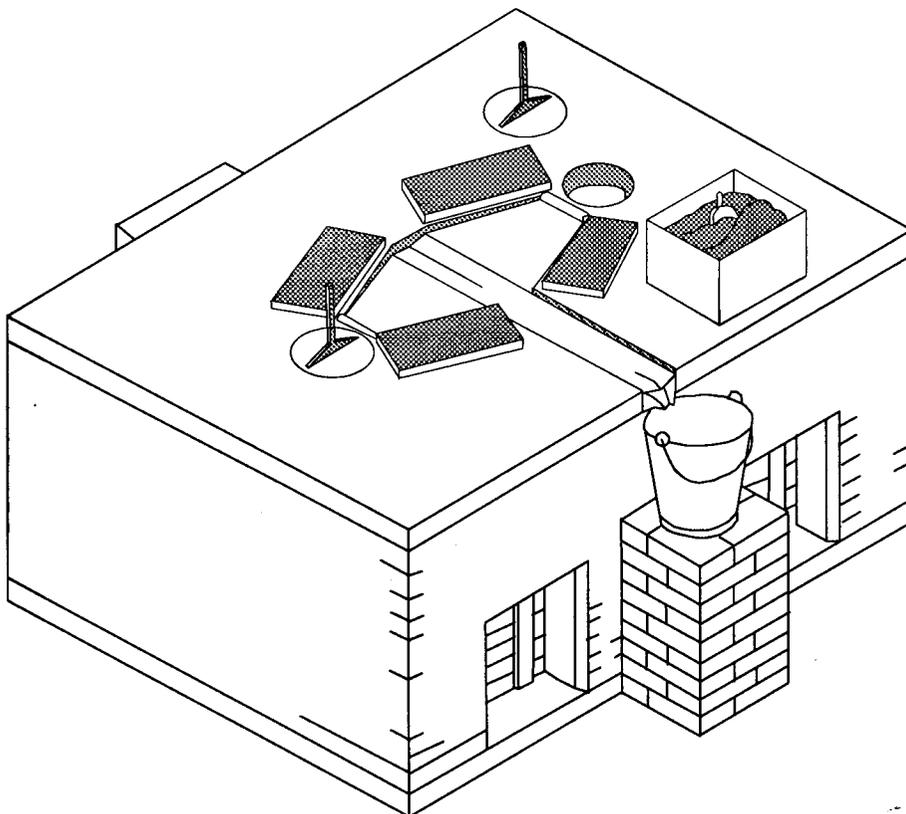
A large vent draws air up through the pile from an air intake below the net along the rear wall of the chamber. Airflow evaporates the liquid on the floor and on the "wicks", made from strips of polyester or rayon fibre, hung from the net.

Evaporation and biological processes are assisted by painting the pipe and chambers black and positioning the unit in an exposed position. The toilet seat is kept covered and the intake and vent pipe insect screened, with a large area to allow air to flow.

To start, organic matter is placed on the mat with some garden soil to inoculated the chamber with aerobic microorganisms.

When almost full the alternative chamber is used.

The Vietnamese Compost Latrine



Source: Rybczynski, W. et al. 1982

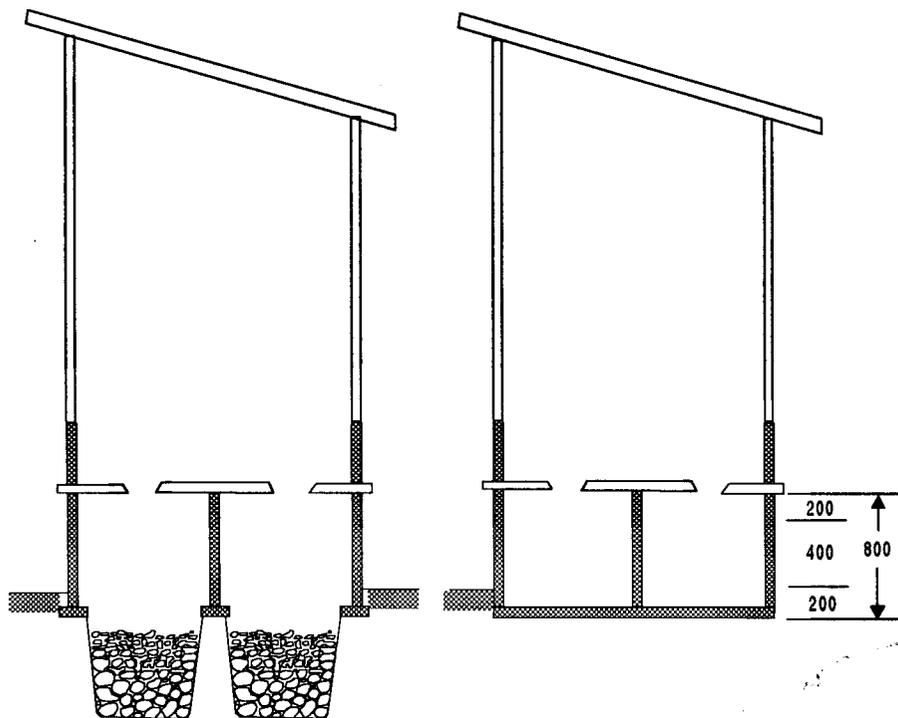
A double septic bin design having two small vaults of about 0.3 m³ capacity. The bins are emptied about every 45-60 days. They are built entirely above ground level on an impermeable base.

Urine is separated. It is drained away through a special channel in the squatting slab. It is diluted and used as a liquid fertiliser or disposed of in a soakaway.

Wood ash is sprinkled on the contents after use. When 75% full the vaults are sealed, after filling the space above the excreta with dry soil.

The product is removed via two small doorways. Not enough time is available to destroy all pathogens. These toilets are used extensively in Vietnam, but are now being discouraged by UNICEF in Hanoi because of the danger of spreading pathogens from undigested compost. The compost produced is less hazardous than the raw excreta used in agriculture before the introduction of the toilets. These toilets are also used as overhung latrines over fish ponds.

The African Batch Compost Latrine



Open-bottom compost latrine

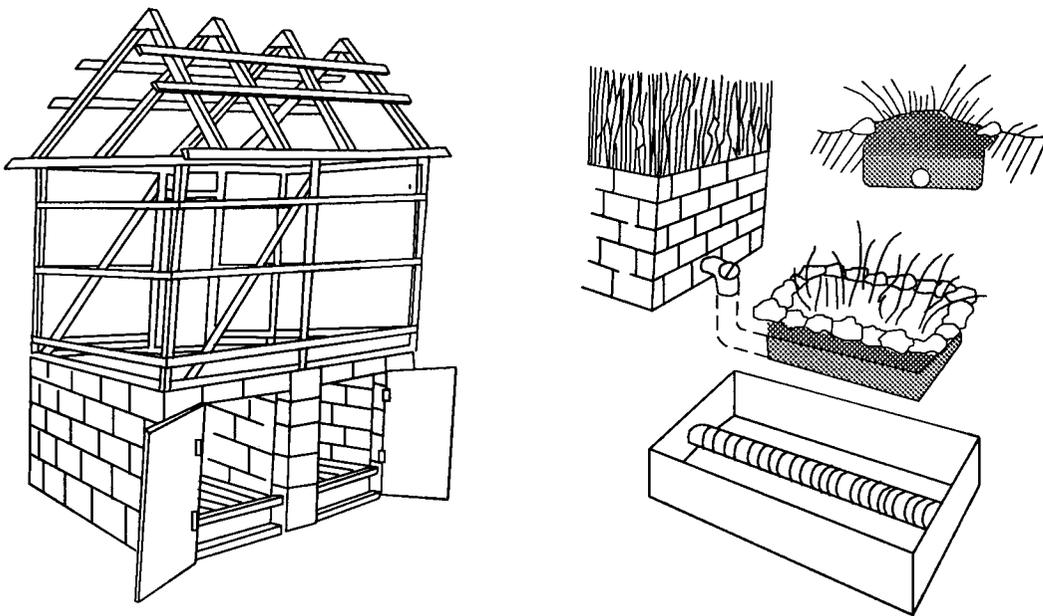
Closed-Bottom compost latrine

An early double vault batch compost latrine. It may have permeable or impermeable bases to the vaults. Vault sizes are designed to give at least one year's use before it reaches 75% full and is "retired".

These toilets are used in many parts of Africa. They do not exclude urine, (because of the prevalence of urinary schistosomiasis). Compost piles rarely get above 50°C.

They may have a concrete base slab, with walls of concrete blocks or brickwork. The cover slabs are generally made of reinforced concrete.

The Kiritimati Alternating Batch Latrine with ET Trench



Source: Crennan, 1996

Based on an owner-built design used in Australia.

Consists of two chambers with sides approximately 1 m x 1 m x 1 m. Chambers each have a floor grate with a drainage tray below. The drainage tray has a 50 mm outlet from 25 mm above the base, therefore there is a standing liquid level. Chambers have two hinged doors, with mesh covered vent holes in them for the entry of air and to seal against flies. Each chamber has a vent pipe which extends 1.5 m above the roof of the building.

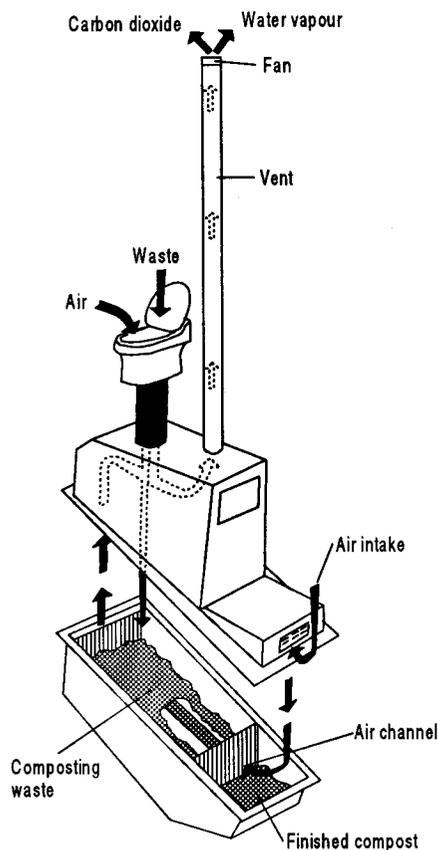
A pedestal or squat plate is rotated between the two chambers. As each chamber fills and is closed off, the plate or pedestal is moved to the other one.

The top slab forms the floor of the toilet building. Access stairs or a ramp are needed. The toilet can have traditional or non-traditional wall-cladding or roofing materials.

Liquids overflow to an evapotranspiration trench, 2 m long, 600 mm wide and 500 mm deep with a durable plastic liner such as HDPE, on a bed of coral aggregate, (to deter crabs from burrowing underneath), backfilled with coral aggregate around the slotted pipe and filled in the top 200 mm with sand. The top of the trench is then planted with appropriate indigenous species.

Approximate costs are \$2000-2500 AUD.

The Clivus Multrum



Design originated in Sweden over 50 years ago.

Alternative sizes are CM8, CM20, CM40, CM60. The number represents the number of uses x 1000 per year, e.g. CM8 = 8000 uses per year, for a small family home.

A continuous system with a single container. Excreta is deposited at the top of the bin, and slides down the inclined base to be emptied from the "end-product" chamber in a composted form.

Wastes accumulate in the tank along with carbon rich material added for bulk, (wood shavings, lawn clippings, leaves, sawdust and other biodegradables). All the materials decompose together in the tank's oxygen rich environment. Baffles and air channels in the tank control air flow to aerate the pile and accelerate decomposition.

A small fan, (can be solar photovoltaic system), in the vent pipe draws off odour continuously.

Decomposed wastes will be reduced by 95% of the original volume.

Disadvantages - sometimes blocks and needs raking to move material down the bin.

Commercial Alternating Batch Latrines

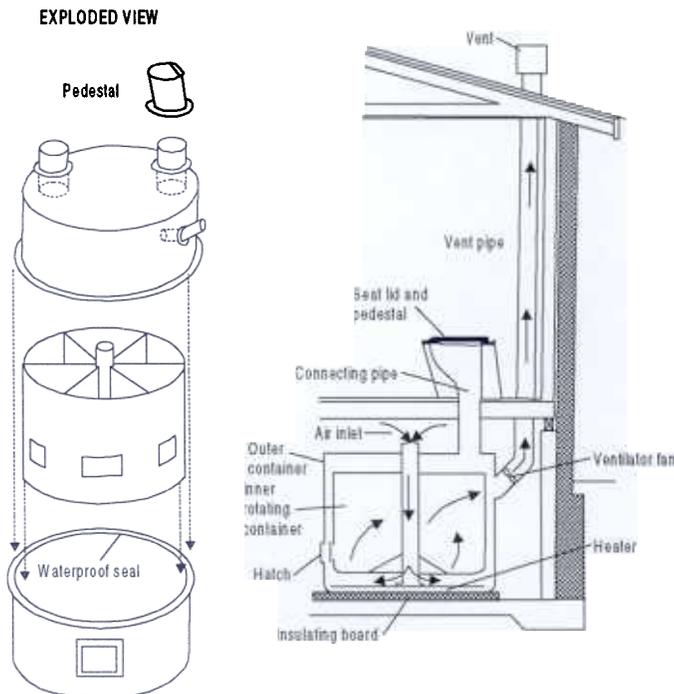


Diagram of the Rota-Loo biological toilet.

Commercial prefabricated alternating batch systems using two to eight containers. Allows a period of time for the composting process to take place.

Commercial makes include Rota-Loo, Vera Carousel, Nature-Loo

SOME DESIGN CONSIDERATIONS

Components the system needs:-

- an adequately sized container,
- ventilation, preferably a heated air flow, to assist decomposition and reduce odor,
- a good air flow through the solid material to promote aerobic conditions,
- a supply of carbon to maintain a suitable Carbon:Nitrogen ratio,
- some way of dealing with excess fluid,
- a means of extracting and using the product of the composting, and
- a suitable and unobtrusive superstructure.
- an easily cleaned, well ventilated and pleasant facility for the users.

Vaults or Containers

Also called digestion chambers, bins or receptacles, they can be made of concrete, blockwork, zinc sheets, polyethylene, fibreglass, 200 litre drums, etc. They can be unsealed where they are built into the ground, where decomposition is largely anaerobic, and where there is no major risk to the ground water system.

If there are volcanic soils present it may be possible to use cement or lime stabilised soil for construction of the walls. They should be built on a concrete base, using a 4% cement, mix, 300 mm thick, rammed into moulds.

It may be possible to build the vaults with coral blocks mounded up with sand at the sides. The base could be lined with concrete plaster or plastic sheet, drained to an evapotranspiration, (ET), trench, which should be covered to keep out the rain.

It may be possible to use old 200 litre drums to contain the solids. These can be ventilated with PVC pipes, liquids drained from the base, and an air inlet provided. The drums could be removed and replaced, with no need for a double structure. The drums may have to be cut down to reduce the overall height.

Large vault size translates into high costs, especially with concrete block construction.

The size of chambers will depend on usage, (number of users), and desired emptying frequency.

A number of formulae have been used to calculate the optimum size of a receptacle.

If no local data is available, use 0.03-0.06 m/year per person.

An effective composting system will allow smaller chambers because of the reduced time needed to achieve decomposition and pathogen destruction. This will translate into reduced cost for the construction of containers by using smaller blocks, thinner concrete lining, etc.

Access for removal of solids could be from the toilet floor rather than external.

The contents could be taken before decomposition to a central controlled composting operation, as happens in China.

False floors can be incorporated at the base for ventilation and drainage of solids.

It may be possible to provide strong mesh screen, (stainless steel or other cheaper material at floor level, covered with coconut leaves to catch the solids, which could be slid out on aluminium tracks for emptying.

Treated timber, used as a false floor at the base of bins eventually rots and would have to be replaced.

Ventilation

Ventilation is needed to remove odour and make the toilet a pleasant place to visit.

It may also help *trap any flies* which get inside the vault.

Circulation of air to the vault helps *create* the necessary *aerobic conditions* by ensuring sufficient oxygen is present to “feed” the decomposition process.

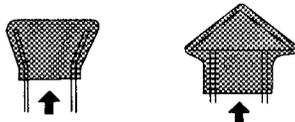
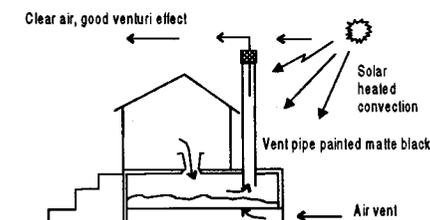
If there is a good, airflow the *temperature of the pile is increased* and the length of the resting period can be decreased due to the lower survival time of pathogens. This means a smaller vault size can be used.

Research has shown very clearly that the wind blowing across the top of the vent pipe is much more important than convection.

Continuous airflow will also *increase evaporation* of the fluids.

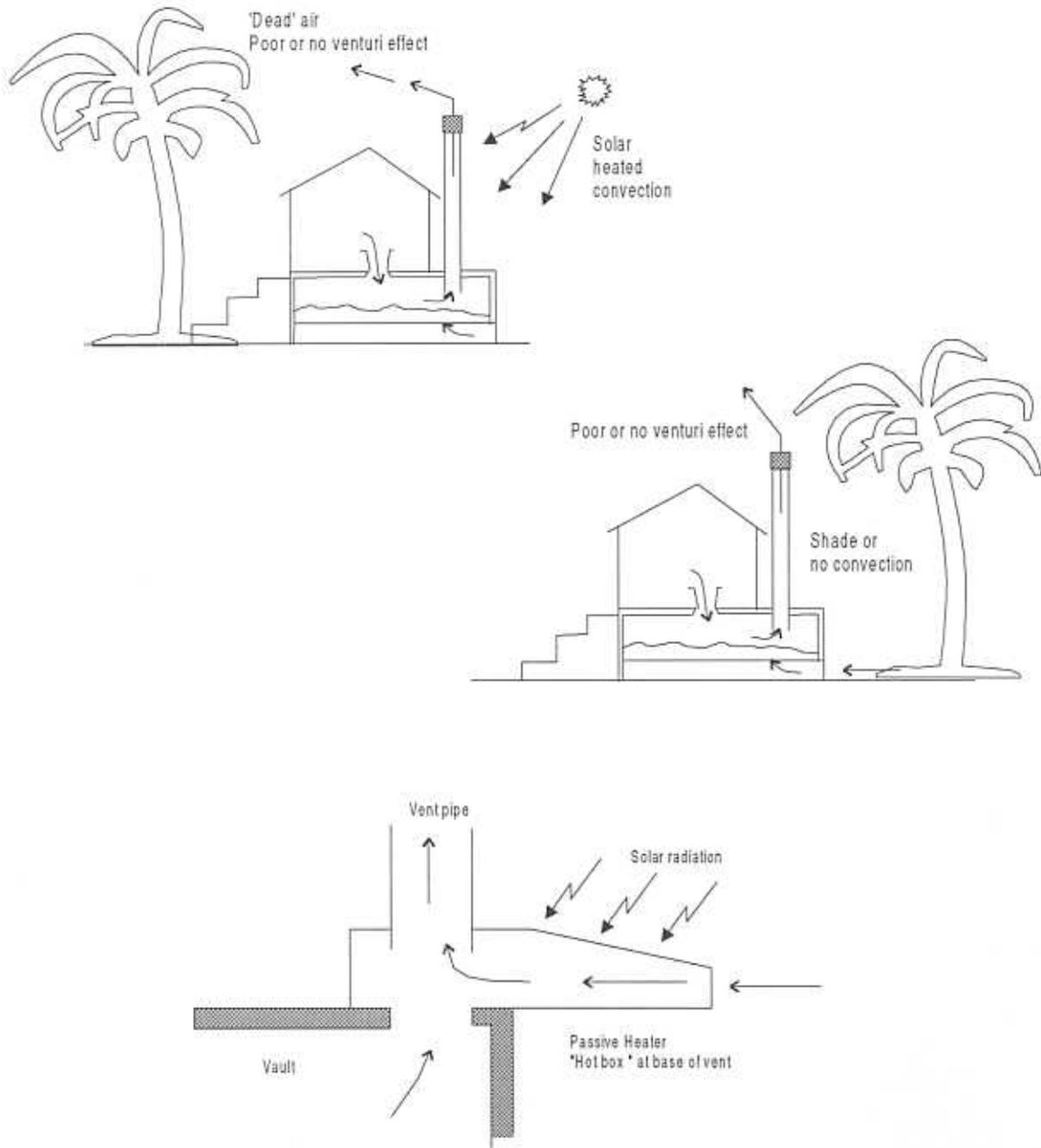
To induce a natural airflow you will need:-

- >10 degree rise in temperature to create convection,
- breezes blowing across the top of the vent pipe,
- sun on the vent pipe, which should be painted matt black, to assist convection,
- ventilation pipe at least 150 mm in diameter and smooth, (PVC),
- ventilation pipe to extend to a height where it is clear of vegetation and adjacent buildings,



- top of vent pipe belled out to make up for head losses from fly screen cover

Note effects of trees and sun on the venturi effect and convection



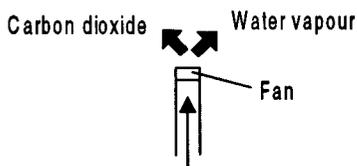
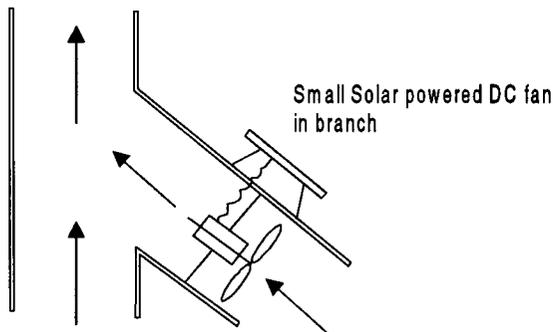
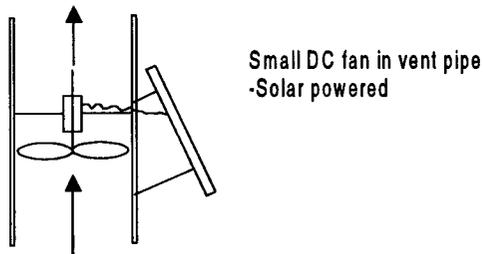
The use of a "hot box" at the base of the vent pipe, perhaps made from black HDPE will assist the air to flow.

Mechanically assisted airflow can be incorporated in the design:

Mains, battery or solar powered fans can be used to force the flow. NB solar fans won't operate at night.

They should be placed in a Branch Tee if possible to avoid corrosion from water vapour and ammonia coming from the vault.

Wind powered extractor fans on top of vent pipe can be used. Home made versions can be easily made.



Commercial composting toilets have electric fans for forced ventilation, e.g. Rota-Loo.

Flies

Insects are attracted to human excrement and decomposing organic matter. Latrines, therefore, attract insects and make an excellent breeding ground, especially for flies. If the receptacles contain fluids, there is also the risk of mosquitoes being able to breed.

Adult flies can transmit infectious organisms on their feet, bodies and by regurgitation and defecation. Many diseases can be transmitted in this way including typhoid, cholera, dysentery and diarrhoea, but the importance of flies as disease vectors is still not clearly understood. If flies are important, then it is houseflies (*Musca domestica*) that would pose the greatest threat to human health. Houseflies, however, do not usually breed in latrines. They prefer animal faeces in dung heaps and domestic garbage, and human faeces lying in open areas. The latrine breeding flies tend to be blowflies, (*Chrysoma*), and sometimes flesh flies, (*Boetscherisca*). Blowflies are not as important as houseflies in transmitting diarrhoea-causing pathogens, as they are slow flying and avoid and have less contact with humans. They may not be a pest of any appreciable medical importance.

One of the main problems with fly-breeding in toilets is that they are a nuisance and may result in people choosing open defecation over fly-ridden toilets.

The control of insects in toilets can be achieved by keeping the pit dry, keeping the toilet room dark and by proper construction of a ventilation system.

The vent pipe with screening at the top is necessary to prevent flies from entering the pit, attracted by the odour. Any that enter will leave the pit attracted by the light at the top of the vent pipe. The screen will prevent their exit.

A dry odourless pit will not attract flies. This can be achieved through diversion of urine away from the pit.

Temperature

Pathogens are destroyed by exposure to moderately elevated temperatures.

Temperature-die-off charts such as that shown below, (Feacham et al, 1983), indicate that 1 month at 43°C or 12 months at 42°C kills off all tested pathogens. Enteric viruses require 1 month at 33-35°C.

The most resistant pathogens are ascaris and salmonella.

However, over-elevated temperature can be counter productive to producing good compost. High temperatures will produce just a dessicated product *because* the bacteria and other agents, (e.g. worms), for compost formation, operate in the mesophilic range, (19-45 degrees C), *therefore* composting latrines need to provide the optimum temperature and time for excreta decomposition in the receptacle followed by some dessication.

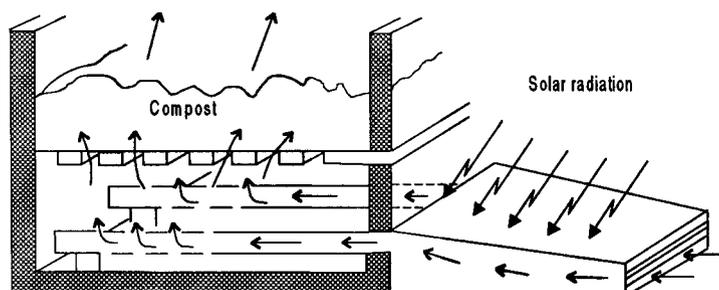
Heating the Vaults

Structures, therefore, should be built to **attract the heat** available. In particular they should be built to use the heat of the sun in tropical island situations.

Large continuous vaults or, preferably, smaller double vaults should be provided with each latrine to **allow time for decomposition** to take place and for all pathogens to be destroyed.

Some methods

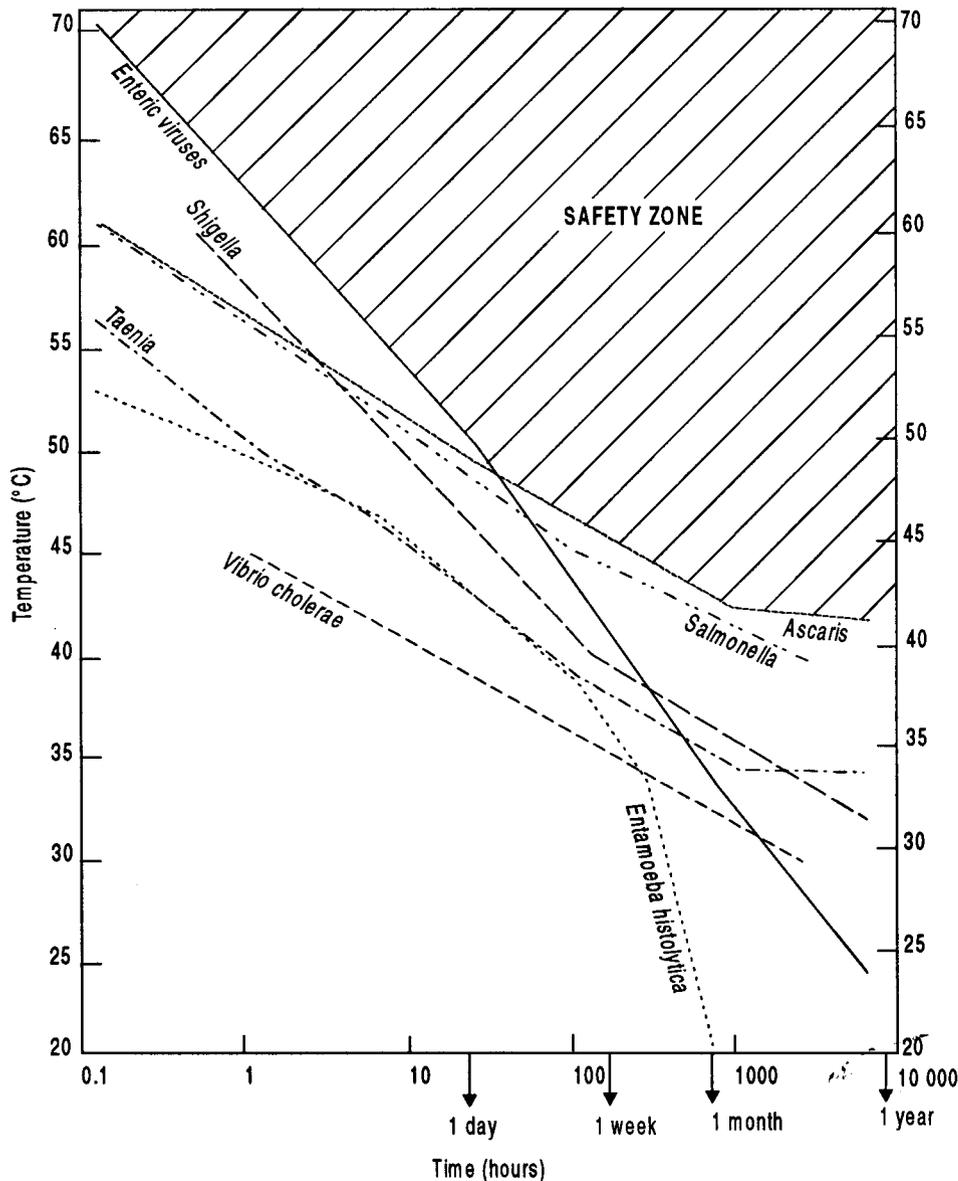
A passive heater could be constructed to heat the air and direct it to the vaults.



Access hatches and rear walls should be painted matt black to attract the heat of the sun. Toilets should be oriented to take advantage of the available sunshine.

Heated air should be directed below the suspended floor of the vault, if one is in the design.

Modern designs of composting toilets have immersion heaters in their design to create the warmth needed, particularly in cooler climates, e.g. Rota Loo, which is equipped with an electric heater to maintain proper temperatures for microbial activity.



A temperature-duration curve for pathogen inactivation in night soil and sludge. Processes with the 'safety zone' should be lethal to excreted pathogens (from Feachem et al, 1983).

Carbon/Nitrogen Ratio - adding Vegetable Material

The aerobic bacteria which break down the contents of a compost pile require carbon and nitrogen in a ratio of 15-30:1.

The C.N ratio of human faeces is about 8:1 therefore some form of carbon-rich material must be added to bring the compost within the optimum range. Urine is rich in nitrogen, (C.N ratio 0.8:1)

The higher amount of carbon is usually supplied in a composting toilet by the addition of vegetable material. Fresh grass cuttings and leaves have a C:N ratio of about 15:1. Dried material has a much higher ratio.

Where urine is not excluded from the toilet a good supply of dry carbon-rich bulking agent must be added to the vault on a daily basis. It is also a good idea to fill the container loosely with dry vegetable matter before use.

Where urine is excluded, as in Vietnam, the toilet only requires the addition of a small amount of ash or sawdust after each use.

Use of coconut husk fibre has been recommended for the trials in Kiritimati in Kiribati as the primary bulking agent, supplemented by leaves.

Dried leaves are generally available throughout the tropical islands of the Pacific.

Excess Liquid

Moisture Content

The moisture content of the pile in the vault should be controlled between 40-60%.

Where relative humidities are below 20% faecal matter can be desiccated, with little value as a conditioner/fertiliser. Above 60% relative humidity, the faecal material can become a soil

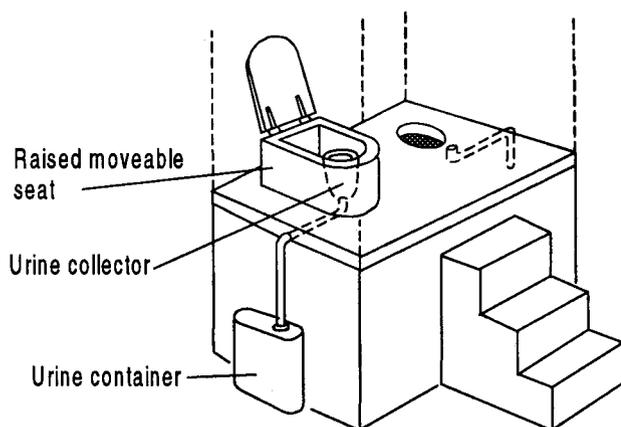
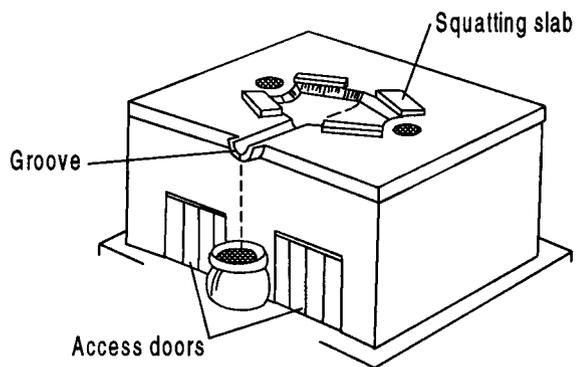
supplement/soil conditioner. Fortunately the mean values of relative humidity in the Pacific are about 75-85%.

The addition of dry vegetation to the pile assists in creating the right moisture content by absorbing moisture within the vault and can be used to adjust the moisture content.

Excess liquid can be dealt with either by not letting it enter the vault or by draining it from the base of the vault. In tropical climates the amount of liquid in a latrine is often small.

Separation of urine

Various designs for preventing the urine from entering the vault have been tried. Below are the Guatemalan design and the Vietnamese design. People, particularly males, can be encouraged not to urinate in the toilets, but to "water" fruit trees with the nitrogen rich urea.



Disposing of excess fluids from the vaults/containers

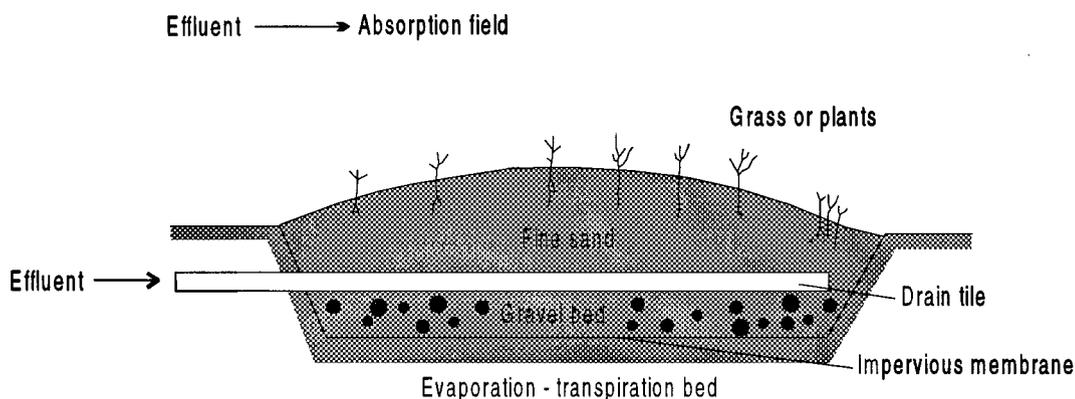
Where excess fluids enter the container a number of methods are available for removing them. These include:-

If a false floor is incorporated in the design,

- Direct heated air onto the fluids, particularly if you have a sloping floor.
- Use air wicks to soak up the fluids, as in the CCD design.
- Use coconut husks, fibrous side up, directly on a sand base to soak up any excess fluids. These can be removed when the vaults are emptied.
- Use a zigzag groove to the outlet to increase the time of exposure to evaporation.
- Seal the base and raise the outlet to create an overflow via a weir.
- Build a contaminated fluids disposal trench.
- Use a "garden" arrangement to dispose of fluids, as in the CCD design.
- Use sugar cane in the ET trenches to soak up nutrients, especially nitrates. Use a 2 part trench, consisting of sugar cane, a divider wall, and then taro.

N.B. However, no food crops should be grown for consumption using the excess liquid trench.

N.B. with diarrhoea, faecal material can run directly to trenches.



End Product - Use and Safety

According to Voltaire bees are superior to humans because one of their secretions is useful. He suggested that nothing a human secretes is of use and whatever we produce makes us disagreeable to be around, (Voltaire, Dictionnaire Philosophique, "Abeilles" V 1 , 41).....

But, human excreta contains nutrients, therefore it is potentially a product of value rather than a waste to be disposed.

Average Composition of human faeces and urine. (Approximate content - % of dry weight)

	Faeces	Urine
Calcium	4.5	4.5 - 6
Carbon	44 - 55	11 - 17
Nitrogen	5 - 7	15 - 19
Organic Matter	80 - 97	65 - 85
Phosphorus	3 - 5.4	2.5 - 5
Potassium	1 - 2.5	3 - 4.5

But, the material "harvested" from dry latrines should not be considered as a fertiliser. its nutrient content, that is the percentage of the major plant nutrients, nitrogen, phosphorus and potassium, and the minor nutrients, calcium, magnesium and sulphur, varies widely. the composted materials also spike only in certain trace elements which are beneficial. it is, therefore, better considered as a soil conditioner.

However, the humus produced is an excellent soil conditioner, generally free of human pathogens if composted correctly, As a safety measure the humus can be trenched around ornamental plants and/or tree crops, such as bananas to avoid human exposure or direct contact with food crops.

Tropical island soils, especially those on small atolls, are generally low in organic content. The addition of the composted material as humus can only benefit these soils by making them easier to cultivate and by improving their moisture holding capacity.

The compost and hygiene

The product should be used in gardens within the house site. It should be free of pathogens. Testing, if carried out, should reveal the presence or absence of such pathogens as round worm, whip worm, Ancylostoma, hook worm and intestinal protozoan cysts such as Giardia lamblia. Bacterial tests should also be carried out.

Of more use as a fertiliser is the urine for urea, which can be collected from some forms of dry latrines and diluted, (5:1 water:urine), for application on crops.

The Superstructure

The superstructure provides shelter and privacy for the user. The design is irrelevant to the operation of the latrine but is crucial to the acceptability of the latrine to the user. It may range from simple shelters of stick and sack to be bricks/blocks costing more than the rest of the latrine.

The choice should reflect the income and customs of the user.

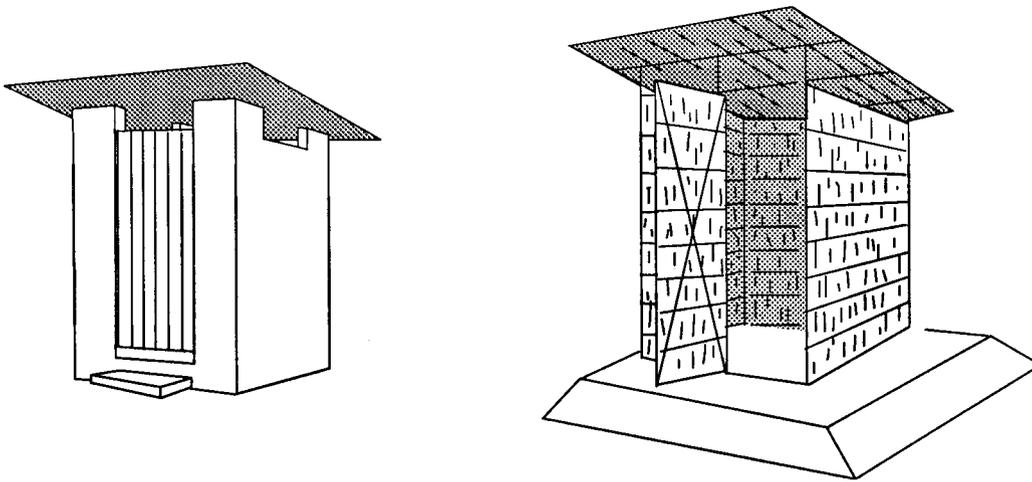
The structures could have a simple wooden framework on which can be fixed traditional or imported cladding and roofing material.

There is a need to provide a robust external door and to clad or otherwise weatherproof the gable ends and eaves.

The roof should be used to collect rainwater for handwashing, if no other local source is available and accessible. A 200 litre drum could be used for water storage with a tap fixed at the base.

A set of operating instructions should be prepared for the general toilet user and displayed inside the toilet room.

A set of instructions for facility manager should also be prepared. Backup information should be made available to him or her, including a brief list of "things that could go wrong with your toilet".



Superstructure, Height

Because the design of a composting latrine requires efficient ventilation if aerobic conditions are to be encouraged, the vaults or containers should be above ground. The building superstructure must therefore be constructed above the bins.

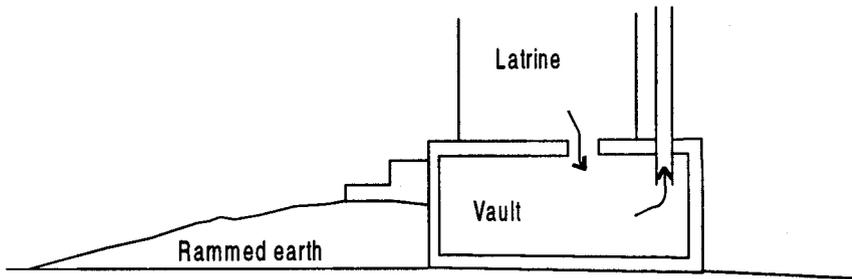
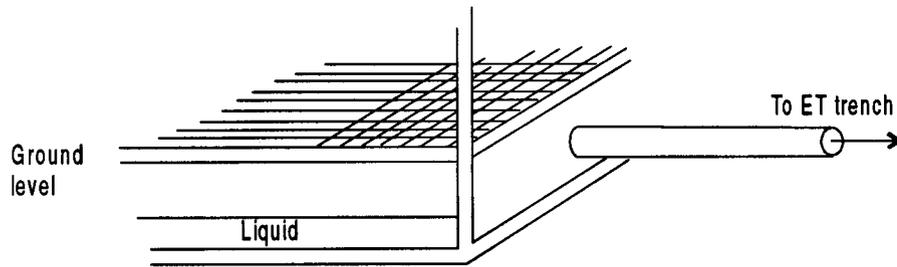
Elevation of the superstructure allows the air to flow maintaining the solids in an aerobic condition and minimising odour. Raised structures allow ease of removal of the composted material. The liquids can be drained by gravity to an evapotranspiration trench.

The resulting high elevation means that the structures are highly visible, sometimes being the tallest building in the vicinity and require steps or a ramp for access.

One of the results of this is that visiting the toilet is not a private activity and may deter users. Another is that access for older people and invalids is difficult.

To overcome the elevation problem it may be possible to:-

- sink the house into the ground, about 300 - 600 mm, using a false floor at ground level to remove solids and draining liquids below ground level to an ET trench



- join the toilet to a house or connect by a verandah with covered access
- use on-site mounding to reduce the number of steps

Cost Considerations

Elevated structures designed to look to be too expensive for subsistence communities. Locally built composting toilets on Kiribati cost in excess of AUD\$2000.

SOME CONCLUSIONS AND FINAL THOUGHTS

Problems which need to be Resolved

When designing a waterless composting latrine for small tropical islands include:

- How to minimise costs. This remains the major constraint to the introduction of composting latrines on a large scale in small Pacific islands. Use every means of reducing the costs of materials by utilising local materials wherever possible
- How to reduce the height of the structure. This is linked to the overall cost and to the acceptability and use of this type of latrine.
- How to make the toilet simple to operate. Composting is a technically complicated procedure, but it is not beyond the ability of the general public to be able to produce a good product from these latrines. Clear instructions on the amount of vegetable matter to be added and the time needed for the compost to be safe to use are needed.
- How to ensure effective destruction of all pathogens. Research projects are needed to test the effectiveness of any installations of these facilities in Pacific island countries.

Don't consider using composting toilets if :

- sufficient user care cannot be reasonably expected;
- there is insufficient organic waste material available;
- the users are unwilling to handle the composted humus; and
- there is no local use or market for composted humus.

Do consider using composting toilets if :

- there is a shallow water table from which water is used regularly;
- you are concerned about a deteriorating environment; and
- water is not available in plentiful supply all the year round.

Further information on composting toilets can be obtained from:

World Health Organisation
20, Avenue Appia, CH-1211 Geneva 27, Switzerland

Dr Stephen Winter, Appropriate Technology Enterprises, Inc.
P.O. Box 607, Chuuk, Federated States of Micronesia 96942

Dave Rapport, Director, Center for Clean Development
1227 W 10th Avenue, Eugene, Oregon 97402, USA

Dr Leonnie Crennan, Centre for Environmental Studies
Department of Geography and Environmental Studies, University of Tasmania
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&

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