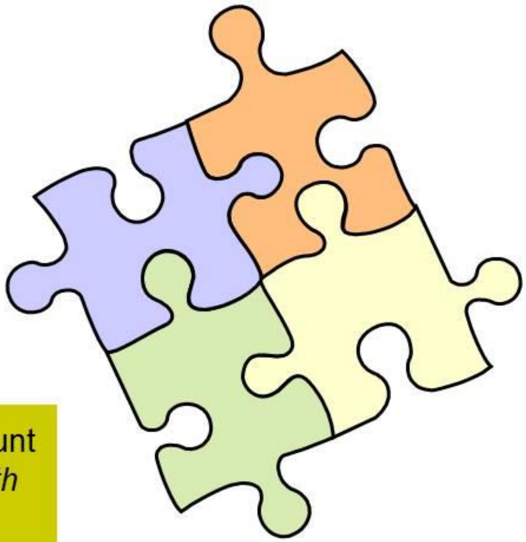
2.7 Construction and monitoring - save on scarce resources

What bottlenecks are there for councils and residents? Are there ways to go about it?



Learning objective: the paramount role of *good* construction for *smooth* operation. How to raise ambitions without stretching council capacity

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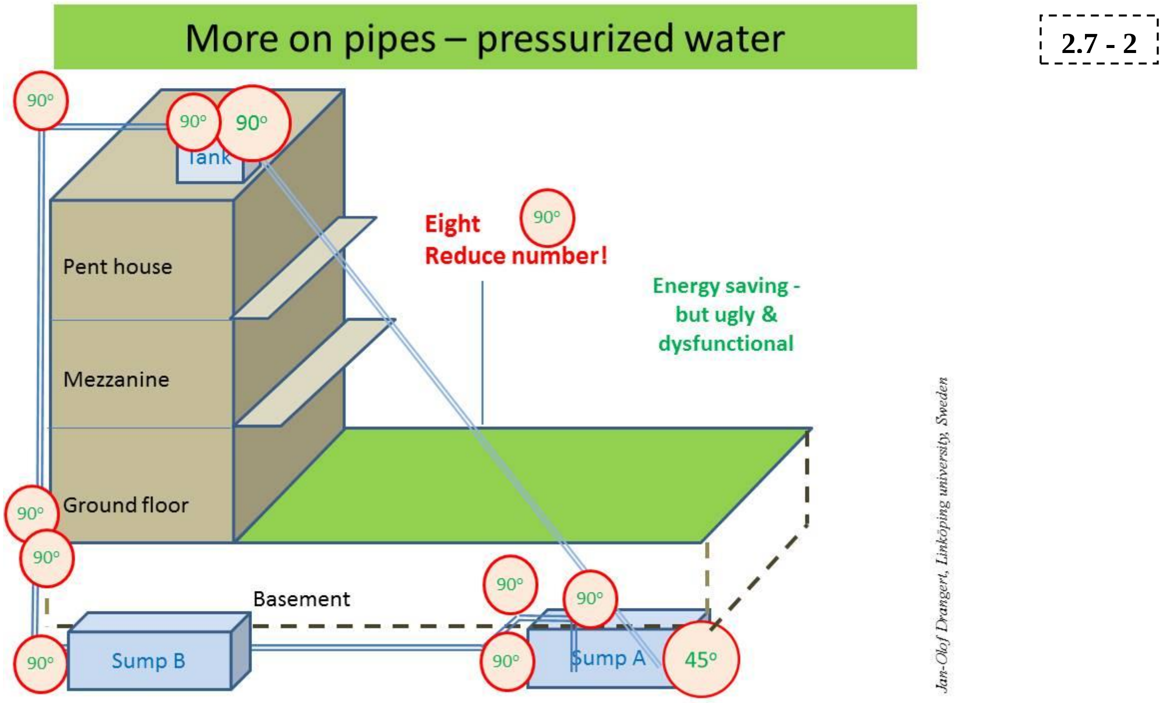
This module provides guidance for development practitioners on how best to engage residents to monitor the construction of sanitation arrangements so that they can reap all the benefits of their new arrangements. In most installations worldwide, there are quality problems. They include obvious wrong connections of water pipes to sewers, rough cement floors that are difficult to clean, and vaults for faecal matter which leak air, defeating any ventilation effort. Who is expected to ensure that construction and installation are done properly? Theoretically it is the builder, contractor, municipal inspector, and product controller at manufacturing firms. But the present control measures are not effective, as shown by the many design and building faults which occur. The truth is that only the house owner and residents are deeply interested in getting everything right.

Toilets built by small contractors can have minor or major faults that could have been avoided. It takes more information than a drawing of the construction to make masons competent to perform their task. Inspection quality must also improve. In many cases, visits by inspectors are rare, presumably because of a lack of transport – a problem that will not go away. The suggestion here is to mandate house owners and school staff to take on the immediate responsibility of daily inspection at the building site, since they are there all the time.

This strategy will be successful only if all stakeholders have a common understanding of what the final outcome of the construction should be. A good technical drawing is promising first step, but not enough to provide all details. Only photographs can give a complete understanding of how things should look at each stage of the construction. A pictorial manual is therefore as important for those who build the installations as it is for the residents monitoring the process. The purpose is to avoid conflict and make the installation cheaper for the contractor and the house owner.

Simple building errors can ruin a toilet by making it smelly or difficult to keep clean and by making greywater handling messy. Inviting eager home owners to assist in inspections makes use of a locally abundant human resource without straining scarce professional resources. This module indicates what a manual for such inspections could contain.



A 4-storey house is presented to introduce ways of designing and constructing sustainable water supply for a house intended for rainwater harvesting. It is built with a collection sump below the basement and a gravity-distribution tank on the roof. A submersed electric pump brings the water to this tank. By clever design of pipes and tanks the energy use could be minimized. Likewise, the risk of leaking joints is minimized. Four possible “solutions” are compared.

(a) A straight water pipe from sump A: s bottom to the roof tank would cause minimum of friction and thus require least energy. With only one 45^o - and one 90^o -elbow a 2% increase of energy usage compared to no elbows. However, such a visible pipe in the garden would look ugly and becomes an obstacle to activities in the garden.

(b) An architect proposed to take the water pipe horizontally along the ground and then vertically up to the tank. In this case, the drawing shows eight 90^o -elbows which together increase energy usage by 5-10%. This will increase the operational cost and also increase the investment cost for the more powerful submersed pump.

(c) If the architect instead had placed the water sump under the main part of the building, only one 90^o -elbow would be required. However, such a placement of the sump would increase the risk of cracks in the sump from the weight and movement of the house. It is not worth taking such a risk.

(d) Next alternative shows the sump placed just a few meters away from the main building in order to avoid faults. A slightly slanting pipe is laid from the sump to the house wall and continues vertically up the wall. Only two 45^o -elbows and one 90^o -elbow is required in this case. This alternative uses the least energy and does not disturb activities in the garden nor risks unwarranted cracks in the sump or leaking joints.

In the case of pumping water to the roof tank, the height from the sump is most influential on the magnitude of energy required (Table below). Second most important consideration is the efficiency of the pump, since that can range from as little as 5-10 % to more than 60 %. This implies that the energy bill increases by a factor 10 between the two extreme pumps. The investment in the energy-efficient pump should be compared with the life-time saving on running costs.

Table 2.7.1 Pressure reduction and pump power when pumping water in vertical pipes.

			Water velocity 0.1 m/s				Water velocity 1 m/s			
Inner diameter of pipe	Pressure reduction due to gravity	Pressure reduction due to 8 90° elbows	Pressure reduction due to pipe friction	Total pressure reduction	Flow rate	Pump power (net)	Pressure reduction due to pipe friction	Total pressure reduction	Flow rate	Pump power (net)
(mm)	(kPa)	(kPa)	(kPa)	(kPa)	(l/s)	(W)	(kPa)	(kPa)	(l/s)	(W)
22	150	2.0	3.1	155	0.038	5.9	21	173	0.38	66
28	150	2.0	1.9	154	0.062	9.5	16	168	0.62	104
35	150	2.0	1.2	153	0.096	14.7	12	164	0.96	157

[Pa (Pascal) is the SI unit for pressure. 1 Pa = 1 N/m$^{2.}$ (1 kPa = 1000 Pa)]

The third most important consideration is the dimension of the pipe and the water velocity. Sub-optimal arrangements may raise the energy use by some 10 %. The rules of thumb are that (1) the smaller the pipe dimension, the larger is the energy required, and (2) the higher the velocity, the more energy is used (increases by the square of the velocity). Therefore, it is beneficial if the roof tank is big enough to cater for at least a day's total consumption, and if the pump fills the tank by a whole night's slow pumping of water through a relatively big pipe.

The extra energy required for many elbows is relatively small (some percentage points), but is heavily influenced by the pipe dimension and the smoothness of the inside surface of the elbow. Therefore, these aspects together with the size of the tank and regulating the flow rate should be in focus.

There are tables and calculation programmes that can assist in calculating energy and cost savings. The Table below provides some guidance (in the case of this house):

Table 2.7.2 Water velocity and energy requirements to pump water in vertical pipes (Water velocity =1 m/s)

Inner diameter of pipe	Flow rate	Pump power (net)	Time to pump up 1 m^3	Energy (net) to pump up 1 m^3	Energy (gross) to pump up 1 m^3 for pump with efficiency η=0.40	Energy (gross) to pump up1 m^3 for pump with efficiency η=0.20
(mm)	(l/s)	(W)	(s)	(kJ)	(kWh)	(kWh)
22	0.38	66	2632	173	0.12	0.24
28	0.62	104	1613	168	0.12	0.23
35	0.96	157	1042	164	0.11	0.23

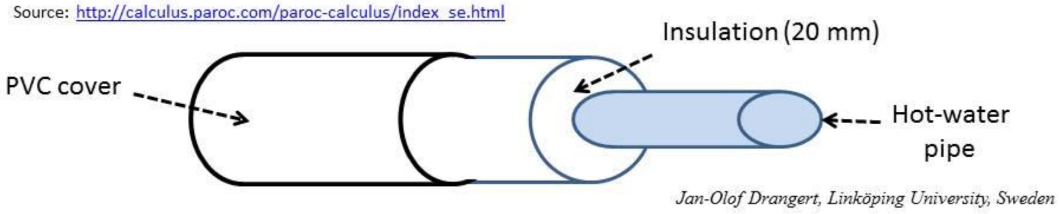
Water velocity in pipes is often in the range of 0.1 – 1 m/s, or 0.038 to 0.38 litres per second in 22 mm pipes. This provides about 8 m^3 to 80 m^3 per 24 hours, or 1 and 10 m^3 respectively in three hours. As for the energy required to pump 1 m^3 to the roof tank 15 m above the sump in a 22 mm pipe is 0.12 kWh or 0.24 kWh respectively depending on pump efficiency (η= 0.4 and η= 0.2). The local cost per kWh now gives the cost of pumping 1 m^3 to the roof tank in local currency.

2.7 - 3

Calculating the impact of insulating hot water pipes

Pipe diameter (mm)	Insulation thickness (mm)	Energy loss [kWh/(m·y)]	Energy saving **with** insulation [kWh/(m·y)]
22	No insulation	250	
22	20	51	199
22	60	32	218
35	No insulation	350	
35	20	66	285
35	60	41	309

Source: http://calculus.paroc.com/paroc-calculus/index_se.html



Heating household water requires energy, while cooling the hot water is a process where the heat dissipates into the surroundings. A common situation for Swedish households is that a third of the used water is hot water and the cost of heating is high. Fortunately, a lot of this energy can be saved by not letting the water cool down and requiring re-heating before use.

The proposed energy-saving installation is to insulate all hot water pipes from the heater/geyser to the taps. This can be done in several ways. A pre-insulated pipe may be available in shops or the plumber adds insulation on site. The plumber can fix a piece of readymade insulation around the hot-water pipe. Furthermore, in order to protect the insulation from weathering, the insulated pipe can be inserted into a second larger PVC-pipe as a shell.

The table above shows how much energy can be saved per meter insulated pipe in a year if the hot water temperature is 55°C initially and outside ambient temperature is 20°C.
The table indicates two “rules of thumb”: The first is that a thin layer of insulation of 20 mm saves several times more energy than additional 40 mm insulation. The second rule is that the larger the dimension of the pipe is, the greater is the energy loss.
For greater temperature differences between the hot water and the ambience, the energy saving for properly insulated pipes will be even greater.

The required investment cost for insulating pipes with 20 or 60 mm thick insulating material should be compared with the savings in energy cost.

Another suggestion for multi-storey buildings is to let hot water circulate in a ”closed loop” and whenever a hot-water tap is opened the hot water comes immediately. This is very different from the common case where several litres of lukewarm or cold water (that has cooled off while standing in the pipe) have to be discharged before the hot water appears. This improvement requires only an additional pipe when building the house.

A small heat exchanger in the bathroom placed at the drain pipe trap where the hot water after bathing is draining off could pre-heat cold water going into the heater.

All three provide strong case to insulate all hot water pipes to save on energy and money.

2.7 - 4

Urine pipes are not water pipes

Urine is not water! - requires different piping to handle salts and low volumes.

- **No 90° or other sharp bends!** They slow down velocity and are difficult to pass through with a mechanical "snake" when removing blockage. Instead:

  Connect two 45° bends to maintain velocity and allow for "snake"

- **Go as vertical as possible!** Yes: No:
  Keeps up the velocity and prevents salts from settling in pipe!
  Use caustic soda to dissolve crusts of salts.

- **Don't mix urine and water!** ⇒ less smell, mix not needed for plant uptake

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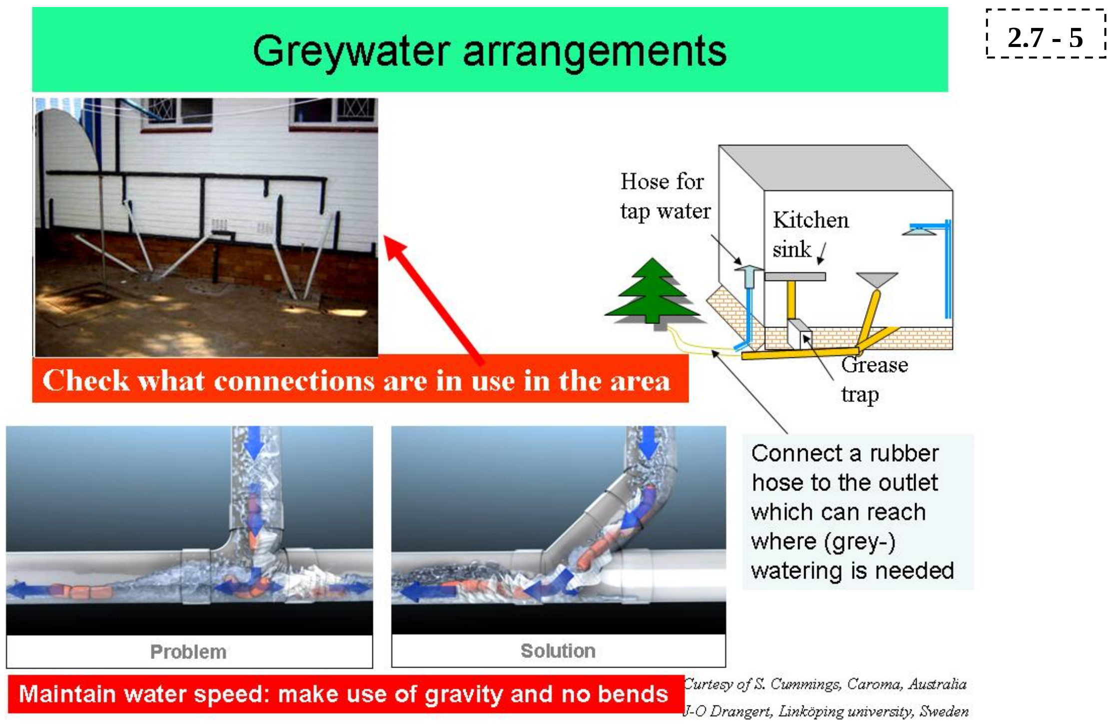
A common mistake is to think that the same pattern of piping can be used for urine and water. The volume of urine is small and irregular; say 0.2 litres twenty times in a day. This gives an average of 0.4 litres per hour and almost zero in the night. Thus, salts in the urine have time to settle unless we design for good slope and velocity. Experience shows that horizontal urine pipes cause unnecessary problems with crystallization. Fortunately, caustic soda can be used to dissolve most blockages. In severe cases a mechanical snake is needed, but the pipe breaks easily when the snake is forced through a 90-degree elbow.

'*Go as vertical as possible*', and not as in the left-hand picture where the pipe is vertical and then horizontal. The pipe should be as short as possible. In this case the pipe could instead slant between the urinal and the hole in the wall. If an elbow is unavoidable, make sure it is not 90^{o} since this reduces the velocity of the urine to almost zero. It is better to connect two 45^{o} elbows which slow down the velocity much less and also allow to insert a mechanical snake more easily.(Please see slide 2.7 - 4 above)

The right-hand photograph shows a disastrous prefab design (several 90^{o} elbows and horizontal sections) that will make the urine crystallise. The blue-coloured pipe dimension is also too small. The recommendation is 25–35 mm for vertical pipes, and 45–70 mm if sloping.

The design of the urinal bowl towards the hole should be like a funnel which does not allow urine to stay anywhere, and thus no smell is emitted. There is no agricultural or other reason to mix urine and water – in fact the mixture smells more than just urine. Also, if water is added the storage container has to be much bigger – or emptied more often.

All these design and construction recommendations will facilitate operation and maintenance for the benefit of the users. Good design and installation is not more expensive, and therefore there is no excuse for poor design of urine pipes.



Finding a robust, simple and affordable solution for on-site greywater treatment is a challenge if the household is not conscious or does not take care about what they put into the water while using it. The better the greywater quality, the simpler the treatment method.

Greywater can be used for watering the garden after little or no treatment, depending on the degree of contamination from kitchen and shower. The household is in control of the quality of its wastewater and knows what they have added to the water before use in their own garden. Treatment methods for other uses are dealt with in the module on reuse (Module 4.2).

The picture (top left) shows a home where they use all the greywater to water a nice garden, which would otherwise wilt during water restriction periods. They have connected all pipes – except from the toilet – and can direct the greywater whenever they need water in the garden. Keen gardeners are not likely to contaminate the water when using it, since they apply it in the garden afterwards. Not only do they save on fresh water and money, but they also reduce the volume of wastewater to the municipal treatment plant.

The bottom picture shows how solids in the transparent pipe behave in different elbows. Most of the solids passing the 90^{o} elbow continue as intended, but some solids are pressed backwards in the horizontal pipe. A combination of two 45-degree elbows instead of one 90^{o} elbow is superior – not only for greywater but for urine and air as well. All solids flow in the intended direction. The two-elbow version also retains a high flow velocity for the greywater.

In addition, to secure enough gradient for gravity-driven irrigation (top right) the house could be built on a raised foundation, and with a raised floor in the shower. Pipes should slant as much as possible from the entry point to the highest point in the garden in order to maintain the velocity of the greywater (slide 2.6-3). This extra supply of nutrient-rich irrigation water is good for gardens with food crops and trees as well as pleasure gardens.

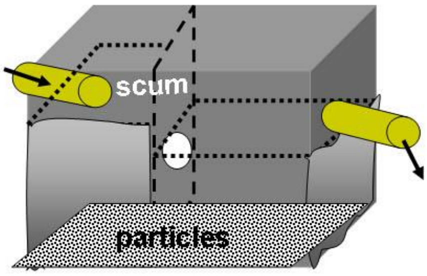
The last part of the irrigation pipe should be a rubber hose (flexible pipe) that can be placed where water is needed (top right). It is also helpful if a piped water tap can be connected to the rubber hose (blue vertical pipe top right) to be able to flush the flexible pipe occasionally.

Grease trap for kitchen water

2.7 - 6

The white pipe from kitchen sink distributes the water between two (black) boxes. Each contains a lilac plastic screen to catch coarse material (easy to empty). The water sinks through a layer of coconut fibre in which organisms live from nutrients in the greywater.

A common grease trap lets the greywater through two sections slowly enough to allow grease to float up (scum is removed). The coarse particles sink to the bottom where some degrade.



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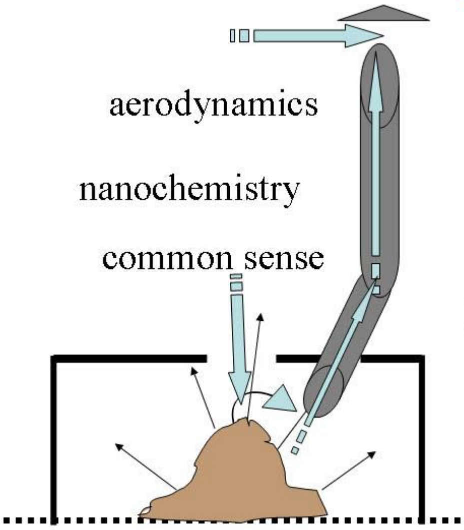
Kitchen water requires an extra effort of cleaning due to a high load of organic material. Warm dishwater and detergents dissolve fat, oil and grease (FOG). A conventional grease trap (right) is intended to allow the dishwater to cool down and FOG to float, and particles to settle. The retention time must be long enough for this to happen. FOG forms a scum on the surface and has to be removed regularly. This task is a bit messy, but the FOG is a valuable input to any compost or biogas reactor. A better way would be to reduce the valuable FOG content by wiping off grease from plates and cooking pots and add it on organic waste compost.

The degradation of organic matter at the bottom of the box (to the right) is mainly anaerobic and may produce some smell if not emptied occasionally. A smell indicates that the system is overloaded and if a thick black slime layer develops, the process becomes totally anaerobic and non-functional.

An improved grease trap with a mulch filter (to the left) was developed in Kimberly, South Africa. Its function is, firstly, to take away coarse particles in the wastewater from the kitchen sink e.g. food residues and fibres in a pre-filter or screen. Secondly, the water passes through an aerobic adsorption filter of coconut fibres where macro and micro fauna live and digest the carbohydrates, FOG and other easily biodegradable organic material in the water passing through. The aerobic process is odourless and easy to maintain by emptying the plastic screen in a separate organic waste bin. The unit is also educational in the sense that residents know that if they throw food remains in the sink, instead of in the waste bin in the kitchen, they have to empty the screen more often. The outgoing water with a reduced BOD level is rapidly drained in a connection pipe to other greywater and treated further (see Modules 4.5 – 4.7), after which the treated greywater can be used or infiltrated. The Kimberly unit was tested for more than a year, and found to perform very well, in spite of the heavy spring rainfall in 2006 which exceeded all previous records (Ridderstolpe, 2004).

Ventilation: Let us follow the bad smell

2.7 - 7



Think of this to reduce bad smell

- ❑ Vent pipe intake close to heap & drop hole
- ❑ Bends cause friction and lower air speed
- ❑ Any air leak on the box lowers air speed
- ❑ Vent pipe vertical otherwise more fiction
- ❑ Diameter of vent pipe 110-150 mm for optimal natural air flow-not smaller, not larger!
- ❑ The vent pipe should be at least 1 m above the highest point of the roof to catch wind and temperature difference
- ❑ Vent pipe outside the toilet room to be heated by the sun only in warm climates, but not if nights are cool. The vent pipe above the roof should be insulated.
- ❑ In cold climates vent pipes should be indoors and insulated above the roof.

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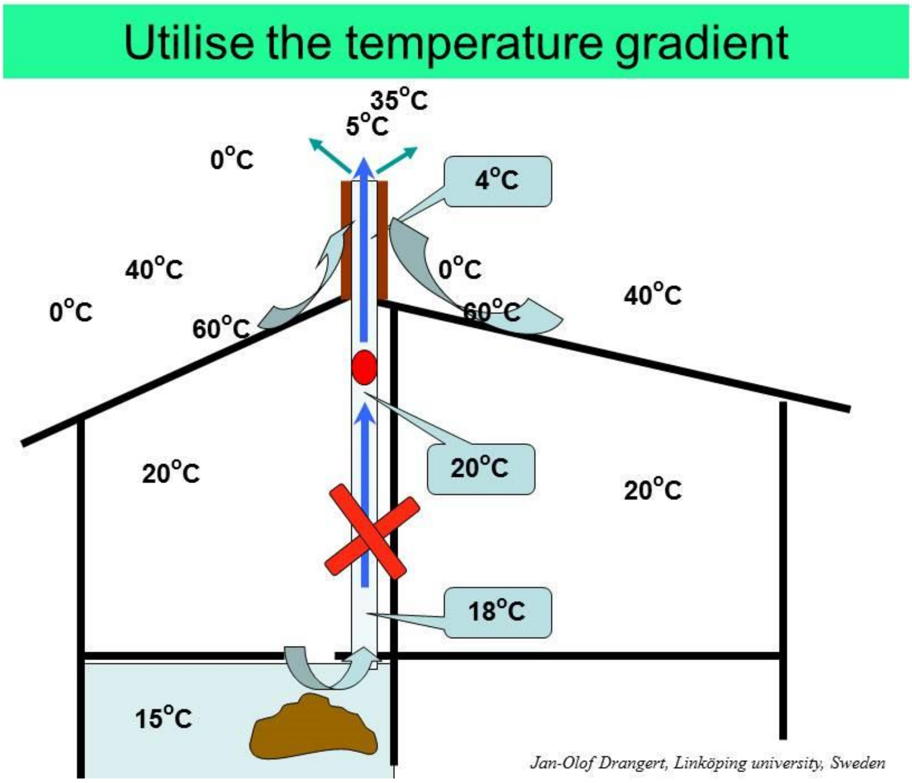
Bad odour is not appreciated and it has to be prevented by proper ventilation. Fortunately, natural ventilation is usually sufficient, provided proper design has guided the installation.

We learn at an early age what odours to like and dislike. Odour is a complicated biochemical issue involving the delicate sensors in our noses which can register very small particles released from the faecal matter (National Geographic, 1986). We will not delve into this, and instead look at how bad smells can be reduced by technical means. Common sense tells us that if we put an airtight box over the faecal heap, no smell will come out. But we need a drop hole in the box for the faecal matter. This allows gases to leave unless we open a second hole in the box and connect it to a vent pipe which goes above the roof. When air gets sucked up the vent pipe, it causes a downward draft of air from the toilet room to replace the air leaving the box. The downward draft must be strong enough to prevent emission of bad odours up through the drop hole. If so, no smell will be detected in the toilet room, only above the roof.

Air moves up the pipe for two main reasons. If a wind blows, the air current will create an under-pressure in the pipe above the roof, and air from the box will fill the void. The other reason is due to temperature differences. The warm air in the box has less density than the often cooler outdoor air, and will therefore move upwards. In both cases air in the toilet room enters the drop hole into the box and from there leaves through the vent pipe. If there is no wind or temperature difference, the air in the box will stay put and the odour-causing substances may enter the toilet room even if the toilet lid is closed. When the door to the toilet room is opened, an under-pressure occurs in the toilet room and air from the box enters the room. Fortunately, the degree of odour can be reduced by adding a drying agent on the fresh faecal material.

The above draft processes will not occur if the box is not air-tight (except for the two holes) since the suction down the drop hole will decrease. The best suction results will be achieved if the vent pipe is close to the heap and drop hole, and if the pipe has no elbows. The pipe diameter should be 110–150 mm to optimise air flow. The pipe should reach at least one meter above the highest point of the roof, and the outdoor part should be insulated. There is no reason to add a net to trap flies, because it is easier to trap the flies in the box itself (slide 2.1-9).



2.7 - 8

The previous slide explains how to optimise air speed in the vent pipe and thereby lower the risk of bad smells if the toilet room is inside the home. If the toilet is in the yard there is no need for a vent pipe. The trick is to ensure that the draft in the drop hole is always downward. Experience tells us that there may be some bad odour in the mornings in areas with big differences in temperature between day and night. The same problem occurs in cold climates. The reason is usually faulty design and lack of insulation of the vent pipe above the roof.

It is easy to understand the air movement if one thinks about the density of air rather than temperature. The density or weight per litre of air decreases when it gets warmer. An increase in temperature of ten degrees equates to a reduction of about 3% in weight at normal air pressure (760 mm Hg). We give three examples of temperature gradients in order to discuss what can happen. There is no fan or forced ventilation.

Example 1: The first picture shows a situation in which the outside temperature is 0°C. The room temperature is 20°C and the box (faecal chamber) is a bit cooler, say 15°C. Therefore, the air in the box is some 5% heavier and tends to stay still unless forced to move. The air in the toilet room is lighter than that in the box, and will not go down the drop hole unless forced to. Bad odour may enter the toilet room. But, the air starts moving above the roof because the light air in the pipe (20°C) moves up through the cold outdoor air (0°C). When air moves upwards in the pipe, the air in the box is sucked out and is likely to be replaced by air from the toilet room via the drop hole, and move on top of the colder air in the box. Because the air flows from the room to the box rather than from the box to the room, there is no foul smell in the room.

However, if the pipe is not insulated above the roof, the air inside the outdoor pipe will cool down towards 0°C while it is still inside the pipe. This metre of heavy cold air will prevent the underlying warm air from forcing its way upwards because it is not light enough to push the heavy cool air column upwards. Therefore, without insulation there is a likelihood of bad smells in the toilet room. Bad odours increase when the toilet entrance door is opened, causing the pressure in the room to fall and air to be sucked out of the box.

A strong wind outside can also cause the pressure in the toilet room to be lower than the pressure in the box, particularly if windows are open or not airtight. It is easy to check the air movement by following the smoke from a cigarette. Keep the lit cigarette above the drop hole and if the smoke tries to go downwards the design and temperature is okay. But it is also vital to check what happens when the pressure in the toilet room changes. Ask somebody to open and close the door to the toilet room while you observe the air flow in the drop hole. It may happen that the air/smoke flow turns upward due to the momentary under-pressure. The smell then also enters the toilet room. If that is the case, action should be taken (slide 2.7-7). Three first-aid remedies are: to make the door less air-tight by cutting it or drilling ventilation holes in it, or to open the door very gently to allow time for the air to enter the room, or to have the door opening into the toilet room (see school toilets slide 5.3-8 for more information).

Example 2: The next situation has an outside air temperature of +40°C and an indoor temperature of 20°C and the box temperature is 15°C. This time the 20°C air in the pipe needs some support to move upwards through the 6% lighter outdoor air. With no wind it is still likely to move because the roof itself is heated by the sun to much more than 40°C, say 60°C. The heated air near to the roof moves upwards around the pipe, and creates an under-pressure inside the pipe. The air in the pipe starts moving slowly upwards and in turn sucks air from the box and ultimately from the toilet room. This time it is more uncertain whether the air flow is strong enough to hold back smell from the box.

The above discussion presupposes that the box is airtight with an airtight door (for emptying), which means that the air from the toilet room moves through the box into the vent pipe up above the roof. The ventilation pipe of plastic (to avoid corrosion) is vertical. In this case it is not necessary to attach a separate exhaust fan to move the air from the box (still, it is advisable to install an electric outlet for possible future installation of a fan). The section of the pipe outside the house must extend at least one metre above the roof in order to catch the wind – and be insulated.

Another small solution is to attach a heating jacket for the last part of the vent pipe. This can be designed with a small energy foot print of no larger than 20 W or even less, and will ensure constant movement of air. The jacket is particularly useful at the 'neutral' point in the vent i.e. when the air neither moves up nor comes down because it has attained equilibrium both of thermal equalisation and weight equalisation.

Another kind of protection against bad odour from a dry toilet is to cover the fresh faeces with a drying agent such as ash, sawdust, soil, lime, sand, cut straw, or dry food waste such as flour, starch, and dried crust.

2.7 - 9

Pressure reduction and flow rate for ventilation pipes at different air velocities

Pipe diameter	Pipe height	Pressure reduction due to:				Flow rate	Fan power (net)	Fan power (gross) η=0,40
		Height	Each 90° elbow	Friction	**Total**			
(mm)	(m)	(Pa)	(Pa)	(Pa)	(Pa)	(l/s)	(W)	(W)
Air velocity 1 m/s								
75	15	177	6	4.6	188	4.42	0.83	2.1
110	15	177	6	2.8	186	9.50	1.77	4.4
75	10	118	6	3.07	127	4.42	0.56	1.4
110	10	118	6	1.87	126	9.50	1.20	3.0
Air velocity 2 m/s								
75	15	177	6	15.3	198	8.84	1.75	4.4
110	15	177	6	9.35	192	19.00	3.65	9.1
75	10	118	6	10.2	134	8.84	1.19	3.0
110	10	118	6	6.24	130	19.00	2.47	6.2

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In the case of ventilation of air through pipes, the situation is different from that of pumping water through pipes (See tables 2.7-1 & 2). Air is light and is easy to push. Therefore, resistance in pipes and elbows become dominant aspects of design. Losses due to friction are some 40 % less in the larger pipe. As in the case of water, it is the velocity that influences the amount of energy used to move the air.

The Table above gives some values of pushing air vertically upwards through 75 and 110 mm pipes some 10 to 15 meters. Height remains the single most important parameter, while friction in the pipes is the second-most important. In this case, also the velocity and number of 90-degree elbows are important.

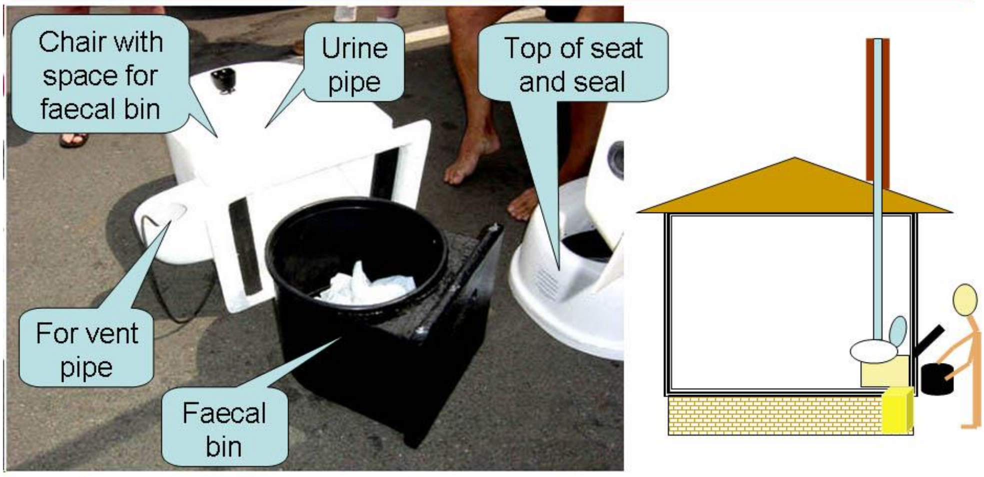
A velocity of 3 m/s pushes 13 litres of air per second, and requires about 75 second to push 1 m^3 through a 75 mm pipe. A 1 m/s velocity requires four minutes to push 1 m^3. The corresponding times for a 110 mm pipe are 35 seconds and 105 seconds, which shows that this pipe dimension has about twice the capacity of the 75 mm pipe. This, in turn, translates into higher energy usage for smaller dimensions.

Composting toilets have a potential to save on fan ventilation. Let us first consider the WC with its water seal preventing smell from faecal matter once it is submerged. However, the odour released to the toilet room during the fall from the user´s bottom to the water seal has to be evacuated regularly. A common building norm tells that all air in the room should be replaced every second hour. Let us imagine a 2 by 3 meters toilet room, which has an air volume of some 15 m^3, half of which is to be evacuated in an hour. A fan with the capacity of 3 m/s would take less than 4 minutes to evacuate through a 110 mm vent pipe. This is too often.

A composting toilet has to evacuate the small air volume in the collection box of some 1 m^3. The ventilation requires only one-fifteenth of that of the WC. Moist from showering can be reduced by removing water drops from walls and floor with a rubber scrape instead of with air.

2.7 - 10

Waterless toilet – the Kimberley type



- no water in the faecal bin
- throw paper in the bin
- under structure air tight
- empty often to avoid flies

- empty often so that bag is light
- instruct children and visitors
- co-compost faeces with organics
- keep vault and pile dry

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There are hundreds of designs of dry urine-diverting toilets in the world (Module 5.4). Many are suitable to install indoor in the house. The one in the picture is a South African model which is a modified Separett toilet made of hard plastic (www.separett.se).

The whole pedestal stands on the toilet room floor and is fixed to the wall (right). The faecal 'bin' is hidden under a sliding cover that opens when you sit on the ring. The bin is removed through an opening in the wall of the house (right sketch). Both the bin and the urine container can be picked up by someone without having to enter the house or flat. Ideally, the household has a biodegradable bag in the bin (or just newspapers) to protect it from being soiled but also to make emptying easy. A knot on the opening of the light bag and it can be placed in the compost directly or stored or collected by a farmer.

Urine (which comprises 90% of the total volume of excreta) either fills a plastic container or is diverted through a hose straight to the plants to be fertilised. The latter may cause clogging of the hose unless it is washed out from time to time. Also, a flexible pipe allows distributing the urine anywhere in the garden and thus avoiding over-fertilisation of one specific area.

The ventilation of this dry toilet is through a pipe attached to the chair just under the sliding cover (picture). There is no drop hole and in order to be on the safe side this toilet has a built-in electric fan to assist nature to exhaust foul air from the pedestal.

2.7 - 11

a) Urine-diverting pedestal in plastic, South Africa

b) Urine-diverting squatting pan in fibreglass, China

c) Urine-diverting chair in porcelain, Sweden

More indoor toilets

d) Old urine-diverting toilet in wood and porcelain, Sweden

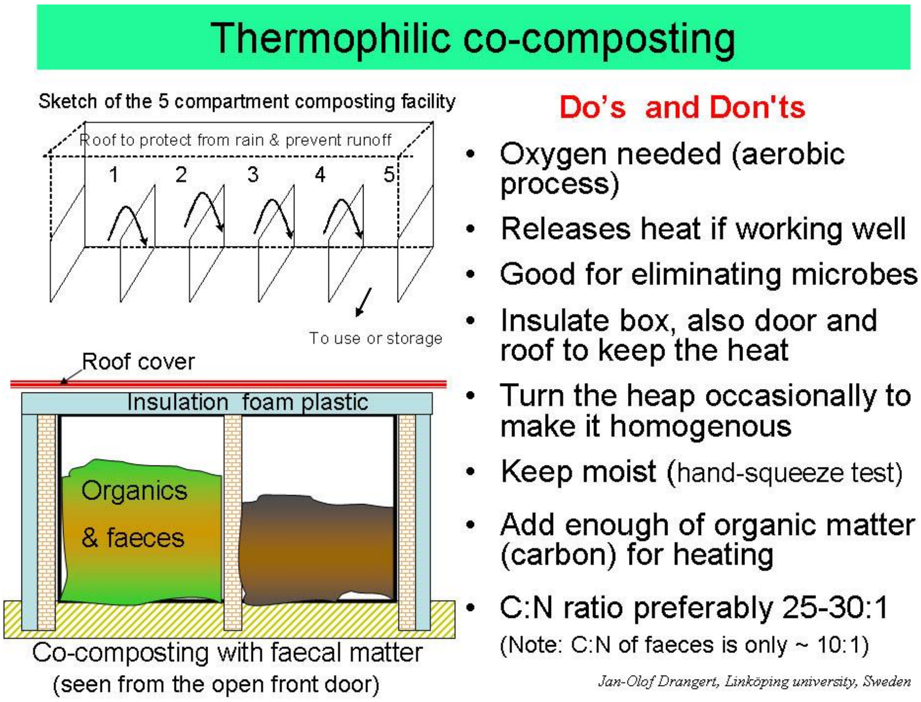
Jan-Olof Drangert, Linköping university, Sweden

There are several million urine-diverting squatting pans in rural China (b) and over one hundred thousand urine-diverting toilets with an attached urinal in South Africa (www.envirosan.co.za). The more than 100,000 urine-diverting toilets of various makes in Sweden (c) are found mainly in summer cottages.

In the year 1915 one-fourth of the flats in Stockholm, the capital of Sweden, were equipped with dry urine-diverting toilets indoors (d), while almost half had outdoor toilets with buckets, and one-third had flush toilets. The revival of the idea of diverting urine at the source was partly inspired by the 19th century invention of toilets with two bowls; the front one for urine and the rear one for faeces.

Urine-diverting toilets can also be installed in larger housing complexes with collection of the urine in one shared underground tank. The content is transported to a farm where it is stored in a urine tank until being applied as a fertiliser on farmland in the appropriate season (Module 2.1). The faecal matter and cleansing paper may be collected in a biodegradable plastic bag and disposed of in the same manner as organic waste from the household (Module 5.4).

2.7 - 12



Co-composting of faecal matter with garden and food waste can be carried out using a row of boxes (see top left sketch). Each box is roughly cube-shaped with each side being about a metre and the front wall not shown in this picture. The structure can be made of almost any material that stands the weather and coated with an insulating material (lower picture). A layer of fresh garden waste (no faeces) can be put on the earth floor of all boxes, since this lowest part of the material will never reach a high sanitising temperature. Food waste and sturdier organic material such as garden waste is added to the pile, and occasionally faeces and whatever cleansing material, and again food waste. This mixing of material continues till the box is full. In this way, food waste and faeces are mixed right from the start with some sturdier organic material. Thermo-tolerant micro-organisms in the heap have easy access to air (oxygen) and they decompose starch and other organic material and this process releases heat (see Module 4.4).

The composted material is moved stepwise (see top left sketch). The stabilised compost in the last compartment (5) is taken out to be used or stored further; the material in compartment 4 is then moved to compartment 5, and so on. If there are, say, 5 boxes and the retention time is two weeks in each box, the material has been composted for more than 2 months and turned four times or more. However, this process gives enough hygienization only if the temperature has been above 55^{o}C for four days in the whole heap (WHO, 2006). If you are uncertain about whether the material is hygienic enough to use, a good precaution is to let it rest for another few months before applying it to the garden.

Access to oxygen, the right moisture level and enough carbon are necessary for successful co-composting. If the compost is too wet, there is too little oxygen for the microbes, and another group of less efficient microbes which prefer anaerobic conditions may take over. In this case fermentation starts, and the heap releases a bad smell from methane and other gases. Unfortunately, the pathogens do not die off fast under anaerobic conditions since the temperature will hardly be above ambient temperature. Smell can therefore be used for a crude assessment of the process and if smelling, dry organic carbon-rich material should be added to make the heap aerobic. It is thus far better to keep the compost on the dry side, rather than too wet.

When the material is moved from one box to the next, its moisture content can be checked by a simple hand-squeeze test. Take a handful of the material and squeeze it gently. If it drips, the material is too wet and some dry material should be added. If the material in your hand falls apart, it is too dry, and you can add water to the compost. Lastly, if the material keeps its shape, but is brittle after being squeezed, then the moisture is just right (50–60 % moisture content). Thermophilic bacteria thrive in this environment and actively degrade all kinds of organic material. The volume of the material shrinks by 70–90 % (WHO, 2006).

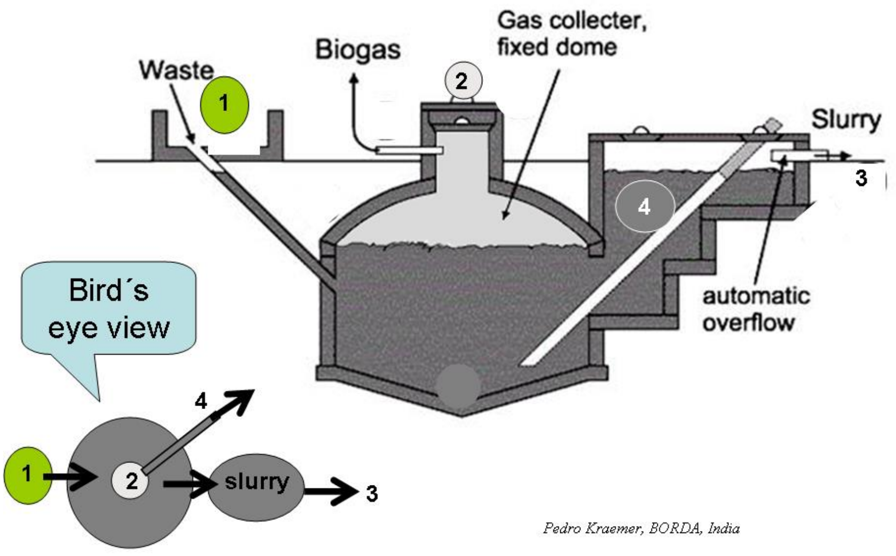
If the heat is over 55^{o}C for a few days, all the pathogens will die off since they are not thermo-tolerant (WHO, 2006). It is therefore crucial to keep the heat in the box or else it will dissipate through the roof and the composted material will cool down. The insulation material (plastic foam) of a thickness of at least 10 cm on walls and even more on the roof will increase the temperature by 10 to 20^{o}C. Without insulation there is no hygienization of the faeces, unless the operator is very skilful.

There are a number of recommendations for how to achieve high sanitation standards in operating the compost. The faecal bin (and the bin for organic waste) should be lined with (news)paper so that the bin is easy to clean. Tissue paper is organic but will take slightly longer to decompose in the compost. The fork or spade used to move the material can be cleaned with grass or paper and water, which goes into the first box and the fork is placed in the sun and UV-rays will sanitise it. It will not re-contaminate the sanitised compost in compartments 5 and 4 next time when the material is moved. If the faecal collection container is soiled it is cleaned with grass or paper and water and the cleansing material goes to the first box.

Vermi-composting is popular for ordinary composts, and some people claim that the worms speed up degradation. However, this method is not appropriate for faecal composting because of high moisture content of 70–90 %, and a low temperature in the range of 15–25°C which is far too low to hygienise the compost by killing off the pathogens.

Fixed-dome biogas digester

2.7 - 13



Pedro Kraemer, BORDA, India

A totally different way to handle waste streams from households is to decompose the mix in a biogas digester. There are several designs of biogas plants (see Module 4.4). The Chinese invention of a fixed-dome digester (picture) has the advantages of low initial cost, simple operation since the scum layer breaks automatically, and low maintenance. There are no moving or rusting parts so it has a long life. The downside is fluctuating gas pressure. Qualified and experienced masons are required to build the gas-tight fixed-dome digester.

Organic solid waste including manure and faeces are mixed with wastewater to a watery mass with a 10% dry matter content. This is fed to the digester where anaerobic bacteria decompose starch and other materials to form methane gas and other products (Module 4.4). The movement of the substrate relies on hydraulic pressure from the added feed.

The gas rises through the scum layer to the upper part of the fixed dome. As pressure builds up, the liquid content in the digester is pushed down and will escape as slurry (no. 3). If the gas is not let out (no. 2) it will start seeping out in the slurry chamber, when the substrate level is at its lowest position. So, it is easy to know from the smell when to empty the gas. Once gas is taken out (no. 2) the liquid substrate rises again and the crusty scum layer on top breaks into pieces when it is pressed up against the upper part of the dome since the diameter of the dome is ever smaller. This makes the system very robust and there is no need to enter the reactor or use a mechanical device to crack the scum crust.

The white pipe (no. 4) is used to empty the degraded sludge at the bottom of the reactor. This pipe is not inserted through the slurry opening as it seems to in the diagram – it enters from another direction (as shown in the bird's-eye view). This sludge can be used as fertilizer. The slurry (no. 3) is still rich in nutrients (except N) and other compounds that have not been decomposed. Therefore, it is suitable to be used as fertiliser. The digester is not meant for reduction of pathogens, but there is a 90 to 99% reduction of pathogens. Further treatment in e.g. a wetland filter is required to make the effluent safe to irrigate the garden.

(a) Increase ambition without stretching capacity

2.7 - 14

Up to now, we have given technical recommendations on how to build and construct in order to minimise operational and maintenance problems (= nuisances).

We have discussed how to design and install

- ventilation with care to avoid smell
- grease trap with care to avoid smell and clogging
- urine pipes with care to avoid blockages
- greywater pipes with care to be able to use the effluent
- compost with care to assure decomposition and die-off

Sustainability is not only about technology, but equally important are human resources and how to organise, build and operate sanitation arrangements.

Jan-Olof Drangert, Linköping university, Sweden

The technical recommendations aim to improve the functioning of sanitation arrangements. This will ensure comfort and save time and money for the residents. It will mean that contractors, builders and others will not be inundated with complaints, and will also reduce the pressure on municipal councils. Poor design and construction, on the other hand, will result in bad smells, clogged pipes and increased health risks, all to be borne by the residents.

Large sanitation projects and large manufacturers of toilets should produce detailed manuals which guide the construction and installation work. Standards, codes and monitoring of these are important tools to assist in getting things right from the start. It is much more expensive to rebuild or retrofit than to install the arrangement correctly in the first place. Training of architects, engineers, plumber and masons is part of the package to improve sanitation arrangements. Codes and standards offer guidance on how to design and build toilets and treatment units, but if the same norms that apply for the house itself are applied to a toilet unit, the toilet tends to become unaffordable. The norms have to be adapted to local circumstances, while still fulfilling reasonably high functional criteria.

It is deemed easier to introduce correct information in a manual than to train project staff and masons on all the nitty gritty details of sanitation installations. The manual includes what has previously been recommended for urine pipes, ventilation, well-ironed and easy-to-clean floors, etc. It also gives advice on the order of tasks to be done. For instance, to make a hole for the urine pipe when building the wall, instead of punching the hole after the wall is finished. Such unnecessary mistakes increase costs and often leave behind spots difficult to clean.

Such a manual could be composed of pairs of pictures, the left picture showing the correct way and the right picture showing the most common or serious fault. These pairs could cover every step of the construction and installation and suggest the best practices to be followed. The mason, the inspector, and the house owner can easily compare the reality at the building site with the two pictures and the mason can rectify any faults immediately. The alternative is to wait till the building is erected and the contractor agrees to partly demolish the structure to get it right. The only person with the time and motivation needed to do such daily “inspections” is the house-owner.

Quality of construction and good finishing of installations requires – beyond skilled masons and plumbers and proper drawings – care and sense of responsibility for the outcome, and not rounding corners. Checking quality of work relies on knowing what to look for and observation skills. However, observation is embedded in culture and often means that only certain things are observed (smell) and others are neglected. Therefore, it is important that both women and men are involved in inspections. Wrongly slanting pipes, too many elbows on pipes, potential leaking joints, and not smooth and easy-to-clean surfaces are examples of faults that will aggravate operation and maintenance. Such negligence occurs more often for new technologies.

There will always be insufficient number of qualified (and honest) consultants, contractors, and inspectors. This scarcity of manpower has to be addressed in any community and any project. The solutions are often found outside the sector, using unconventional approaches. A broad look at the availability of human resources in a community has to be married with the interest among them to get the design and construction right. Sometimes the residents themselves can supply this lacking resource, and sometimes it takes other groups outside the sector such as training institutions.

The following pages provide a set of recommendations which deal with management issues.

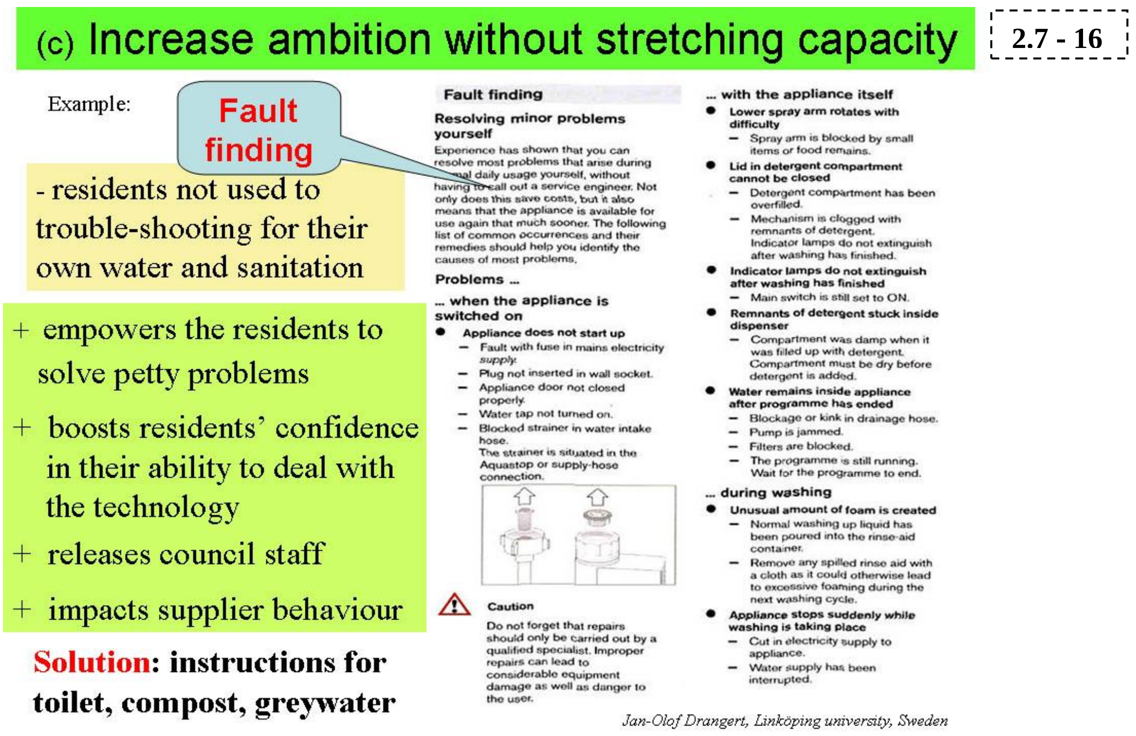
2.7 -15

Urban agriculture is popular in some communities, in particular gardening. Nurseries, flower shops, media and study circles provide sufficient support for residents, and there is no need for the municipality to be involved, except for providing supportive by-laws. In many cities by-laws prohibit some or all urban agriculture. They may even prohibit households from keeping a hen or rabbit in the garden. The first step is to revise such by-laws and make sure health inspectors understand the value of food production in urban areas.

In other communities residents are reluctant to be involved in urban agriculture. A political issue is how to encourage urban agriculture to improve food security. If residents are reluctant they may have good reasons, such as poor self-image, noise of a cock in the morning, earns more at work, etc. Instead of trying to push residents, the approach can be to organise garden shows and competitions. Depending on ownership of the plot, it may also be possible to offer some of the open space in a neighbourhood as allotments to interested persons, even to people not living in the area. Reluctant residents will protest against giving others access to 'their' piece of land, and they may prefer to do it themselves rather than have others grow food in the vicinity. Indirectly such measures impact on how urban food production is viewed and this is achieved without a large expenditure of council or housing company resources.

Another way to promote urban agriculture as well as other sustainable household activities is to engage mass media, churches, etc. Their ongoing activities can be complemented by making environmental efforts credible and widely known and thereby modifying social norms.

Most of our training institutions have student projects as part of the curriculum. This is a resource which, for almost no cost, can be used for investigations and small sanitation-related projects. There is a host of possibilities within the environmental field where students can contribute important knowledge and practices to urban agriculture. Municipalities and companies can engage students at a minimal fee to do something useful and exciting by giving them an opportunity to use and extend their knowledge. The right-hand picture shows students doing fieldwork by studying a greywater treatment unit. Such two-sector cooperation is mutually beneficial and will make the students' studies more relevant and add to the competence of the training institution. The engagement will result in better practices in the future with minimal input from the municipality or building company. And not least, residents will benefit from such cooperation.



Why do manufacturers of mobile phones, washing machines, cars etc. provide customers with a manual for operation and maintenance? Essentially in order to have more satisfied customers and to save company money. Let us assume that it takes two hours to manufacture a mobile phone. If we spend twenty minutes in the shop asking simple questions about how to start the phone, or how to delete some information, we have taken 15% of the time to produce the phone, and probably the whole profit margin. The company cannot afford that, so they prefer to spend money on a good manual in order to receive as few uniformed questions as possible from the customers. The customers are also prepared to use the manual because they save time and, if successful, gain self-confidence.

Why is something similar not done for sanitation devices? Well, the market is not very competitive. But more important is who is responsible for answering customer queries. In the case of the mobile phone, you return to the shop or get in touch via internet. But if your toilet is smelly, the builder is not around; you do not know who the plumber was, etc. So, you end up trying to identify the project management – if they are still around. Or you may get in touch with the council or its consumer complaint board. No one really cares whether your toilet is smelling or not. If the toilet was installed as part of a project, the management might even be happy because then they may ask for funds for rehabilitation of the toilets.

The solution is for manufacturers of specific items to provide manuals for each item. And the manual for system issues should be prepared by councils (water and sewage departments or waste departments) or projects or universities depending on the local situation.

An example of a fault/finding exercise is given in the picture (regarding a washing machine). The information may be formulated in different ways, but it addresses one problem at a time. For each problem, the checklist starts with the easy-to-fix faults, and continues with more difficult ones. For each fault there is a suggested measure to solve the problem, sometimes with an explanation.

On the next slide, some indicators are given for the proper functioning of sustainable toilet arrangements, and an exercise on producing a fault-finding manual appears in slide 2.7 - 18

Check-list: indicators for dry UD toilets

2.7 - 17

Toilet room
- 1. Smell?
- 2. Flies?
- 3. Second drop-hole closed?
- 4. Cover for the drop hole in use?
- 5. Ash/other drying agent available?
- 6. Urinal functional? Smell?
- 7. Clean floor?
- 8. Clean squatting pan?
- 9. Cleaning utensils in the room? broom etc.

Outside the toilet room
- 1. Vent pipe insert in floor intact?
- 2. Pipe insulated above roof?
- 3. Fly screen intact?
- 4. Vent pipe properly fixed to wall?
- 5. Quality of door and hinges?
- 6. Lock on door?
- 7. Quality of stairs?
- 8. Urine jerry cans available?

Outside the toilet room (cont)
- 9. Handwashing facility?
- 10. Water and soap available?
- 11. Ablution water treated?

Vault
- 1. Vault door and box airtight?
- 2. Leaking urine pipe?
- 3. Equipment stored in the vault?
- 4. Amount of faecal material in vault?
- 5. Kind of wiping materials?
- 6. Plastic, broken glass, etc. in vault?
- 7. Moist pile, or liquid on the floor?
- 8. Stick to pull down top of heap?

Agriculture
- 1. Reuse of urine in situ?
- 2. Garden suitable for reuse?
- 3. Reuse of dehydrated faecal matter?
- 4. Contract with farmer/entrepreneur?

Jan-Olof Drangert, Linköping university, Sweden

The operation of an sustainable urine-diverting toilet can be checked by using a number of indicators. The list above is organised according to location, and brings up points which are likely to cause problems. There are two uses for a check/list. One is for monitoring of the system, and the other is to identify what needs to be included in a fault finding manual. Firstly, some comments are given to the above points.

It helps to distinguish between the smell of urine, faecal matter and wastewater in locating the origin of a smell problem. Our nose is the tool and has to be put close to each corner of the toilet room and installations, just like a detective would do. It is easier to identify the origin of bad odour if the floor, squatting pan, and cleaning utensils are cleaned beforehand.

Flies can be attracted by smell but also by light. Take a look at the toilet room from the fly's point of view. A moist faecal pile or liquid on the vault floor attracts flies. Therefore, it helps to cover the pile with a drying material such as wood ash, sawdust or even dry sand.

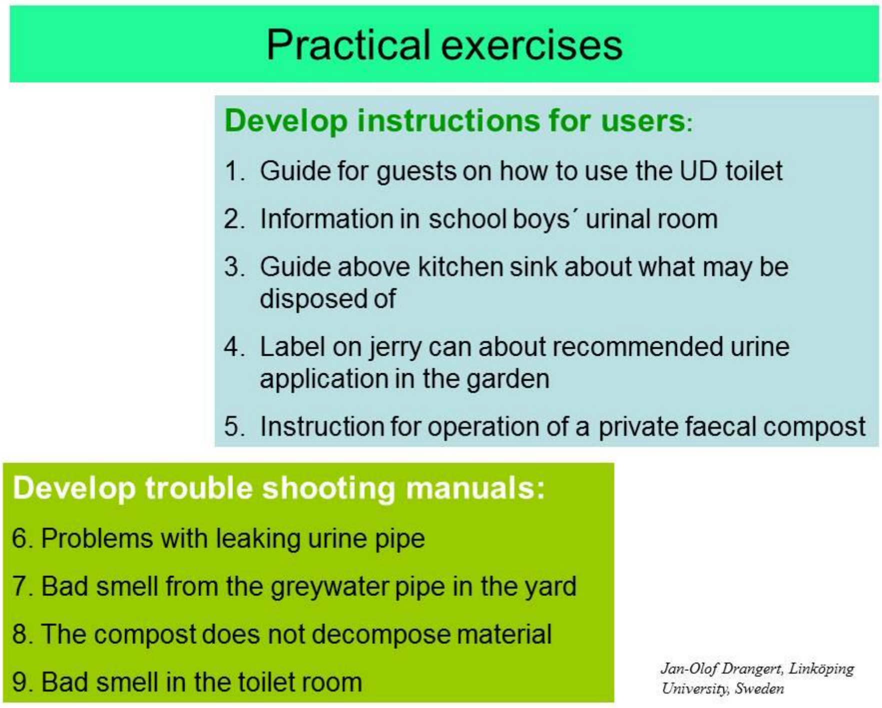
The direction of air flow at the drop hole is easy to establish by watching the smoke from a lit cigarette. If the air current goes in the wrong direction, a cover for the squatting pan or lid for the toilet chair minimises the escape of smells from the vault. Also, the cover and lid increases the speed of the air passing by on its way down the drop hole (slide 2.7-7).

The condition of the vent pipe is decisive for air flow and intruding water. The vault and the door used for emptying it must be air-tight in order to achieve optimal evacuation of air from the toilet room.

The extent of use of the toilet is indicated by the amount of faecal material in the vault and also if there is an alternative toilet on the plot or in the house. Plastic, broken glass, etc. in the vault is an indication of a low appreciation of the unit, and possibly also of a lack of understanding, and a lack of appropriate facilities for the disposal of such waste.

The size of the garden is important for assessing the recirculation opportunities. Is only urine used or only faecal matter?

2.7 - 18



Students, preferably working in groups of two, tackle one of the nine tasks in the picture. The first five tasks deal with instructions to users about how to operate the installation correctly. For each of the five situations there are many recommendations. The task is to select the most important ones, and make a short, easy-to-understand set of instructions. A helpful selection tool is to think through what quality is desirable for the discharges. Work backwards from there to select the measures you find most appropriate to recommend. The instruction should not contain more than two or three messages, since the reader is not supposed to stand and read the instruction carefully, but rather just have a quick glance at it.

The messages can be delivered as a drawing or written text, or as a combination. Remember that pictures can convey additional messages that are intended or wanted. Therefore, the suggested instruction should be tested on fellow students in the groups.

The trouble-shooting manual requires more space and the reader is expected to read slowly. He or she wants comprehensive guidance for finding answers to questions or finding a solution to a problem (slide 2.7-18) for washing machine example).

An example is provided in the following to outline what can be expected as an outcome of the exercise discussions. The chosen problem is that “it smells from urine in the toilet room”.

1. Sniff around the urinal to locate the origin.
2. Find out if the smell is from inside the bowl or from the floor or pipe fittings.
3. If the smell is (a) from the pipe or leaking connections they have to be cleaned and tightened. If it still smells, the search continues.
4. If it is from the floor (b) it should be cleaned thoroughly of standing urine. Test the smell again after the floor has dried up (a long-term solution is to paint the floor to prevent urine from being sucked permanently into the cement. The space between tiles in the floor which have not been sealed with special water-resistant cement or silicon may have to be redone correctly).

5. If the smell comes from the bowl it should be cleaned with some water or acid (vinegar) but not chemicals since these will affect the stored urine negatively. If this measure does not help, pour some hot water or caustic soda into the urinal to remove potential urine crystals/salts which have settled in the pipe and prevent urine to flow freely. If the smell remains, check if the urine pipe into the collection container is above the level of urine. If so, the urine pipe should be inserted further to some 3 cm from the bottom. Now, only the area of the cross-section of the pipe can emit smells reaching the toilet room. If the urine pipe is inserted into the container in such a way that it is (almost) air-tight, bad smells will not reach the toilet room.
6. If the urinal still smells, the only solution will be to prevent air flow in the pipe. Disconnect the pipe under the urinal and attach a rubber (preferably a condom that has been cut at the top and lengthwise with two slits, so that when attached to the urinal pipe the two rubber flaps stick together. When urine comes along the flaps allow it to pass, and then stick together again. In this way no bad air can backflow to the toilet room.

This trouble-shooting can be summarised as follows:

- Find out if the smell comes from the floor, fitting or inside the bowl.
- Clean the floor thoroughly.
- Tighten the urine pipe connections and clean them all.
- Clean the urine bowl with a damp cloth or vinegar.
- Pour hot water into the urinal to remove settled salts.
- Pour biodegradable caustic soda in the urinal. NB. Do not use any chemical since it will destroy the urine in the container and make it useless as a fertiliser.
- Make sure the urine pipe reaches almost to the bottom of the container (to minimise the area that can emit smells).
- Check that the entrance of the urine pipe to the storage container is (almost) air-tight.
- Prepare a condom or other rubber tube to prevent urine odour from flowing back into the urinal.

See also the School toilet Module 5.3.

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