A Study on the Reconstruction of the Ventilation System of the Dry-toilet at Haozhaokui Community of Erdos City

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Zhu Tianle, Professor
Environmental Engineering Department
Beihang University, China

ABSTRACT

The urine/feces separation dry toilet is capable of saving water resource, reducing the investment & operation cost of the sewage treatment system, and making full use of the nutritional ingredients in the feces and urine. Therefore, it is increasingly stressed by the public and governments, especially in the developing countries. Currently, such toilets are being applied at some rural districts and small towns, in which China-Sweden Erdos Eco-town Project (EETP) in Haozhaokui Community of Erdos City, Inner Mongolia is the largest EcoSanRes programme of utilizing the dry toilet so far. In order to better exploit the social, economic and environmental benefits of the project, and to avoid such adverse effects as transmission of diseases and deterioration of the indoor sanitary conditions, this study analyzed the existing problems in smell isolation, feces storage mode, ventilation, construction quality and routine maintenance & management, and proposed the corresponding reconstruction measures. And, the following reconstructions have been implemented: adding S-type water trap to the wall built-up urinal, adding odor isolator to the toilet, replacing the sponge sealing with the sealed cabinet, replacing the axial fan with centrifugal fan with bigger capacity, balancing the pressure loss of the ventilation branch ducts by using the inclined Y-shape tee joint, regularizing the duct arrangement, and so on. Meanwhile, the specific requirements are imposed on the system management/maintenance and daily use of users. After taking the above measures, the odor problem has been much mitigated. There was subjectively no more peculiar smell in the reconstructed toilet rooms. And, the ammonia concentration in the toilet rooms has dropped to less than $0.2mg/m^3$, satisfying requirements set forth in "Standards for Indoor Air Quality" (GB/18883-2002).

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1 Overview

During the period of "10th Five-Year Plan", the state has attached good importance to the implementation of the sustainable development strategy, which is aimed at saving resources, protecting environment, coordinating the relationship between economic development and resource/environment protection, and constructing the resource-saving society. Along with the increase of global population and the rapid development of urbanization and economy, the severe water pollution and water shortage has emerged within an ever-larger range. The studies on the protecting freshwater resources, decreasing sewage discharge and utilizing wastes have become the important subjects for sustainable development. And, a number of policies and regulations have also been promulgated.

Under such a situation, all industries have carried out a series of reforms under the guidance of the policy of reserve-saving and waste-recycling, in which the toilet revolution also becomes a critical part. Traditional toilets don't recycle the human excreta and the nutritional ingredients are wasted, which tenses up the currently severe situation about resource shortage. The application of flush toilet consumes substantive clean water and causes greater shortage of water resources. Therefore, the toilet revolution is of great importance not only in water-saving, but also in the reclamation and the reuse of wastes.

1.1 Toilet types and their features

Toilet, as an indispensable sanitary facility plays an important role in people's daily lives. However, it was indicated on the World Congress of Fresh Water Resources held on December 3-7, 2001 that 2.4 billion of people are unaware of the sanitary facilities, and 2.8 billion of people are still using the simplest pit toilet. About 10 million viruses, 1 million bacteria and 100 parasitic ova can be released by a few grams of human excreta after being put into water. In such a situation, the sanitation safety of people's dwelling environment cannot be effectively guaranteed, while the scattering of multiple causative organisms under fragile control may result in the spread of a great many diseases and cause adverse effects to both the environment and human health. In regard to if the water is used or not, the toilets can be classified as: flush toilet and dry toilet. Among them, the flush toilet is considered to be the ideal sanitary facility.

As shown in Fig 1.1, the construction, installation, use and maintenance of the flush toilet are of great convenience. However, the flush toilet also has certain drawbacks. Firstly, it consumes extensive water to flush away feces and urine. The survey shows that an adult excretes 400-500 liters of urine and 50 liters of feces per year, while the consumed flushing waster can reach as high as 15000 liters, counting for 1/4 to 1/3 of total domestic water consumption.

Fig 1.1: Flush Toilet

At present, the world is suffering from the severe shortage of water resources and over 1 billion of people are unable to obtain enough clean drinking water, and over 6,000 children die from water shortage or unclean water every day. Under such a situation, the behavior of using clean water to flush the toilet is considered a great waste. Meanwhile, the traditional flush toilet requires considerable investments and operation cost because water supply & sewerage treatment systems have to be constructed. In addition, the human excreta contain many useful nutrients. The use of flush toilet causes the waste of such resources, makes them become pollution sources. Therefore, the traditional flush toilet is not perfect.

The traditional dry toilet is the pit toilet as shown in Fig 1.2. The pit toilet is generally constructed outside the dwelling house, and can be classified into deep-pit dry toilet (with a pit as deep as 1.5m or over) and shallow-pit dry toilet (with a pit as deep as 1~1.5m). Such toilets are easy to be constructed and don't consume any water. However, the pit toilet may be harmful to the environment.

Fig 1.2: Pit Toilet

A survey conducted in 174 villages of 9 towns & townships in China showed that the portions of households that use shallow-pit dry toilets, deep-pit dry toilets, and flush toilets are 54.6% %, 14.9%, and 27.1%, respectively. The rest 3.4% of the households use a public toilet as they do not have a private one, as shown Figure 1.3.

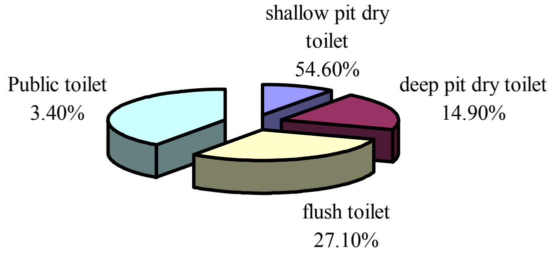


Fig 1.3: Types of Toilets Used In Rural Areas

We can see that the majority of households in the research-targeted area use shallow-pit toilets. The disadvantages of this type of toilets are

a) Because the excrements store pond has no anti-infiltration mechanism, the pit bottom of the toilet easily collapses, which may shake and endanger the foundations nearby buildings.

b) Foul odor dominates the place and flies heavily breed. The air is polluted. The major components of the foul odor are ammonia，methane，hydrogen sulfide，etc. Prolonged exposure to these gases is likely to jeopardize human physiological function.

c) Some pit-type dry toilets do not even have a roof. When there is profuse rain, water will come into the pits, and is likely to overflow.

Pit toilets are likely to pollute the soil and underground water. A survey on rural drinking water and toilets conducted in 10 counties and cities shows that pit-type dry toilets do affect phreatic water. The monitoring of the phreatic water samples indicate that the bacteria quantity is significantly higher than that regulated in the National Hygiene Standard.

The various problems with traditional toilets in the rural area call for the use of ecological sanitation toilets. Ecosan toilet is not only friendly to environment and water-saving, but it also helps to revert nutrients to the soil. To be more specific, Ecological sanitation is implemented on basis of three principles: preventing pollutants from discharging rather than treating the pollutants; sanitizing both urine and feces; applying treated excrements to agricultural production. The gist of such sanitation approach is sanitization and recycle. And the so-called pollution prevention is to stop spreading of pathogens and pathogenic bacteria. Under specific circumstances, different treatment methods could be employed to attain this aim, such as urine/feces source separation, bacteria decomposition, composting, packing etc. The treatment is to kill harmful bacteria in the feces to make the nutrients therein nuisance-free, so as to be used as fertilizer for agricultural production. In this way, feces are sanitized and recycled. The system of eco-toilet is a looping process of regenerating and reusing resources, which runs right in line with China's current development strategy of sustainable development and cycle economy. At present, the major globally popular types of Ecosan toilets are:

1) Urine/feces separation eco-toilet

A urine/feces separation eco-toilet refers to one that urine and feces are respectively collected and treated. In the urine/feces separation eco-toilet, urine goes into a store tank through a drainage pipe, where some special chemicals are added; then it is used for agricultural production. Feces, on the other hand, is blended with some filling agent before treated in dehydration process to have the dwelling parasites and pathogenic bacteria killed; and then, with nutrients retrieved, it is used in farm fields as fertilizer. This type of toilet is not only good for its properties of water-saving and environment-friendliness, but also it is a radical solution for the dilemma of feces recycling and deterioration of both resources of feces and water, since no water is added in the process of feces treatment, so that valuable nutrients are preserved in the feces.

2) Urine/feces combined processing eco-toilet

A urine/feces combined processing eco-toilet is to decompose the organic matters of feces in the bacteria’s metabolic process, with H_2O and CO_2 as the target products. The water produced in the process can be reused for toilet flushing after appropriate treatment, or can be discharged when it is up to environment protection standards. There are four types of combined processing: aerobe approach; membrane separation approach; highly active overwhelming bacteria approach; and anaerobe approach. A urine/feces combined processing eco-toilet does not consume fresh water for toilet flushing. This is water-saving, and the urine used for flushing is not a pollutant for environment. But there also exist some drawbacks in this kind of toilet. Firstly, the toilet’s internal environment has to facilitate the growth of the bacteria helping with the processing. Secondly, the process requirements, such as temperature, humidity, oxygen content, pH value, etc, are overcritical. Besides, in the course of the bacteria’s metabolic process, methane and incontrollable reclaimed water are produced. The former is explosive, and the latter will add to the possibility of cross contamination in the course of recycling.

3) Dry packing-type eco-toilet

A dry packing-type eco-toilet means putting excrements in special bags for convenience of transfer. The bags are generally made of biodegradable plastic films. The whole toilet consists of bags, the mechanical system, and the store tank. Whenever a user finishes defecation, the mechanical system will pack and seal the excrements so that bad smell does not escape. A specialized operator will collect and transfer the packed excrements to a centralized processing plant for further sanitization treatment. The advantages of this type of toilet are that no water is needed for flushing and there is no pollution in or from the toilet itself. But the packed excrements could leak and cause secondary pollution. In order to prevent such shortage, cost of transfer will have to be higher. Besides, the cost of supporting human labor is considerably high.

4) Dry composting toilet with bacteria

The key component of the toilet is its reactor with biological stuffing. Excrements are decomposed in the reactor by bacteria. The reaction will bring temperature up to an extent that pathogens and other bacteria in the excrements are killed. Depended on whether oxygen is needed in the composting process, the toilets can be further classified into the aerobe type and the anaerobe type. During the compositing, the excrements will be turned into organic fertilizer. The fertilizer can be directly applied to agricultural production.

5) Biodegradation dry toilet

A biodegradation dry toilet degrades human feces with the help of specially cultivated bacteria, which will produce high protease that is able to degrade organism. They will reduce the organic matters of feces into small molecules of sugar, fatty acid, amino acid, etc., which are further reduced into H_2O and CO_2 later on. Plenty of heat is released during the degradation process. The high temperature will be sufficient to kill pathogens. And the final product is a sort of organic dregs rich in nutrient elements of nitrogen, phosphor, potassium, etc. It can be used as fertilizer. The advantage of biodegradation dry toilet is that no fresh water is needed, and that nutrients in feces can be retrieved. Its drawback is the difficulty to maintain correct urine-feces ratio as required by the specially cultivated bacteria in their multiplying process.

6) Solar-powered dry toilets

A solar-powered dry toilet dries human feces by means of solar energy. The external wall with sunny exposure is maintained warm and utilized as a solar collector, where a number of adaptable ventilating ports are installed so that the warm air inside the heat absorbers are automatically exchanged with the cold air inside the toilet. And feces are dried and sanitized while the air is circulating to gain thermal balance. This is significant for areas with poor heating condition. The solar power system not only keeps up the room temperature, but it also help to prevent water pipe from bursting in the toilet. In this way, possible repair & maintenance cost is kept low while making best use of energy. A solar-powered dry toilet is a convenient, beautiful and clean toilet with high economic, environmental and social benefit. The disadvantage of the kind of toilet is that bad smell would not get out of the toilet and feces are not dried promptly during rainy and overcast days. In this way, the humid feces will breed pathogenic bacteria and jeopardize living environment. The Table 1.1 gives the features of all the above-mentioned toilets.

Table 1.1 The main toilet types and their features

Toilet Type	Flushing Water	Drainage	Bad Odor	Environmental Pollution	clean-up & Convey	Disinfecting
Traditional Dry Toilet	no	no	yes	yes	yes	no
Traditional Flush Toilet	yes	yes	yes	yes	yes	no
Urine/feces separation Ecosan Toilet	a little	no	a little	no	yes	yes
Urine-Feces Combined Processing Ecosan Toilet	a little	yes	a little	yes	yes	no
Dry Packing-Type Ecosan Toilet	no	no	a little	yes	yes	no
Dry Bacterizing Composting Toilet	no	no	yes	yes	yes	yes
Biodegradation Dry Toilet	no	no	no	no	no	yes
Solar-Powered Dry Toilet	no	no	yes	yes	yes	no

1.2 Urine/feces separation dry-toilet

1.2.1 Definition

In 1985, in his book named "Sanitation without Water", Mr. Uno Winblad of Sweden put forward the idea of "Not to mix feces with urine or with water." This laid the foundation for urine/feces separation dry-toilet. The gist of urine/feces separation is to separate feces from urine at the source. Urine is collected in a separate tank, and directly applied in farm fields after preliminary fermentation. On the other hand, feces are dropped into storage devices, topped with some plant ashes or fine earth, then ferment and get dry. Pathogenic bacteria and parasites that dwell in the feces are killed in dry condition. The feces are totally sanitized after half a year's time. The dried feces are loose and odorless that looks like humus soil. It is a very good fertilizer.

1.2.2 Feasibility of urine/feces separation dry-toilet

The gist of an ecosan toilet is to sanitize human excrements, recover their nutrients, and then utilize them. A urine/feces separation dry-toilet is an innovation on basis of a traditional dry toilet. The human body has separate systems for generation of urine and feces, and separate channels and mechanisms for their excretion. This is the primary factor to support urine and feces separation.

Studies show that urine, except the smell, is basically harmless because it doesn't carry pathogenic bacteria. But on the other hand, feces contain numerous bacteria, parasites, and other microorganism. Therefore, feces are considered a tremendous carrier of pathogens that will cause diseases like schistosomiasis, typhoid, diarrhea, hepatitis A, etc. According to statistics, a person averagely goes to toilet for 6-8 times every day, which is about 2500 times a year. The excrements carry abundant nutrients, with predominant quantity of nitrogen, phosphor, and potassium. An adult's average annual production of excrements contains 4.5 kg of nitrogen, 0.5kg of phosphor, and 1.8kg of potassium. And 80% of these nutrients are in urine. So, recycling of urine is simply a matter of resource reusing. On the other hand, feces are not a fertilizer as good as urine. But they help to increase variety and quantity of microorganisms in soil and improve the soil's aeration and water retention property. They are an excellent soil improver that helps to improve soil hardened and degraded in productivity because of abuse of chemical fertilizer. Therefore, implementation of urine/feces separation dry-toilet not only avoid pollution of large quantity of clean water resource by even a tinny quantity of feces, but the nutrients in human excrements are well recycled and utilized. This ideology answers for China's current situation of environment and resources, and meets the requirement of sustainable development.

Two major approaches are applicable at urine/feces separation dry-toilet for elimination of pathogens in human feces. They are dehydrating approach and decomposing / composting approach. The principle of dehydrating approach is to make feces dry and maintain a certain length of time to let most of the dwelling pathogens die. The primary condition for realizing this approach is separation of urine from feces. No water should be let into the feces storage system. And the drying process can be sped up by adding some sawdust. On the other hand, the principle of decomposing approach is to let feces-dwelling pathogens and pathogenic bacteria got killed in the process of feces decomposition while a series of physical, chemical, and biological actions take place.

1.2.3 Significance of urine/feces separation dry-toilet

A urine/feces separation dry-toilet is simple in technology, but represents the currently foremost concept and trend for human excrement treatment. It signifies that ecological sanitation approaches are attracting more and more public concern. In view of the present global condition of resource and energy, the implementation of urine/feces separation dry-toilets will help more and more people to involve in environment protection activities, so that the ideology of environment protection and resource caring will sink in with everyone in everyday life. This creates good social effect.

So far, the majority of towns do not have a diversion system to separate greywater from rainwater, so that greywater mixed with toilet flushing water merges with rainwater in the sewage treatment network. This adds to the burden on sewage treatment system and brings up equipment cost. And a small quantity of flushing water pollutes a large quantity of greywater. It causes hideous waste of water resource. The receiving waterbody is likely to have eutrophication and red tides, and the various pathogenic bacteria that lurk in feces are likely to cause spread of infectious gastro-intestinal diseases and parasitic diseases. The local resident’s health is endangered. In urine/feces separation dry-toilet system at Haozhaokui community of Erdos city, blackwater is separated with greywater. While nutrients in human excrements are recycled, the rivers and lakes are saved from eutrophication, and flushing water is remarkably reduced in quantity. Saving of water is of good social benefit nowadays when water shortage is becoming a more and more pressing issue. Urine/feces separation dry-toilet also help to reduce water treatment facilities investment and operation expense. Studies reveal that if we replace all the flush toilets with urine/feces separation dry-toilet, about 5 billion tons will be saved.

Urine/feces separation dry-toilet separates urine and feces at the very source. This not only preserves the nutrients in the urine, but also curbs the breeding of microorganisms in feces. The concept is to prevent pollution instead of treating after allowing pollution, and to implement local treatment of feces instead of a centralized handling. Therefore, a urine/feces separation dry-toilet has very high practical value and environmental significance. It is the major technology being popularized currently.

2 The Problem Identification for Ventilation System in the Dry-toilet

2.1 Background information

2.1.1 An introduction to the Haozhaokui community

Located in the heart of Erdos highland along the upper reaches of Yellow River in West Inner Mongolia, Erdos City has a geographic location of 39°50′north and 109°59′east, with a mean sea level between 1000m and 1500m. Boasting a unique natural environment, Erdos is high in the east and low in the west, with complicated and diverse landforms. Characterized by the typical continental climate of the temperate zone, this area is abundant in solar radiation and distinctive in four seasons, with a short duration of frost-free period, lesser rainfall precipitation and disproportionate spatiotemporal distribution. Erdos is also featured by a great evaporative capacity. The number of days with wind of gale force greater than Grade 8 can reach 40 or above, while the frost-free period can reach 130-160 days.

Financed by Swedish International Development Authority and jointly implemented by Stockholm Environmental Institute of Sweden and Dongsheng District People's Government of Erdos, "China-Sweden Erdos Eco-Town Project" is constructed by Dongsheng Environment Protection Bureau and related departments and aimed to build a eco-town capable of accommodating 2005 households at Haozhaokui Village of Tianjiao Street Office of Dongsheng District, as shown in Fig 2.1. This demonstration project is the first and largest ecosan system project being implemented in multistory buildings and applied in the city from the worldwide perspective.

Fig 2.1: Haozhaokui Ecological Community of Erdos City

This project continues to adopt the ecosan approach to apply the traditional concept of feces recycling in China's rural districts in the modernized urban areas. It is aimed to, within a coverage of a small town, carry out harmless treatment on all wastes generated by the household, allowing waste recycling.

Located at Haozhaokui Village of Tianjiao Street Office of Dongsheng District, this eco-town covers a total land area of 55.6 hectares and a gross construction area of 300,000 m^2, with the greening area inside the community reaching over 45%. Boasting a total investment of RMB 210 million, the entire eco-town project is implemented in three phases. 19.73 hectares of lands have been developed in the first-stage construction of this project and 11.56 hectares of residential communities have been built, while the completed 42 apartment buildings can accommodate 656 households, with the greening rate reaching 48%.

This ecological community fully adopts the ecosan system recommended by Stockholm International Environment Research Institute of Sweden. Capable of carrying out the ecological treatment of human excreta, domestic sewage and household refuse, this system can enable harmless and cyclic utilization of such wastes and achieve zero discharge of pollutants inside the community. Upon completion of this project, the first ecosan system based eco-town of the world will be built in Dongsheng District.

2.1.2 General aspect of the urine/feces separation dry-toilet

The urine/feces separation dry-toilet adopted by Haozhaokui Community of Erdos City boasts such features as sanitary, odorless, water-saving, environmental and convenient. Designed by Swedish Environmental Institute, such dry-toilet focuses on the separated collection and harmless treatment of feces and urine. Compared with other approaches as anaerobic fermentation to achieve the decontamination of feces, the urine/feces separation dry-toilet adopted by Haozhaokui Community realizes the harmless and fly-free treatment of feces by dehydrated drying. By adopting the urine/feces separation dry-toilet, the feces and the urine can be treated separately, and the nutritional ingredients contained in the urine can be recycled to the maximum extent, while the possibility of disease spreading caused by harmful microorganism, pathogen and parasite in the feces can be reduced to the minimum extent. Through the use of dehydration method, such toilets are characterized by the strong freeze-proof capability, and can thus be applied in cold rural districts.

In order to achieve the separation of urine and feces, the toilet of the dry-toilet at Haozhaokui Community is different from the traditional flush toilet, and it has two holes, as shown in Fig 2.2. The urine is drained through the urine hole in the front of the toilet, through which the urine from all households will be drained into the underground urine storage tank nearby each building. Then the property management station of the community uses the urine-suction vehicle to regularly suck the urine and deliver to the farmland as the fertilizer source. The feces will fall into the feces storage bin in the basement via a vertical chute connected with the rear hole of the toilet.

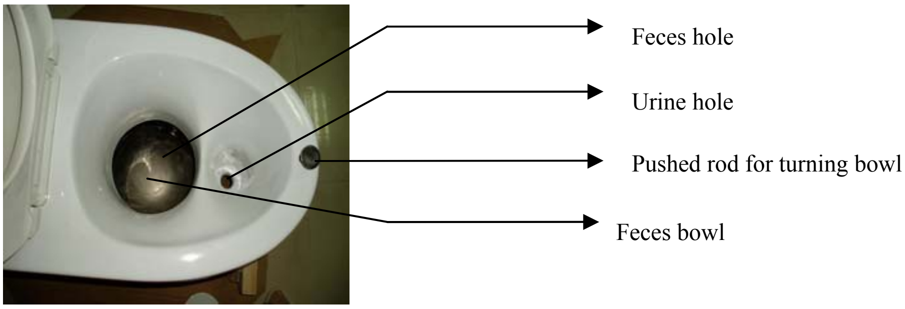


Fig 2.2: Structure of the toilet for the urine/feces separation dry-toilet

In order to avoid the bad visual feeling because of the exposure of the feces chute and the feces storage bin, a rotatable feces bowl is designed for the toilet. As shown in Fig 2.3 and Fig 2.4, the feces bowl and its supporting structure are made of stainless steel whose surface are coated with the Teflon in order to make cleaning easy. When it is not used, the convex side of the bowl faces up, so that the feces chute won't be exposed. During the use, the bowl will rotate with the concave side facing up to collect the feces by pushing the rod for turning bowl. After use, the bowl automatically turns over to drop the feces, and the convex side faces up again.

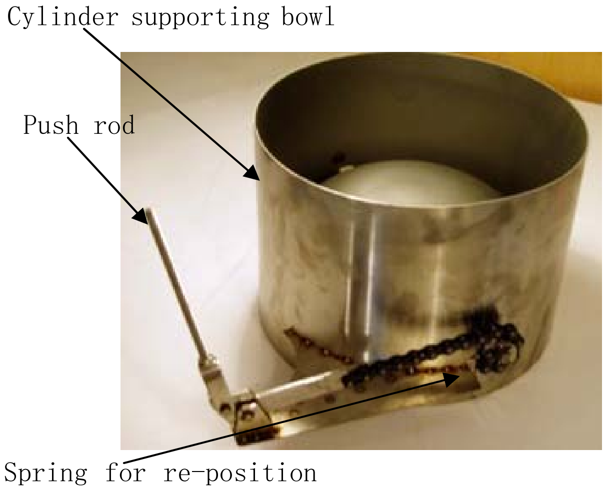


Fig 2.3 The appearance of the rotating bowl

Fig 2.4 The rotation structure

When using such toilet, a certain amount of sawdust is added to the bowl before and after the defecation in order to prevent feces from sticking on the bowl, to absorb the water contained in the feces, as well as to improve the proportion of feces ingredients. The sawdust is stored in the sawdust tank equipped with a ceramic cover with a glass observation hole for checking the fill-up situation of the sawdust, as shown in Figure 2.5.

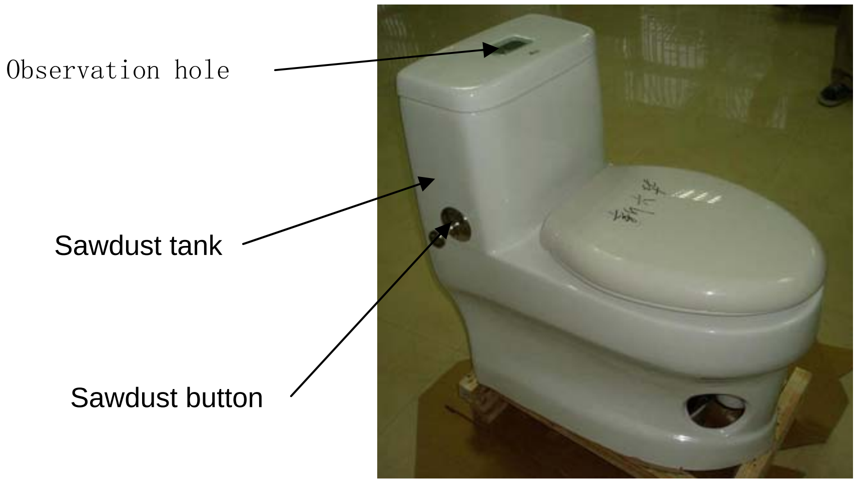


Fig 2.5 The sawdust dispensation system of toilet

Most of buildings at Haozhaokui Community are 4-5 storey buildings, and each flat is equipped with one seating toilet and one urinal. As shown in Fig 2.6, the independent feces chute is installed for each toilet and connected directly to the feces storage bin placed in the basement.

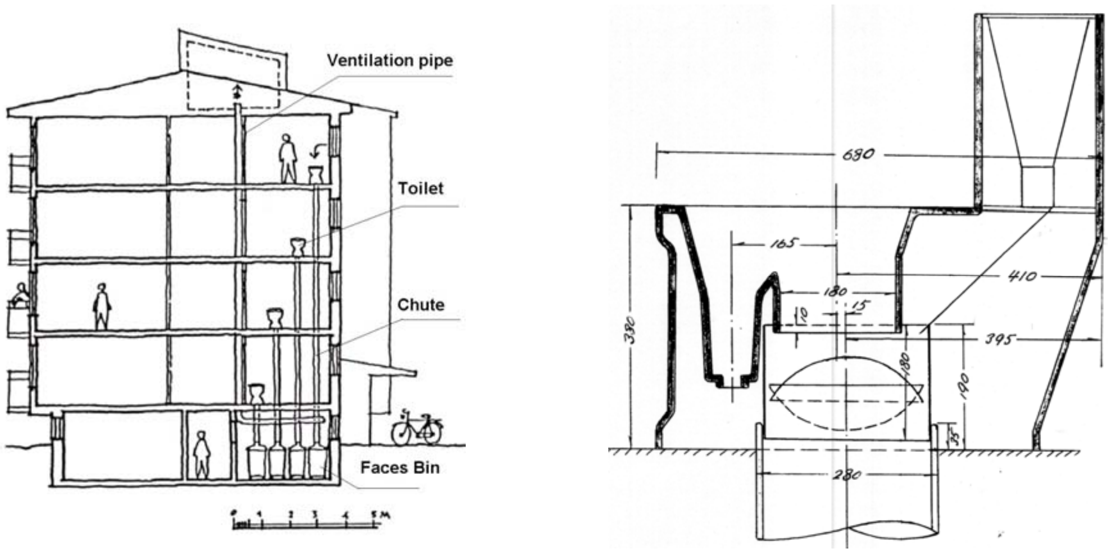


Fig 2.6 The schematic diagram of the ventilation system for toilet room

In order to exhaust the stinky smell of the toilet room and maintain the favorable indoor air quality, each apartment is equipped with a set of ventilation system connected to the feces collection system to accelerate the drying and pathogen elimination of the feces in the bin, as shown in Fig 2.7.

In the ventilation system, the negative air pressure is created in the toilet room. The air is sucked by a fan from toilet room through feces chute and vent duct flows up to the roof to prevent the odor. This ventilation system can also avoid reversed flow of the air in the feces chute and storage bin into the toilet room. After the drying process, the feces will be delivered to the eco-station of the community for composting.

The independent urine drainage pipe is installed for each toilet, and is directly connected to the underground urine storage tank. After being sealed in the tank for one month, the urine can be used for farm production.

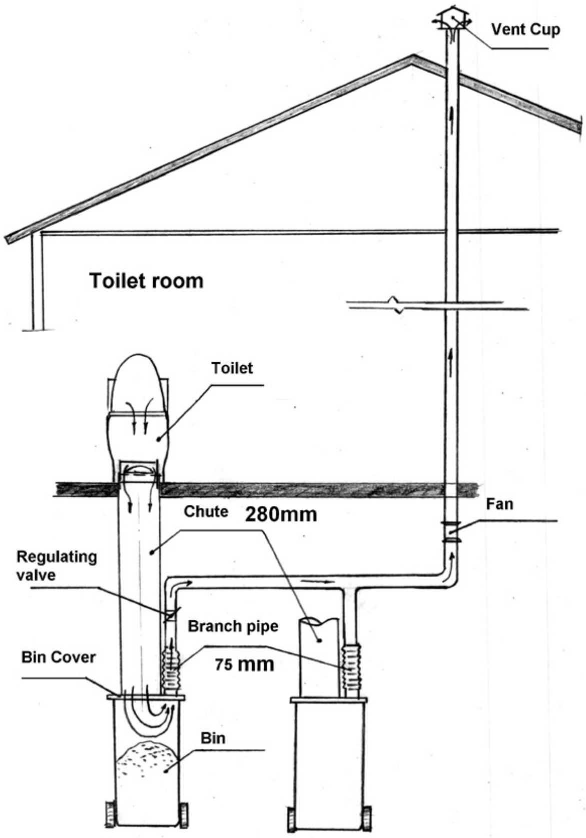


Fig 2.7 Ventilation system for dry-toilet

2.2 The problems related to the feces storage system

The urine/feces separation dry-toilet at Haozhaokui Community adopts the removable feces storage bin with a cover plate to store the feces, as shown in Fig 2.8(a) and 2.8(b). During the use, the feces will fall into the feces bin via the feces chute. When replacing the feces bin, the uplift and push-down of the cover plate are realized via a set of lever and framework system.

(a) The feces storage system (b) The uplift of the cover

Fig 2.8 The feces storage system

2.2.1 The sealing sponge is prone to aging and damaging

The feces chute is connected with the cover of the feces bin via a soft plastic pipe. In order to ensure the air-tightness of the feces storage system, the sponge material is applied between the bin cover and the bin body. The often strain would result in physical aging and slack and its internal structure thus change, which will cause further drop of its various performances. During the field survey, it was noticed that some sponge sealing materials had been broken, as shown in Fig 2.9. As a result, the air in the basement seeped into feces bin from the broken part, which, thus, decreases fresh air amount to displace the odor air in the toilet room and accumulates the bad smell gas in the toilet room.

（a）

（b）

（c）

（d）

Fig 2.8 Air leakage of the sponge sealing

2.2.2 The mechanical components are prone to abrasion

In order to observe the situation of feces deposit and replace the feces bin, the bin cover is often lifted by the operation worker with the help of a set of mechanical structure. Such an operating mode results in the heavy workload. On the other hand, the mechanical components are easily deformed and the service life of the sealing components thus shortens.

As the entire system is placed in the basement, it is inconvenient to carry out maintenance activities in the limited space and the maintenance will also affect the normal use of the toilet. In addition, the operation worker will directly see the feces when he replaces feces bin, which is a disgusting thing.

2.3 The problems related to the sawdust dispensation system

The sawdust dispensation system consists of a sawdust tank, a sawdust button, a sawdust dispenser, a sawdust trough. When the button is pressed, the sawdust in the tank will fall into the turnover bowl through the dispenser and trough. When the sawdust is running out, the householder can open the cover and reload the sawdust. The field survey showed that there exists following problems in the sawdust dispensation system.

2.3.1 The fluffy sawdust causes biological pollution

During dispensing the sawdust, the sawdust may become suspended particulates because of its low density and rebound effect and further contact with the people's skin or organs. A large number of bacteria are adhered on the sawdust, so people are faced with the health risk when they are exposure to the fluffy sawdust. Especially, the fluffy sawdust may contact the female's external genitalia when they are using the toilet, which will cause terrible health hazard.

2.3.2 The sawdust emission causes air pollution

Generally, the sawdust, along with the feces, falls into the feces storage bin as the feces bowl inverts. However, some light sawdust would enter the atmosphere by following the exhausted air, which is very harmful to the mucous membrane of human respiratory tract. Meanwhile, a variety of causative agents carried by the sawdust will also endanger human health. During site survey, the sawdust is not only found inside ventilation ducts, but also in outdoor air in the community.

2.3.3 The sophisticated structure brings people inconvenience in use

The sawdust dispensation is realized by pushing the sawdust button. To do so, users have to take an enough large physical strength. It is almost impossible for a child or old person to finish the activity, which means that these people must be in pursuit of other person's help even if they defecate. Meanwhile, owing to the innovative and sophisticated feature of the dry toilet, the guests who visit the community will face such problems as how to use the toilet. Likely, the householder has to instruct their guests to use the new type of toilet. The above-mentioned doings are both troublesome and embarrassing.

2.4 The problems related to the ventilation system

The ventilation system is one of the key components of the urine/feces separation dry toilet. It plays a crucial role both in controlling odor gas and in dehydration of feces. On the basis of the comprehensive analysis of the design and construction for the ventilation system, the following problems in the ventilation system were identified.

2.4.1 There existed unbalance pressure loss between the branch ventilation ducts

In the exhaust system for toilet room, one fan, placed in the basement, serves for 4 or 5 toilet rooms. With the help of the fan, the air of each toilet room is firstly sucked into the feces hole of toilet and passes through the feces chute to the feces bin. Then, the air is converged with the air from the other households in the same unit and is finally discharged via the fan and the main duct to the roof. When visiting the feces storage chamber in the basement, we found that there existed serious unbalance pressure loss between the branch ventilation ducts for the identical exhaust system. Actually, it is almost impossible to balance the pressure loss between the branch ducts even if the valves are utilized, which are because the distances between the storage bins and fan are too short. Taking the Unit 2 of Building 4# as an example (as shown in Fig 2.9), there are four feces storage bins in the basement, corresponding to household 103, household 203, household 303 and household 403 of this unit. By inspecting the ventilation duct arrangement of the basement, it was noticed that the blower fan for the ventilation system was installed near the feces bin of household 303, while the branch vent ducts corresponding to household 203 and household 403 were on both sides of the blower fan, and that of household 103 was the farthest one from the blower fan. Such a kind of duct arrangement cannot achieve balanced air flow rate distribution of the four bins. The household enjoying the shortest distance from the blower fan generally has the lowest pressure loss and the greatest air flow rate, which, accordingly, can be ensured that unclean air in the toilet is timely exhausted. Those households having the longer distance from the blower fan will suffer from greater pressure loss, and can only be distributed with lesser air flow rate. As a result, the odor gas was accumulated in the toilet room. In field investigation, we also noticed that householders resided in different flats of the same unit have different comments on the odor of the toilet room.

Fig 2.9 Basement of Unit 2 of Building 4#

2.4.2 The capacity of fan can not meet the requirement of controlling odor

The ventilation rate of the toilet room should be determined in accordance with the size of the toilet room, the ventilation requirement for toilet room of residential buildings and the potential sanitation-related problems of dry toilet. Owing to the climatic characteristics of Erdos City, there will be a great temperature difference between the indoor and outdoor in winter. So, the excess air exchange will result in an increase of the heat burden in winter, which is uneconomic. On the other hand, under the precondition of ensuring the operation performance of the ventilation system, the air exchange rate shall be low as far as possible to reduce power consumption. Upon comprehensive consideration of various factors, the air exchange rate was determined to be 3 times/hour, then:

Exhaust flow rate of each toilet room = volume of the toilet room × air exchange rate

$$=2.1\times1.7\times2.7\times3 = 29\ \mathrm{m^3/h}$$

If the ventilation flow rate of each toilet room was selected as 30 m^3/h, the total air flow rate of a fan should be 120 m^3/h because a fan serves four households. However, the measurement showed that the air flow rates of most ventilation systems are actually lower than this value, as shown in Table 2.1.

2.4.3 Low air flow speed causes sawdust sedimentation in the vent duct

As the above-mentioned, the branch duct far away from blower fan suffers from a high pressure loss. On the other hand, low capacity of fan results in a decrease of ventilation amount. Both high pressure loss and low ventilation capacity have the adverse effect on air flow. When air flow speed is too low to drive the sawdust, the sawdust will deposit inside the duct, especially in the bent or tee branch where the eddy flow happens. Actually, serious sawdust sedimentation has taken place in the ventilation ducts far from the blower fan in the community, as shown in Fig 2.10.

Fig 2.10 Sawdust sedimentation in the vent duct

Table 2.1 Air flow rate of ventilation system

Building No.	Basement location	Blower fan source	Duct inner diameter (mm)	Flow rate (m^3/h)
2#	West	Shangyu	105	47.1
	East 1	Sweden	105	100.9
	Mid West	Shangyu	105	28.7
	Mid East	Shangyu	105	39.9
4#	East	Shangyu	105	58.6
	East 1	Sweden	105	74.8
	East 1	Sweden	105	23.4
	East 1	Sweden	105	16.4
9#	East	Shangyu	105	79.8
11#	Mid 101	Shangyu	105	133.7
	Mid 102	--	70	1.6
	Mid 402	--	70	1.7
23#	East	Sweden	105	154.5
	East 1	Sweden	105	142.0
	West	Sweden	105	147.1
	West 101	--	70	3.9
	West 201	--	70	4.2
	West 301	--	70	4.8
	West 401	--	70	7.1
25#	East	Shangyu	105	92.0
	Mid West	Shangyu	105	91.2
	Mid East	Sweden	105	140.8

2.5 The problems related to the urine drainage system

The urine and the feces from the urine/feces separation dry toilet are separately collected at Haozhaokui Community. The wall built-up urinal and the urine hole of the toilet are directly connected to their respective urine pipes, and the urine is drained to the underground urine tank nearby each apartment building. The site visit showed that there exist the following problems in the urine drainage system.

2.5.1 The volatile ammonia enters toilet room from urine drainage pipeline

At Haozhaokui Community householders often complain that there is a kind of peculiar smell in their toilet rooms. And under extreme circumstances, the odor is so intense that they have to give up their own toilets instead of using the public toilets. We think that the peculiar smell is mainly from the ammonia and the on-site sampling analysis also indicates that the air in toilet rooms of some households contains high concentration ammonia. The ammonia can cause corrosion reaction of the upper respiratory tract by absorbing the water content of the human skin to denaturalize the tissue protein, which has an adverse effect on both the living conditions and human health.

On the basis of the field survey, it was found that the facilities in this community are illogical in avoiding the odor caused by urine drainage system. For example, in the urine drainage pipelines of the urinal and the toilet there have no the special odor isolation facilities which prevent polluted gas from entering the toilet rooms, as shown in Fig 2.11(a) and 2.11(b). As a result, the volatile ammonia with low density directly escapes into the toilet rooms, resulting in the increase of the indoor ammonia content.

(a) Wall urinal

(b) Seated toilet

Fig 2.11 Urinal (a) and Toilet (b) with straight-through urine drainage pipe

2.5.2 The dirty gas flows into toilet room through urine drainage pipe

Besides the volatilization of ammonia, the dirty gas directly flows into the toilet rooms through the urine drainage pipe in the winter. This is because the temperature of outdoor air is lower than that of indoor air in the season. There exists density difference between the outdoor air and indoor air and the continuous gas flow if the flow is not blocked by some special isolation facilities. Actually, besides the special odor isolation facilities are not equipped in the urine drainage pipelines of the urinal and the toilet, the outlet of the urine drainage pipe was exposed above the liquid level of the urine tank, as shown in Fig. 2.12. So, the obvious upward gas flow is noticed in portholes of some urinals in the winter.

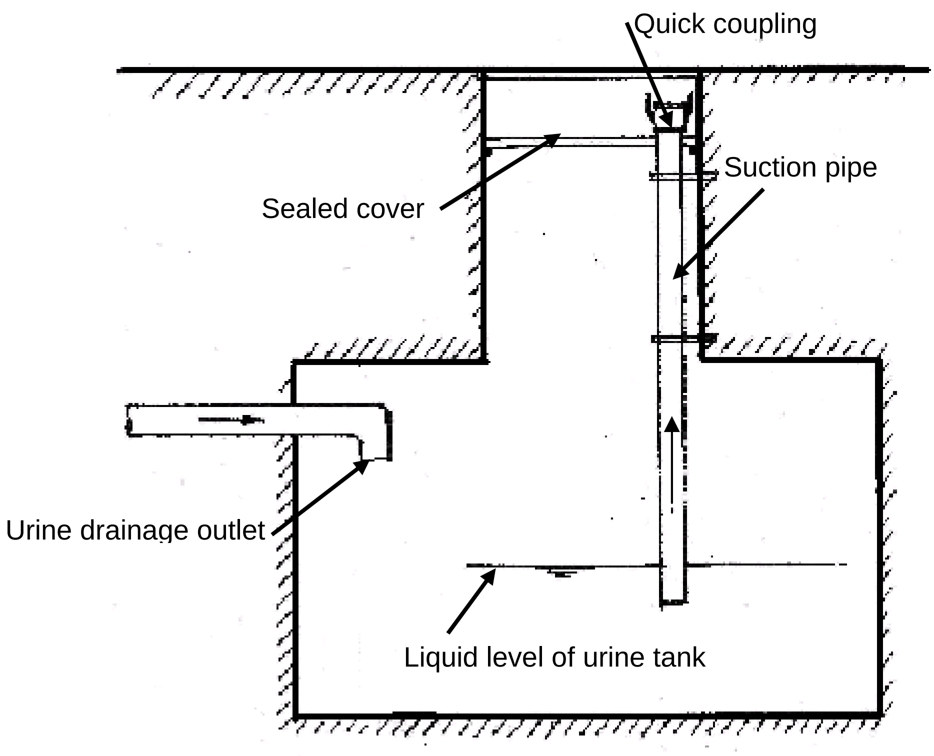


Fig. 2.12 The sketch diagram of urine tank

2.6 The problems related to the project construction

Through site visit, it is found that there are many project construction related problems for the ventilation system at the community and the several serious problems are listed as followings.

2.6.1 Too many bends and tee joints cause the large pressure loss

The duct drag includes the friction drag and local drag and the latter is caused by the local vortex. The vortex is usually formed in the bend or tee joint. The air flow rate of ventilation system is inversely proportion to the duct drag. Therefore, the vortex will result in the decrease of air flow rate of ventilation system. Generally, the sharper the air flow direction changes, the stronger the local vortex is and the less the air flow rate of ventilation system is.

In the ventilation system of the dry-toilet at Haozhaokui community, one fan serves for four or five households. Three bend and three tee joints are used to constitute an integrated ventilation system in the narrow basement, as shown in Fig. 2.13 and Fig. 2.14. Because the bend or tee joint is too close to the blower fan and they themselves close each other, it is inevitable that the strong vortex forms and the air flow rate of ventilation system significantly decreases. It is also hard to balance the pressure loss between four branch ducts because the branch ducts are too short and there are too short distance between the tee joints. Actually, balancing the pressure loss of four branch ducts can not be realized even if the valves are used. Generally, the air flow rate of the branch duct closed to fan is relatively high while those far from the fan are relatively low.

In addition, the ducts and blower fan of ventilation system are too close wall or ceiling of the narrow basement, which makes the maintenance difficult.

Fig 2.13 Too many bends and tee joints

Fig 2.14 The tee joint is too close to blower fan

2.6.2 Too long flexible corrugated-pipe causes the large pressure loss

In order to decrease the air flow drag, the ducts should be arranged as short and straight as possible and the inner wall of the duct should be smooth. However, the principle was not complied with in the project construction of the Haozhaokui community, especially for the flexible duct. As shown in Fig. 15 and Fig. 16, not only is the corrugated duct selected, but also the flexible duct is so long that a redundant bend is formed. As a result, both friction drag and vortex drag increase, which further results in a significant decrease of air flow rate of ventilation system.

Fig 2.15 Too long flexible corrugated duct

Fig 2.16 Too long flexible duct

2.6.3 There exists misalignment between the vent duct and the inlet/outlet port of blower fan

The problem of misalignment between the inlet/outlet port of the blower fan and the vent duct, as shown in Fig 2.17, occurs in the ventilation systems of many buildings. Such a misalignment will result in a considerable pressure loss and make air flow blocked. As a result, air flow rate significantly decreases.

Fig 2.17 Misalignment between the inlet/outlet port of the blower fan and the vent pipe

2.6.4 There exist the insecure connections between the ducts

The field survey showed that the sealing gum was not used for pipe connection in most ventilation systems and the connections between ducts are insecure. The ducts will be disconnected only upon a slight external force, as shown in Fig. 2.18. In case that the ducts break off, the ventilation system is actually out of work.

Fig 2.18 Insecure duct connections

2.6.5 There exists the serious air leakage in the blower fan and duct

During site visits, it was also noticed that many fans have the problem of air leakage, as shown in Fig 2.19. This is because there are many gaps in the scroll shell. Air leakage will result in the significant decrease of the air exchange rates in the toilet rooms. On the other hand, the odor gas could be accumulated at the basement, which will make environment quality of the basement deteriorated. Besides the fan, the same problem is also found at the joints between ducts. Similarly, the assembly glue applied at the joints may become out of work after a long time. The air leakage will also affect the normal operation of the ventilation system and endanger the indoor air quality.

Fig 2.19 Air leakage of the blower fan

2.6.7 There exists the insecure connection between the toilet and the supporting pipe

The toilet of some households is not securely connected with the supporting pipe. As shown in Fig 2.20, the supporting pipe of the urine hole of the toilet is not well aligned with the urine drainage pipe. As a result, the urine leaks to the toilet room and the stinky smell is generated in the toilet.

Fig 2.20 Urine joint is not inserted the supporting pipe

2.6.8 There was a wrong connection of ventilation duct

In field survey, it is noticed that the householders in the Unit 3 of Building 3 suffered so much for the odor that they would not enter the toilet. Monitoring showed that the urine hole of the toilet had an upward air flow as large as 4m/s and the rising air flow disappeared after shutting down the blower fan of ventilation system. Upon the inspection of the duct layout, we found that there was a wrong duct connection. The vent duct for urine that was supposed to be connected to the vent duct for grey water was actually connected to the vent duct for feces, as shown in Fig. 2.21.

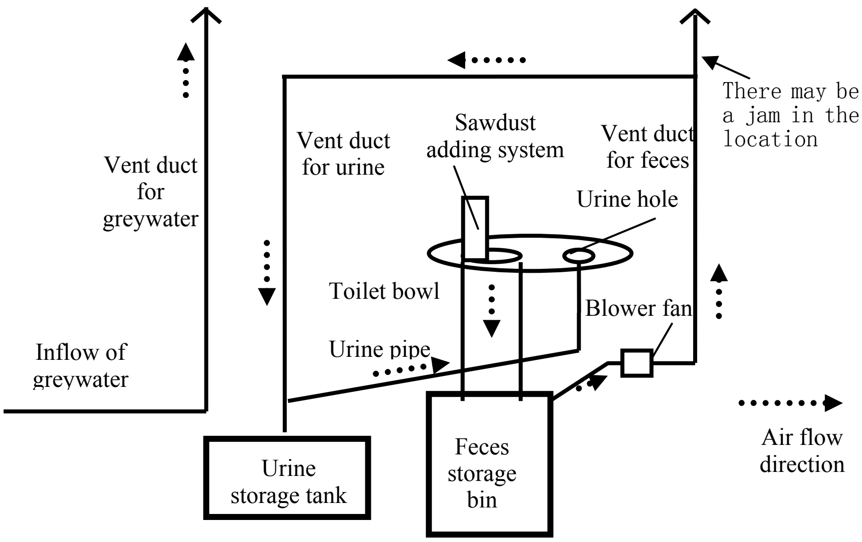


Fig 2.21 The interrelation between all ventilation systems

On the other hand, there may be a jam in the location near the outlet of vent duct for feces. As a result, the air of the toilet room first passes through the feces chute to the bin and then rises to the tee joint along the vertical main ventilation duct with the help of fan. Finally, the air is not discharged to the roof instead of returning the urine hole of toilet, which causes serious odor in the toilet room.

2.7 The problems related to the daily use and maintenance

The use and maintenance of urine/feces separation dry toilet are different from those of the traditional flush toilets. For instance, after using such toilet, only a small amount of water is needed to flush the urine hole and the wall built-up urinal, so as to guide the urine to flow into the urine drainage pipe along the urinal wall and achieve the effect of water sealing, which will isolate the peculiar smell and prevent ammonia from volatilizing and crystallizing. However, some householders use too much water, which not only wastes water resources but also shields the advantages of dry toilets. Especially, once the water enters into the feces bin, the ideal environment for the growth of pathogens and microorganisms will be formed. On the other hand, some householders do not flush the urine hole after peeing. As a result, the urine is prone to crystallization on the surface of the closet and ammonia volatilization.

In addition, some householders are unable to understand the principle of dry toilet, and fail to use it in line with the specification. They may drop plastic bags, ash and bones into the feces storage bin via the feces chute. As the feces in the bin will be used as the soil improvement agent for agricultural production, the above-mentioned objects will increase the burden of post-processing and bring adverse effects to the pipe system.

3 The measures of controlling the odor in the dry toilet room

3.1 Principle for reconstruction

Based on the fact that the building has passed the final acceptance and been inhabited by owners, the reconstruction is aimed at ensuring the urgent sanitation and safety of the living environment. Only easy-to-implement measures were put forward and implemented while those measures that are difficult to realize at this moment were only suggested.

3.2 Reconstruction for the feces storage system

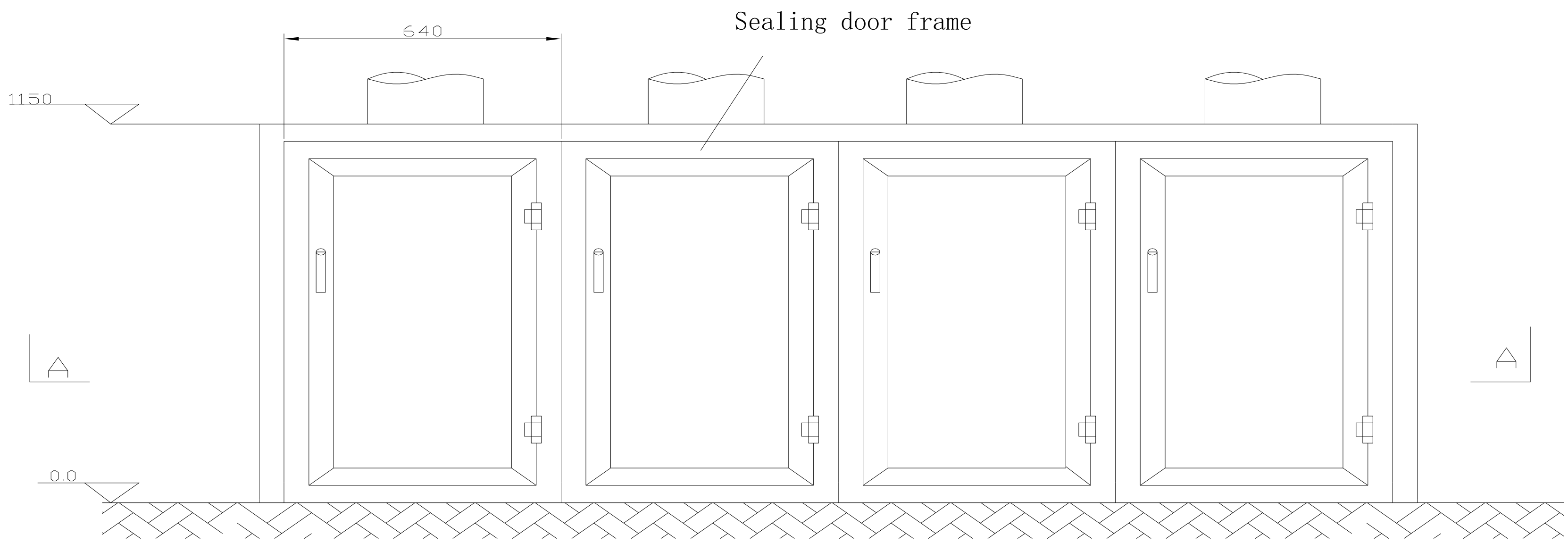
3.2.1 Selection of the feces storage mode

To solve the problems of degraded sealing performance between the feces bin and the cover owing to the aging or breakage of the sponge, damage of the mechanical components due to frequent uplifting or pressing down the cover plate, and in consideration of the air-tightness, operability, structural strength, construction cost, construction difficulty, material source and esthetic appearance of the overall system, cabinet sealing is adopted to replace sponge sealing. The cabinet is made with plastic board, plastic-aluminum board, brick or reinforced concrete. One bin is placed in a compartment with a front door for placing and removal of the bin. There is also a hole on top of the cabinet to observe fill-up extent of the feces in the bin.

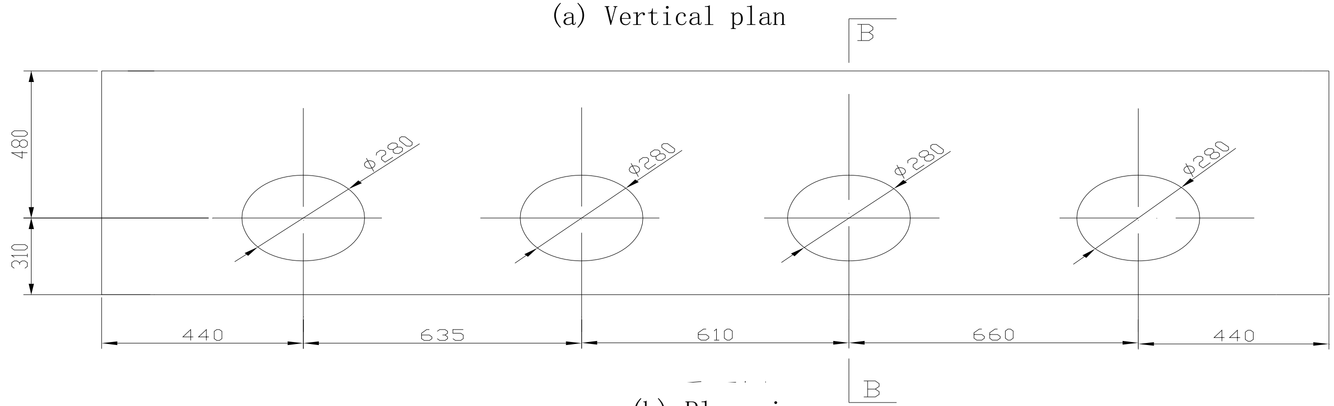
3.2.3 Design drawing

Taking the building 28# as an example, the drawings of cabinet sealed feces storage chamber are shown in Fig 3.1 - Fig 3.3. The physical photo after reconstruction is shown in Fig.3.4. The above measures were proved to be effective on improving the air-tightness of the system and reduce the work load for replacing the bin.

In order to prevent the floated sawdust from endangering human health and polluting the environment, and to avoid the inconvenience in operation of adding the sawdust, and to maintain the appropriate carbon-nitrogen ratio of the feces bin, it is proposed to install a sawdust adding system on top of the feces storage cabinet, and the workers from the eco-station are in charge of adding the sawdust.

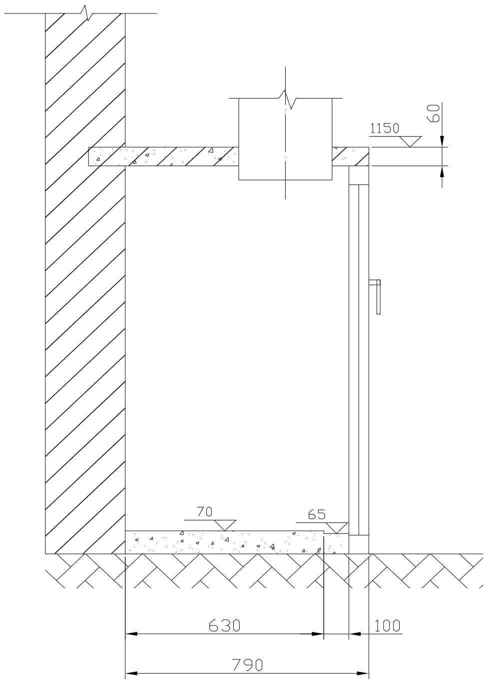


(a) Vertical plan

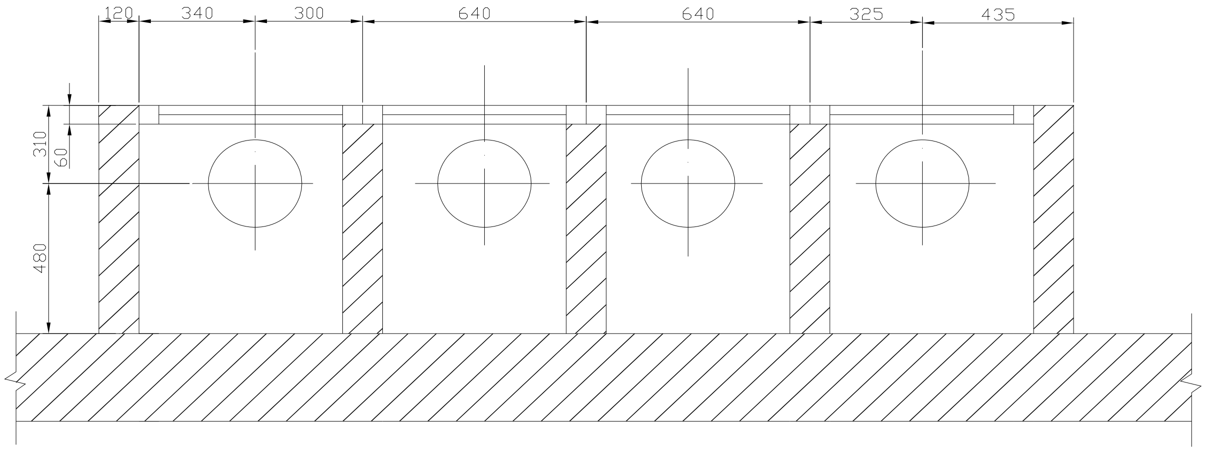


(b) Plan view

Fig.3.1 Plan layout and vertical arrangement

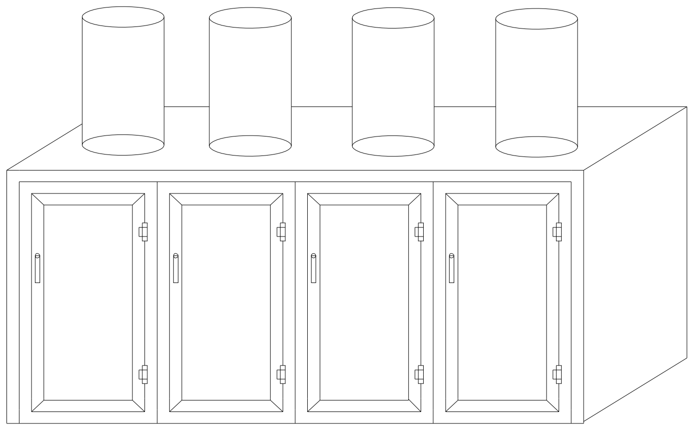


B-B section plan

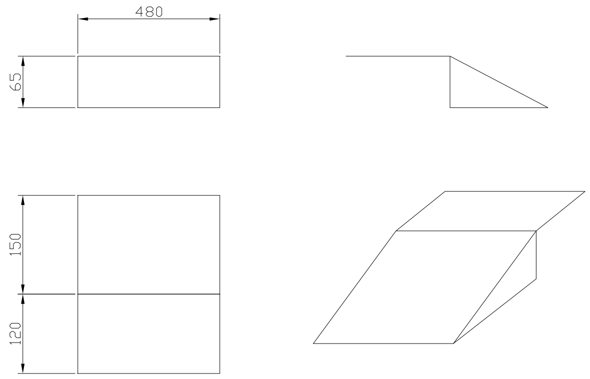


A-A section plan

Fig. 3.2 Section plan



Axonometric drawing



Bridge piece

Technical specification

1. The connection between the vent pipe and the sealed cabinet shall be secure and free from air-leakage.
2. The spacing of brick walls shall correspond with width of the sealing door.
3. The size of the bridge piece can be adjusted in accordance with the site condition, but shall ensure the in/out movement of the feces pail.

Fig. 3.3 Axonometric drawing and bridge piece

Fig. 3.4 The cabinet feces storage system

3.3 Reconstruction on ventilation system

3.3.1 Retrofitting the duct arrangement

As shown in Fig 3.5, the toilets of the identical unit are respectively connected the feces storage bins in the basement through the vertical feces chute in the previous ventilation system. The feces chutes (or the cover plates) have openings connected with the branch vent duct in four routes, while each route of air meets in the horizontal main pipe and is exhausted to the vertical air trunk by the blower fan. Such a duct arrangement is likely to cause the imbalance air resistance and increase pressure loss.

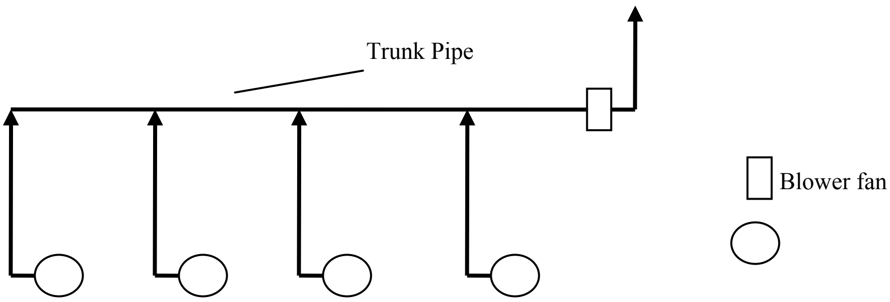


Fig 3.5 The duct arrangement of the previous ventilation system

In order to balance the pressure loss of the branch ducts for four feces bins as well as to reduce the total air flow resistance of the ventilation system, the following measures have been proposed and implemented: two symmetrically installed Y-shaped inclined three way couplings are used to converge the air current of two neighboring feces bins, and a T-juncture is then used to connect the pipes from two sides before sending the air current to the fan. The regulating valve is no longer used, as shown in Fig.3.6. With these measures it is estimated that the deviation of the air flow in four branch pipes can be reduced to within 8%. Furthermore, it is also required that the installation process should be carried out in line with the specifications to ensure the straightness of the air conduit, the alignment between the pipe and the fan. The length of the air duct should be as short as possible and the resistance imposing components should be avoided. The air duct with rough inner wall should be avoided and the residual articles inside the conduit should be removed.

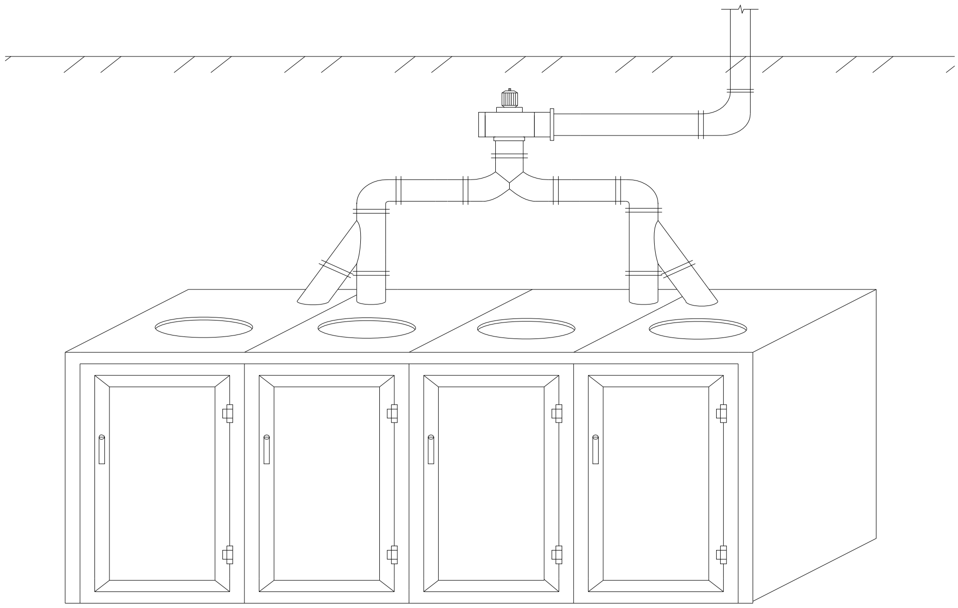


Fig 3.6 The ventilation system after reconstruction

3.3.2 Replacing blower fan

Considering the fact that the blower fans of the existing ventilation system are unable to provide enough air flow rate to satisfy the requirement of exchange polluted air in the toilet room, the air flow rate and pressure loss of the ventilation system are calculated and adjusted over again on the basis the duct arrangement after the reconstruction.

1) The air flow rate

According to the pollution characteristics of the dry toilet in EETP and requirements of the toilets ventilation in residential apartments and toilet room dimension as well as the relationship between the ventilation amount and the odor intensity, it is suggested that the air flow rate for each toilet room should be above 30 m^3/h. So, the total air flow rate for four households of the identical unit is no less than 120 m^3/h.

2) The pressure loss

As shown in Fig 3.7, the duct sections are numbered and labeled with the pipe diameter, length and flow rate. According to the principle of fluid dynamics, the pressure losses of wind duct can be classified into friction pressure loss and local pressure loss. The former is caused by the viscous function, and the latter is caused by the eddy current resulted from the change of fluid direction and fluid velocity as the fluid passes through the tee joint, valve, pipeline inlet/outlet and blower fan etc.

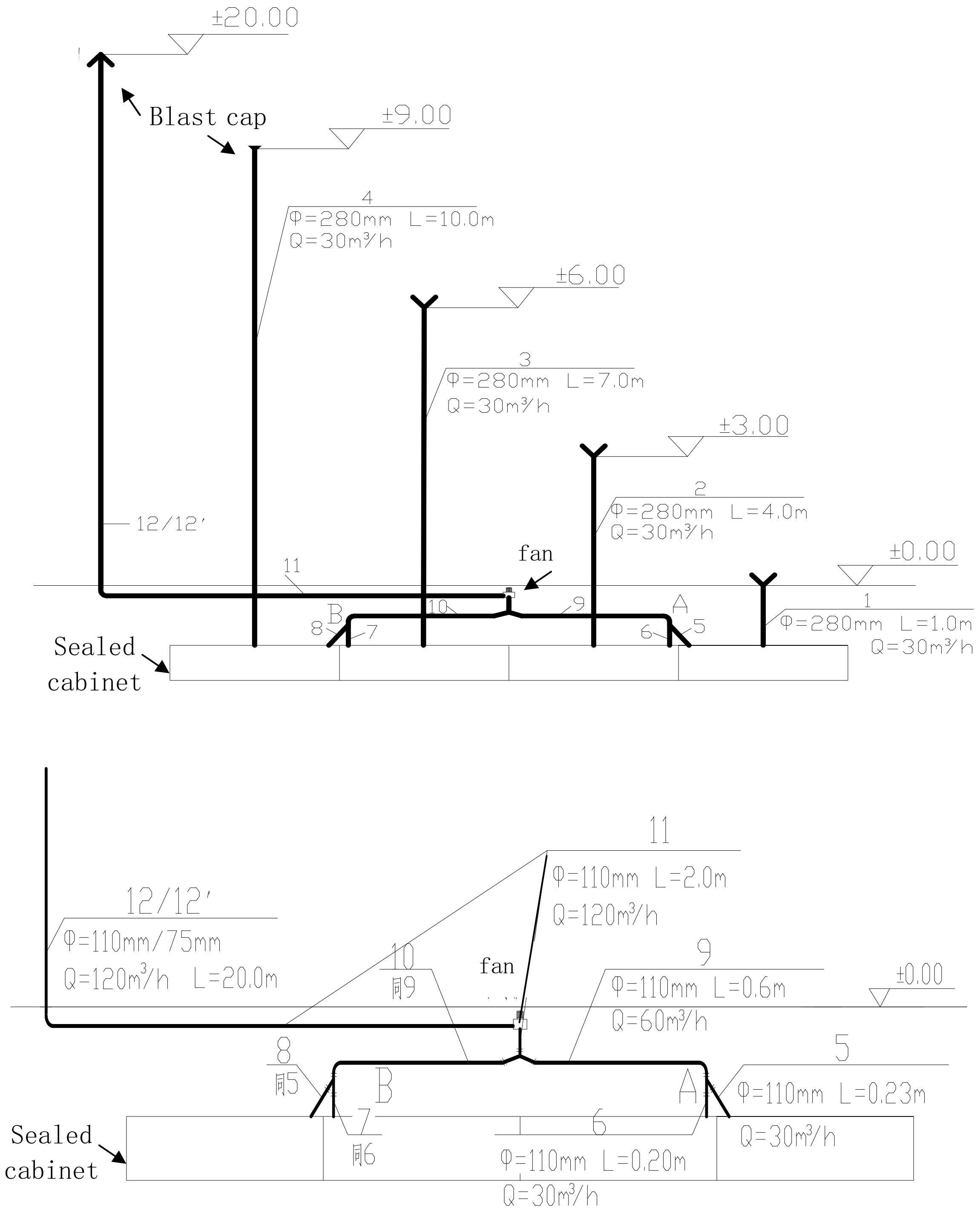


Fig. 3.7 Schematic diagram of ventilation system

2) The pressure loss calculation

<u>$1^{\#}$ duct</u>

$1^{\#}$ duct is a plastic feces chute with the inner diameter of 255 mm and length 1.0m, and the air flow rate inside the duct is 30 m^3/h. The flow velocity thus is

$$v = \frac{Q}{A} = \frac{Q}{(\frac{\pi}{4}d^2)} = 0.164 \text{ m/s} ,$$

Dynamic head is,

$$p_{\mathrm{d}} = \frac{\rho v^2}{2} = \frac{1.204 \times 0.164^2}{2} = 0.016 \text{ Pa} ,$$

By looking up the Concise Ventilation Design Handbook, the friction pressure loss per unit length for the duct (R_{m}) is obtained to be 0.4 Pa/m. So, the friction loss of the duct is,

$$\Delta p_{l1}=0.4\times 1.0=0.4 \text{ Pa}$$

The external diameter of the ratable feces bowl is 240 mm. So, the air flow velocity through the gap between feces chute and the bowl is,

$$v = \frac{Q}{A} = \frac{Q}{\frac{\pi}{4}(D^2 - d^2)} = 1.430 \text{ m/s}$$

The dynamic head is

$$p_{\mathrm{d}} = \frac{\rho v^2}{2} = 1.231 \text{ Pa} ,$$

By checking up the Concise Ventilation Design Handbook, the local resistance loss coefficient for the gap is 1.85. Therefore, the local resistance loss for the gap is,

$$\Delta p_{m1} = 1.85\times 1.231 = 2.277 \text{ Pa} .$$

The other local resistances involved in 1$^\#$ duct can be ignored because of low air flow velocity.

2$^\#$, 3$^\#$ and 4$^\#$ ducts

The material, arrangement way, physical dimension, air flow rate and local resistance of 2$^\#$, 3$^\#$ and 4$^\#$ ducts are same as those of 1$^\#$ duct except the duct length is 4.0m, 7.0m and 10m, respectively. So, the friction pressure losses for three ducts are respectively,

$$\Delta p_{l2} = 0.4\times 4.0 = 1.6 \text{ Pa}$$

$$\Delta p_{l3} = 0.4\times 7.0 = 2.8 \text{ Pa}$$

$$\Delta p_{l4} = 0.4\times 10.0 = 4.0 \text{ Pa}$$

5$^\#$ duct

The air flow rate, the inner diameter and the length of 5$^\#$ duct are respectively 30 m^3/h, 104 mm and 0.23m, then the air flow velocity is,

$$v = \frac{Q}{A} = \frac{Q}{(\frac{\pi}{4}d^2)} = 0.981 \text{ m/s},$$

Dynamic head is,

$$p_{\mathrm{d}} = \frac{\rho v^2}{2} = \frac{1.204 \times 0.981^2}{2} = 0.579 \text{ Pa},$$

By looking up the Concise Ventilation Design Handbook, the friction pressure loss per unit length (R_{m}) is obtained to be 0.25 Pa/m. So, the friction pressure loss for the duct is,

$$\Delta p_{l5} = 0.25 \times 0.23 = 0.058 \text{ Pa}$$

The local resistance of duct $5^{\#}$ results from the transition from the feces bin to $5^{\#}$ duct, and the inclined Y-shaped tee joint. By checking up the Concise Ventilation Design Handbook, the local resistance coefficient of the transition and the inclined Y-shaped tee joint are respectively 1.5 and 0.18. So, the total local resistance for 5# duct is,

$$\Delta p_{m5} = 1.5 \times 0.579 + 0.18 \times 2.317 = 1.286 \text{ Pa}$$

$6^{\#}$ duct

The air flow rate and the inner diameter of $6^{\#}$ duct are same as those of $5^{\#}$ duct and its length is 0.20 m. So, the friction resistance of the duct is,

$$\Delta p_{l6} = 0.25 \times 0.20 = 0.050 \text{ Pa}$$

The local resistance caused by the transition from the feces bin to 6# duct is same as that of $5^{\#}$ duct. The local resistance caused by the inclined Y-shaped tee joint is,

$$\Delta p_{m} = 0.20 \times 2.317 = 0.463 \text{ Pa}$$

So, the total local resistance for $6^{\#}$ duct is,

$$\Delta p_{m6} = 0.869 + 0.463 = 1.332 \text{ Pa}$$

$7^{\#}$ ducts

The friction resistance and local resistance of $7^{\#}$ duct are same as those of $5^{\#}$ duct.

$8^{\#}$ ducts

The friction resistance and local resistance of $8^{\#}$ duct are same as those of $6^{\#}$ duct.

$9^{\#}$ ducts

The air flow rate, the inner diameter and length of $9^{\#}$ are respectively 60 m^3/h, 104 mm and 0.60m, the air flow velocity, therefore, is

$$v = \frac{Q}{A} = \frac{Q}{\frac{\pi}{4}d^2} = 1.962 \text{ m/s},$$

Dynamic head is,

$$p_{\mathrm{d}} = \frac{\rho v^2}{2} = \frac{1.204 \times 1.962^2}{2} = 2.317 \text{ Pa}$$

By looking up the Concise Ventilation Design Handbook, the friction resistance per unit length (R_m) for the duct is obtained to be 0.7 Pa/m. the friction pressure loss for the duct is,

$$\Delta p_{l9} = 0.7 \times 0.6 = 0.42 \text{ Pa}$$

The air flow rate is all 120 m^3/h in ducts after the T-shaped tee joint. So, the flow velocity and dynamic head are respectively,

$$v = \frac{Q}{A} = \frac{Q}{\frac{\pi}{4}(D^2 - d^2)} = \frac{120/3600}{\frac{\pi}{4} \times (0.11 - 0.003 \times 2)^2} = 3.924 \text{ m/s}$$

$$p = \frac{\rho v^2}{2} = \frac{1.204 \times 3.924^2}{2} = 9.269 \text{ Pa}$$

The local resistance of the $9^{\#}$ duct results from a 90^{o} bend and T-shaped tee joint and the resistance coefficients are respectively 0.25 and 1.0. So, the total local pressure loss is,

$$\Delta p_{m9} = 0.25 \times 2.317 + 1.0 \times 9.269 = 9.848 \text{ Pa}$$

<u>10# duct</u>

The friction pressure loss and local pressure loss of $10^{\#}$ duct are same as those of $9^{\#}$ duct.

<u>11# duct</u>

The air flow rate, the inner diameter and length of $11^{\#}$ are respectively 120 m^3/h, 104 mm and 2.0m. So, the air flow velocity and dynamic head are respectively,

$$v = \frac{Q}{A} = \frac{120/3600}{\frac{3.14}{4} \times 0.104^2} = 3.924 \text{ m/s}$$

$$p_{\mathrm{d}} = \frac{\rho v^2}{2} = \frac{1.204 \times 3.924^2}{2} = 9.269 \text{ Pa}$$

By looking up the Concise Ventilation Design Handbook, the friction pressure loss per unit length (R_m) is 3 Pa/m. So, the friction pressure loss for the duct is,

$$\Delta p_{l11} = 3 \times 2.0 = 6.0 \text{ Pa}$$

The local resistance results from the inlet port and the outlet port of the blower fan and a 900 bend and their resistance coefficients are respectively 0.25, 0.30 and 0.25. So, the total local resistance for the duct is,

$$\Delta p_{m11} = \sum \zeta \times p = (0.25 + 0.30 + 0.25) \times 9.269 = 7.415 \text{ Pa。}$$

$12^{\#}$ duct

$12^{\#}$ duct is the vertical duct connected to the roof for building 1, building 2, building 3 and building 4 of this community. The air flow rate, the inner diameter and length of the duct are 120 m^3/h, 69 mm and 20.0m, respectively. So, the air flow velocity and dynamic head are respectively,

$$v = \frac{Q}{A} = \frac{120/3600}{\frac{\pi}{4} \times 0.069^2} = 8.914 \text{ m/s},$$

$$p_{\mathrm{d}} = \frac{\rho v^2}{2} = \frac{1.204 \times 8.914^2}{2} = 47.835 \text{ Pa},$$

By looking up the Concise Ventilation Design Handbook, the friction pressure loss per unit length for the duct (R_m) is 13 Pa/m. So, the friction pressure loss is,

$$\Delta p_{l12} = 13 \times 20.0 = 260.0 \text{ Pa}$$

The local resistance of the duct results from the umbrella-type blast cap and its local resistance coefficient is 1.0.So, the local resistance loss is,

$$\Delta p_{m12} = 1.0 \times 47.835 = 47.835 \text{ Pa}$$

$12'^{\#}$ duct

$12'^{\#}$ duct is the vertical duct connected to the roof of buildings except the building 1, building 2, building 3 and building 4. The air flow rate and length are same as those of $12^{\#}$ duct while its inner diameter is 104 mm and the air flow velocity and dynamic head are same as those of $11^{\#}$ duct. So, the friction pressure loss and local pressure loss are respectively,

$$\Delta p_{l12} = 3 \times 20.0 = 60.0 \text{ Pa}$$

$$\Delta p_{m12} = 1.0 \times 9.269 = 9.269 \text{ Pa}。$$

The pressure loss for each duct and the gross pressure loss for the different floor are compiled in Table 3.1 and Table 3.2.

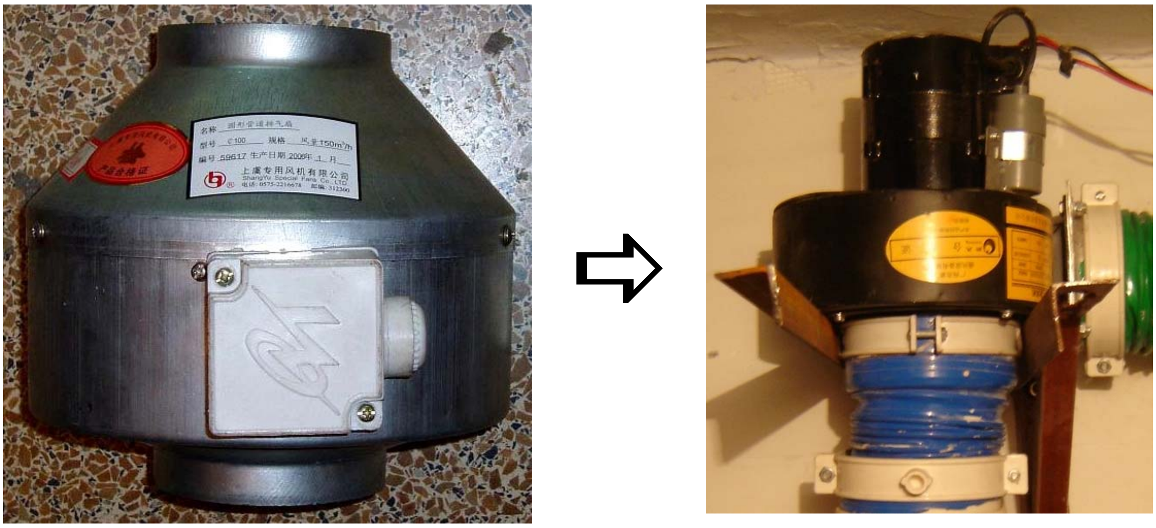
Table 3.1 The pressure loss for each duct

Duct No.	Flow rate (m^3/h)	Inner diameter (mm)	Duct length (m)	Dynamic head (Pa)	Specific friction resistance (Pa/m)	Friction pressure loss (Pa)	Local resistance coefficient							Local resistance loss $\triangle p_m$(Pa)	Gross resistance loss $\triangle p$(Pa)
							Toilet bowl	Feces bin to branch duct	Y-shaped tee joint	90° bend	T-shaped tee joint	Blower fan	Blast cap		
1	30	280	1.00	0.016	0.40	0.400	1.85	--	--	--	--	--	--	2.277	2.677
2	30	280	4.00	0.016	0.40	1.600	1.85	--	--	--	--	--	--	2.277	3.877
3	30	280	7.00	0.016	0.40	2.800	1.85	--	--	--	--	--	--	2.277	5.077
4	30	280	10.00	0.016	0.40	4.000	1.85	--	--	--	--	--	--	2.277	6.277
5	30	110	0.23	0.579	0.25	0.058	--	1.50	0.18	--	--	--	--	1.286	1.344
6	30	110	0.20	0.579	0.25	0.050	--	1.50	0.20	--	--	--	--	1.332	1.382
7	30	110	0.20	0.579	0.25	0.050	--	1.50	0.20	--	--	--	--	1.332	1.382
8	30	110	0.23	0.579	0.25	0.058	--	1.50	0.18	--	--	--	--	1.286	1.344
9	60	110	0.60	2.317	0.70	0.420	--	--	--	0.25	1.00	--	--	9.848	10.268
10	60	110	0.60	2.317	0.70	0.420	--	--	--	0.25	0.70	--	--	7.067	7.487
11	120	110	2.00	9.269	3.00	6.000	--	--	--	0.25	--	0.25+0.30	--	7.415	13.415
12	120	75	20.00	47.835	13.00	260.000	--	--	--	--	--	--	1.00	47.835	307.835
12’	120	110	20.00	9.269	3.00	60.000	--	--	--	--	--	--	1.00	9.269	69.269

Table 3.2 The gross pressure loss of the different floor

Duct No.			Gross resistance loss (Pa)
1st Floor	110 mm vertical duct	1+5+9+11+12’	96.973
	75 mm vertical duct	1+5+9+11+12	335.539
2nd Floor	110 mm vertical duct	2+6+9+11+12’	98.211
	75 mm vertical duct	2+6+9+11+12	336.777
3rd Floor	110 mm vertical duct	3+7+10+11+12’	96.630
	75 mm vertical duct	3+7+10+11+12	335.196
4th Floor	110 mm vertical duct	4+8+10+11+12’	97.792
	75 mm vertical duct	4+8+10+11+12	336.358

From the Table 3.2, it can be seen that the overall pressure losses with the vent duct of Φ110mm and Φ75mm are about 98Pa and 337Pa, respectively. In order to meet the ventilation requirement, a kind of centrifugal fan with bigger capacity was used to replace the previous the axial fan, as shown Fig. 3.8.



Axial fan   Centrifugal fan

Fig. 3.8 The axial fan was changed into the centrifugal fan

3.4 Reconstruction for the toilet and urinal

Directly connection between urinal and the urine hole of the toilet to the urine tank is the main cause of bad smell in the toilet room. It is required to install a “S” trap under the urinal and to install an odor isolator, similar to the ordinary floor drain, at the mouth of urine hole of the toilet in order to block the volatile gases, as shown in Fig. 3.9. At the same time, it was also suggested to use a water spray with volume below 500mL to clean the toilet and urinal after use. The above measures can prevent the gas in the urine drainage pipe from leaking into the room and prevent the residual urine from volatilization.

(a) The S-typed trap

(b) The isolator

(c) The toilet with an isolator

Fig. 3.9 the reconstruction measures for controlling odor related to urine drainage system

3.5 Other considerations

3.5.1 Specifications for construction operation

The entire process of construction operation should be normalized and supervised in line with high standards and requirements from scheme formation, system design, on-site construction and final acceptance. During this process, the corresponding design specifications should be referred to select the appropriate parameters and methodologies, which should also be adjusted and rectified by considering the actual conditions of the construction site. During the final acceptance, performance tests should be carried out to enable the entire system to reach the normalized standards.

3.5.2 Strengthening daily maintenance of the system

The eco-station will be responsible for the maintenance and management of such ventilation system. The staff of the eco-station should be well trained on the theoretical knowledge and technical experiences of such ventilation system, and take the initiative to learn about the situations of using such dry toilets by households who can offer timely feedback opinions and suggestions. The economic incentive measures should be taken and competitive mechanisms should be established to promote the enthusiasm of workers and ensure the normal maintenance and management of the system.

3.5.3 To use the dry toilet in a scientific way

1) The dry toilet will be widely applied owing to the shortage of world's water resources and energy crisis. Therefore, the promotion of the dry toilet should be strengthened to allow more people to learn about such circumstances, and to take cognizance of the unique features and advantages of the dry toilet in saving water resources and recycling human excreta, so that households can actively support and advocate the use of dry toilet and accept it willingly.

2） The corresponding convenient cleaning devices should be provided for the dry toilet, and used for flushing away the residual urine in the front urine hole of the toilet and the wall built-up urinal. Furthermore, an additional sanitation service team shall also be provided to build a favorable sanitation environment for the community.

4 Comparison of sanitary condition before and after the reconstruction

4.1 Basis for comparison

4.1.1 Determination of the comparison index

Odor in the toilet room remains the key problem of the ecological toilet in EETP. Sometimes the smell may cause uncomfortable feeling of the eyes and the respiratory system. Such smell is composed of ammonia, hydrogen sulfide, methane and other volatile organic compounds. Upon analysis, the ammonia is considered to be the most important pollutant. Therefore, ammonia concentration of the toilet room is used as the index for evaluating the sanitation condition of the toilet room in the study. According to the national standard of GB/T14679, the “sodium hypochlorite - salicylic acid spectrum-photometric method” for sampling and analyzing ammonia concentration is adopted. Meanwhile, the subjective sensation of the householder and the inspection personnel on the degree of odor is also taken as reference for evaluation.

4.1.2 Measurement of the ammonia concentration

In this investigation, the Sodium Salicylate-Sodium Hypochlorite Spectrophotometric Method is used for the sampling and quantitative analysis of ammonia.

1) The analysis principle

After the ammonia is absorbed by the absorption solution of dilute sulfuric acid, the ammonium sulfate is produced. With the presence of sodium nitroprusside, the ammonium ion, salicylic acid and sodium hypochlorite react with each other and produce the blue chemical compound. According to the difference in color, the ammonia concentration is determined with the spectrophotometer.

2) The reference standard

According to "Standards for Indoor Air Quality" (GB/18883-2002), the ammonia (NH_3) in the indoor air should be lower than 0.2 mg/m^3 within one hour.

3) The analysis devices

The analysis devices include atmospheric sampling pumps, brown multi-hole glass absorption tubes, colormetric tubes, spectrophotometers and so on.

4) The reagent

The chemical reagents used in this investigation included ammonia-free water, dilute sulfuric acid absorption solution, salicylic acid-potassium tartrate solution, sodium nitroprusside solution, sodium hypochlorite solution, and sal ammoniac standard solution.

5) Sampling method

The 10mL dilute sulfuric acid absorption solution is firstly added into the brown multi-hole glass absorption tube and then samples for 10 minutes at a flow rate of 1 L/min. The sampling device should be positioned at a height of 0.8m-1.5m in order to simulate the noxious gas being absorbed by human.

The samples should be analyzed as soon as possible to prevent them from changing the characteristics. If the analysis cannot be conducted immediately, the sample should be stored under the temperature of 2-5℃ for a maximum duration of one week.

6) Analytical approach

The ammonium chloride standard solution is first used to draw the standard curve of ammonia content-absorbance. The absorbance is measured under the wavelength of 697nm, and the ammonia content (μg) of each sample is determined in accordance with the standard curve.

4.2 Retrofitting the feces storage system

According to the above-mentioned reconstruction requirement on the feces storage system, partial sponge-sealed feces storage systems were changed into the sealed cabinet. After reconstruction, the underground feces storage chamber seems cleaner, and the subjective feeling on air quality significantly improves. The ammonia concentration largely decreases, as shown in Table 4.1.

Table 4.1: The air quality before and after reconstructing feces storage system

Sampling site		Before the reconstruction	After the reconstruction
Mid underground feces storage chambers of Building 28#	Sampling date	October 13, 2006	May 20, 2007
	Ammonia concentration	0.583 mg/m^3	0.191mg/m^3
	Subjective feeling	severe stinky smell	no peculiar smell
East underground feces storage chambers of Building 28#	Sampling date	October 13, 2006	May 20, 2007
	Ammonia concentration	1.134 mg/m^3	0.221 mg/m^3
	Subjective feeling	some flies; peculiar smell	no peculiar smell

4.3 Retrofitting the duct arrangement

Upon reconstruction of the duct arrangement, the four households served by the identical fan are distributed with approximately same pressure loss. And air exchange rates for four households are basically uniform, which also make the indoor air quality improved significantly, as shown in Table 4.2.

Table 4.2: Air quality before and after reconstructing the duct arrangement

Sampling site		Before the reconstruction	After the reconstruction
3 #304	Sampling date	October 13, 2006	April 8, 2007

	Ammonia concentration	0.450 mg/m^3	0.176 mg/m^3
	Subjective feeling	The toilet room is thrown aside; heavy odor	Normal use; no peculiar smell

4.4 Replacing the blower fan

The DZ125 blower fan manufactured by Guangzhou blower fan factory are used to replace the previous axial fan in building 1#, building 2#, building 3# and building 4#. The total pressure loss of each ventilation system in the four buildings is as high as about 350 Pa because the inner diameter of the ventilation duct is as low as 75 mm. After the replacing the blower fan, the ventilation system operates well and the air quality of the toilet and basement has significantly been improved, as shown in Table 4.3.

Table 4.3 Air quality before and after replacing the blower fan

Sampling site		Before the reconstruction	After the reconstruction
West underground feces storage chambers of Building 4#	Sampling date	October 13, 2006	April 8, 2007
	Absorbance	0.307	0.057
	Ammonia concentration	0.724 mg/m^3	0.294 mg/m^3
	Subjective feeling	peculiar smell	no smell
28 #305	Sampling date	October 14, 2006	April 7, 2007
	Absorbance	0.223	0.042
	Ammonia concentration	0.526 mg/m^3	0.225mg/m^3
	Subjective feeling	peculiar smell	no smell.

4.5 Retrofitting the urine drainage system

After adding the S-shaped water trap to the wall built-up urinal and the odor isolator to the front urine hole of the toilet, the resulted water seal isolates the urine from the toilet air, allowing improvement of the indoor air quality. The sampling record of Room 104 and Room 304 of Building 4# before and after the reconstruction of the urine drainage pipe is shown in Table 4.4.

Table 4.4 Air quality before and after retrofitting the urine drainage system

Sampling site		Before the reconstruction	After the reconstruction
4 #104	Sampling date	October 14, 2006	May 20, 2007
	Absorbance	0.347	0.034
	Ammonia concentration	0.818 mg/m^3	0.171 mg/m^3
	Subjective feeling	peculiar smell	no peculiar smell
4 #304	Sampling date	October 14, 2006	April 7, 2007
	Absorbance	0.205	0.041
	Ammonia concentration	0.484 mg/m^3	0.207 mg/m^3
	Subjective feeling	Severe stinky smell	no peculiar smell

4.6 The integrated reconstruction

Besides the cabinet sealing reconstruction of the feces bin in the underground feces storage chamber of Building 28#, the fan was also replaced, air quality before and after reconstruction is shown in Table 4.5.

Table 4.5 Air quality before and after the integrated reconstruction

Sampling site		Before reconstruction	After reconstruction
West underground feces storage chambers of Building 28#	Sampling date	October 13, 2006	April 8, 2007
	Absorbance	0.283	0.035
	Ammonia concentration	0.667 mg/m^3	0.177mg/m^3
	Subjective feeling	No peculiar smell	no peculiar smell.

5 Conclusions and suggestions

5.1 Conclusions

1) The key problems of the feces/urine source separation dry-toilet in EETP are lacking of water seal for the urine system, inadequate sealing of the feces storage system, abrasion of mechanical components, blocking of the ventilating pipes, unbalanced air resistance of branch vent pipes, inadequate fan capacity and unsatisfied routine operation and maintenance.

2) Proposed retrofitting measures are adding S-type trap to the urinal, adding water seal odor isolator to the toilet, replacing the bin cover with the sealed cabinet, replacing the fan, balancing the air pressure of the branch ventilation pipes, and improving the piping arrangement.

3) After taking the above measures, the odor problem has been much mitigated, the sanitary condition of the toilet room has been well improved, and the complaints from households have also decreased significantly The ammonia concentration has dropped below 0.2 mg/m^3.

5.2 Suggestions

1) As this system contains the fly breeding source, it shall be strictly monitored and exterminatory measures shall be taken to avoid the transmission of diseases.

2) The staffs of the eco-station should have good sense of responsibility to timely check or report problems existing in the ecosystem and ensure normal operation of the system.

3) Householders should maintain the sanitation condition of the toilet room and timely clean up residues on toilet that can generate the unpleasant smell. Meanwhile, regulations for using such ecological system shall be strictly followed.

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