

# The idea of "sponge city"—green roof rainwater collection and utilization system

WeiYu Zhan<sup>1</sup>, Qingmei Ye<sup>2</sup>, Xiaotong Wu<sup>3</sup>, Wentao Yan<sup>4</sup>, Yimin Zhu<sup>5</sup>

<sup>1</sup>School of Architecture and Urban-Rural Planning, Zhuhai University of Science and Technology, Zhuhai, 519041, China

<sup>2</sup>School of Architecture and Urban-Rural Planning, Zhuhai University of Science and Technology, Zhuhai, 519041, China

<sup>3</sup>School of Architecture and Urban-Rural Planning, Zhuhai University of Science and Technology, Zhuhai, 519041, China

<sup>4</sup>School of Architecture and Urban-Rural Planning, Zhuhai University of Science and Technology, Lecturer, Zhuhai, 519041, China

<sup>5</sup>School of Architecture and Urban-Rural Planning, Zhuhai University of Science and Technology, Associate Professor, Zhuhai, 519041, China

**Abstract:** This article proposes a plan that takes the original building roof of colleges and universities as an example. The "green roof rainwater collection and utilization system" is converted to achieve the "green roof" landscaping environment, insulation and insulation, and collecting water sources. It is mainly composed of two parts: "Green Roof" and "Rainwater Collection and Utilization System". (Including waterproofing layer, flexible protective layer), drainage water storage layer, filtering layer, light-quality synthetic planting soil, vegetation layer. The "rainwater collection and utilization system" section is to collect, treat and use rainwater in the process of purifying water quality, and use a unique "double-flow diameter, dual filtration, dual collection" to store rainwater. The rainwater of the indoor water storage tank is used to flush the toilet. The water tank is equipped with a water level sensor, which realizes the automatic switching of water tank water supply and municipal water supply to ensure continuous water supply. The water in the underground pond is used on ground irrigation vegetation and moist road surface.

**Keywords:** public building, green roof, rainwater collection, design plan

## 1. Foreword

In April 2016, Zhuhai became the second batch of pilot cities in the construction of a national sponge city. In May 2018, the local regulations "Administrative Measures for the Construction of Sponge City in Zhuhai City (Trial)" were promulgated, and the construction of sponge cities was turned into Zhuhai's long-term adherence to the concept and requirements, and based on this legislation. The system clarifies the approval and management process of sponge city construction projects, realizes the effective management and control of the implementation of the concept of sponge city in the city's new reform and expansion projects, and is intended to build Zhuhai into a "sponge city with high rainwater and stagnation capabilities."<sup>[1]</sup>

As a "typical city of rain", Zhuhai City has a high groundwater level, poor soil permeability in some areas, dense river nets, and has seasonal waterlogging and engineering. The sponge technology adopted by Zhuhai City is "net" and "row" as the main source of sponge measures and storage—the combined sponge facility<sup>[2]</sup>.

As an important part of the sponge city, the green roof can effectively link the urban rainwater runoff pressure, form a good urban landscape, enhance the overall greening rate of the city, absorb the heat of the building, and alleviate the urban heat island effect. Collect the research and implementation of the system.

The school campus has the characteristics of large number of people, large open space area, large water base, high green space ratio, energy saving, and large potential of water saving. Therefore, it is suitable for the construction of rainwater control and utilization systems with green infrastructure as the main body. This study is based on a university in Jinwan District, Zhuhai City as the research object. It

is planned to use the principle of water balance balance, and use the long -term sequence of long -term sequence to collect rainwater volume and water use scenarios. The lack of rainwater collection system in Zhuhai City, the low loss of rainwater into a clean water for bathroom cleaning water, as shown in Figure 1.

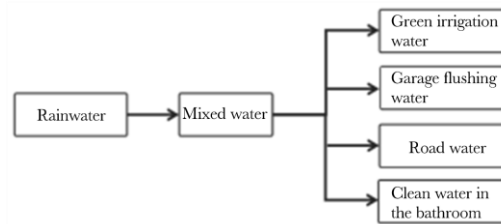


Figure 1: Rainwater use mode

## 2. Status of research in China and abroad

### 2.1 Status abroad

Foreign foreign countries have attached great importance to the research on the green roof rainwater collection system. It has been studying and practical history for more than 30 years. It has a relatively complete rainwater utilization system. At present, Germany has the world's leading level in this technology field.

Germany is located in central Europe, with an annual precipitation of 800 mm, the distribution of rainfall is relatively uniform, and there are many rivers, and the water resources are abundant. Although there is no problem of water resources, for the good ecological environment of Witt, the German government has formulated strict laws and regulations to carry out the development and carry out the development. Research and application of rainwater use. In this political context, German building roofs generally have rainwater collection and utilization systems. One approach is to do anti -seepage treatment of roofs. Set up rainwater collection pipes around the roof to bring rainwater to the underground collection pool, and then provide mixed water in the community; One method is to form a roof garden in the building roof planting plant. The common effect of soil layer and plant can reduce the runoff coefficient of the roof to 0.3. At the same time, plant absorption and soil filtration can improve the water out of the water out of the rainwater<sup>[3]</sup>.

At the same time, there are thousands of such rainwater utilization examples in Japan, including regional rainwater utilization facilities, parks, office buildings, large sports venues and other public facilities, residential areas, single housing and other types of rainwater utilization systems. Most of them are collecting rainwater on the building, using precipitation and filtering methods. Some rainy facilities also have a chlorine device to regularly disinfect the rainwater storage tank<sup>[4]</sup>.

### 2.2 China's development status and case

There are few research on the construction of Chinese sponge cities, the development speed of cities in various cities is uneven, and the concept of the development of sponge cities is not in place. It did not gradually develop until the 1990s. The lack of water resources in the northwestern region of my country. In order to ensure the normal water supply of the region, the country has carried out water recountry and North China. It was not until 2001 that the construction of sponge cities in my country began to flourish booming<sup>[5]</sup>.

#### (1) Water Cube:

The arched roof of the water cubes is special. It can bring rainwater into a central savings pool under the building. It is recycled by collecting procedures such as collecting, abandonment, storage, and disinfection. The water collection area of the water cubes is about 29,000 square meters, and the utilization rate of rainwater is about 76%. On average, it can be recovered by 10500m<sup>3</sup> per year.

#### (2) Suning Tesco Office Building:

There is a room of about a hundred square meters in the underground rainwater recycling equipment room on the second floor of Suning Tesco Building, which is filled with filters, pressurized boxes and other equipment. There is an area of 820m<sup>3</sup> rainwater collecting pool on the back of the wall.

The clearing pool. After the rainwater in the big pond is filtered and cleaned by the processing equipment, it enters the small pond, and then irrigates the greening and landscape near the building through the pipeline.

Due to the differences in regional and climate, the projects are mostly concentrated in water shortage cities and relatively developed cities, and universities have established rainwater reuse projects. There are many university sponge practice projects with higher attention in North China.

According to the results of the survey, there are only two methods of green roof filtering water and pipeline collection of rainwater in the research results. There is no study of combining green roof and rainwater collection system. The domestic sponge cities research starts late, and is usually for public buildings such as office buildings, gymnasiums, and lack of overall research on sponge cities such as campus building and residential buildings. The research is mainly based on the idea of sponge cities. Taking the research of the green roof rainwater collection and utilization system of the green roof rainwater in colleges and universities as an example, it is used as an example to explore the possibility of collecting and utilization systems of green roof rainwater of more types of buildings to make up for the vacancy of the current research.

### 3. Green roof rainwater Collection and Utilization System (Taking a university dormitory building in Jinwan District, Zhuhai as an example)

The dormitory building of a university in Jinwan District, Zhuhai (Figure 2-4) is located in Sanzao Town, Jinwan District, Zhuhai City, Guangdong Province, which has a subtropical Marine climate and abundant rainfall all year round. The building is an existing building with a height of 21 meters and a total of 6 floors. The building structure is a frame structure, the roof is a flat roof, and the height of the parapet is 1500 mm.

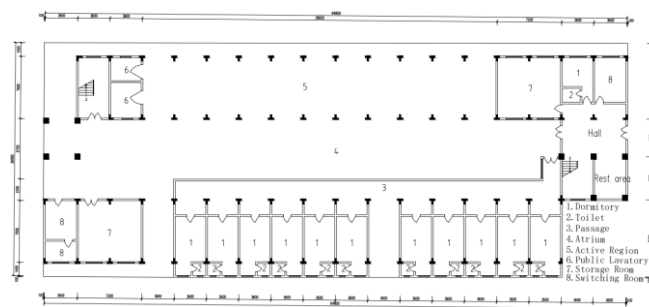


Figure 2: Floor plan of dormitory building

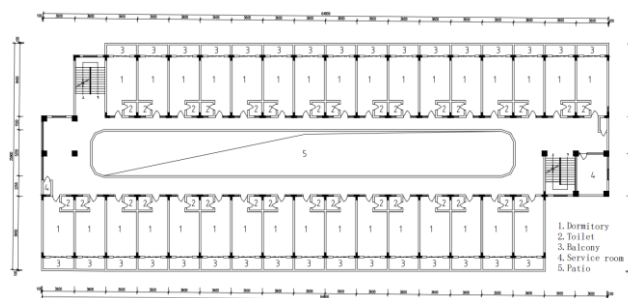


Figure 3: Floor plan of dormitory building

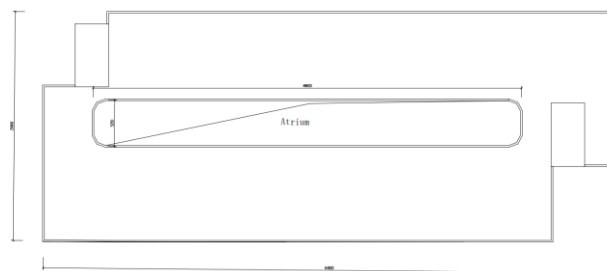


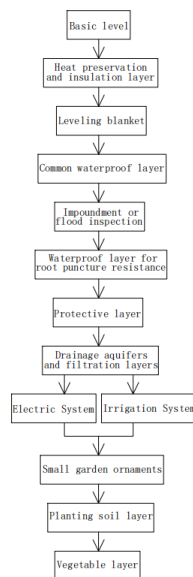
Figure 4: Dormitory roof plan

### 3.1 The "Green roof" study

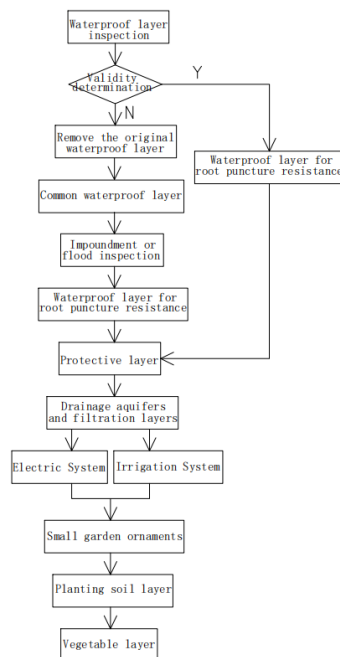
The structural construction process of green roofs is divided into two categories.

The first is the construction process of the green roof structure of the new building roof (Figure 5). The construction sequence is as follows: base layer, thermal insulation layer, screed layer, common waterproof layer, root piercing waterproof layer, protective layer, drainage aquifer, filtration layer, electrical system and irrigation system, planting soil layer and vegetation layer.

The other is the construction process of the green roof structure of the existing building roof (Figure 6), whose construction sequence is as follows: Firstly, the waterproofing layer should be inspected to determine whether it is effective. If it is not effective, the original waterproofing layer should be dismantled, the ordinary waterproofing layer should be rebuilt, the water storage or water leaching inspection should be carried out, and the root-piercing waterproofing layer, protection layer, drainage aquifer, filtration layer, electrical system and irrigation system, planting soil layer and vegetation layer should be laid. If the original waterproof layer is effective, the root puncture waterproof layer is directly laid [6].



*Figure 5: Green roof structure construction process of new building roof*



*Figure 6: Green roof structure construction process of existing building roof*

### 3.2 The "Green roof" scheme

According to the study on the structural construction process of the above green roof, the "green roof" scheme of this study is concluded:

(1) Since the dormitory building of a university in Jinwan District of Zhuhai is an existing building, the original waterproof layer of its roof should be inspected first. After the inspection, the original waterproof layer is judged to be effective.

(2) The waterproof layer with root puncture resistance is laid above the original waterproof layer. The material is elastomer modified asphalt waterproof coil, which has the dual functions of waterproof and preventing plant root penetration, and has good corrosion resistance, mold resistance and weather resistance.

(3) Set a protective layer on the waterproof layer of root puncture resistance, the existing building for the roof, that is, the use of 40 mm thick C20 fine stone concrete, with a separation joint, vertical and horizontal spacing is not greater than 6m, the width of the separation joint is 10mm-20mm, and sealed material embedment, effectively protect the waterproof layer below.

(4) Drainage aquifers are set, and polyethylene plastic concave-convex drainage board is selected to meet the requirements of compressive strength, and 2-5% of the base surface is required to find slope. PVC drainage pipe is set up in the drainage layer to discharge rainwater from the roof along the potential and flow into the storage tank along the pipe to save and reuse.

(5) The filter layer is set up above, and the multi-layer geotextiles are covered on the drainage plate. The geotextiles cover each other by 200mm to prevent mud and water from passing through the geotextiles, silting and blocking the storage and drainage system, resulting in poor drainage and reduced water storage. The coarse sand is laid on the geotextiles above 20mm to form the infiltration and filtration layer to prevent the loss of planting soil.

(6) Laying electrical systems and irrigation systems.

(7) Lay the planting soil layer, and configure the dry weight of nutrient soil  $0.3T/m^3$  and wet weight  $0.65T/m^3$ . The formula of light nutrient planting soil: peat soil, bark blocks, can be used to plant straw mushroom, mushroom waste medium, after grinding, drying treatment to make roof greening light nutrient cultivation soil accounts for about 30%, perlite accounts for about 30%, local planting soil accounts for about 30%, the height of about 600mm, can be planted lawn, ground cover, shrubs, small trees. A buffer zone of pebbles is set between the planting soil and the parapet wall, with a width of more than 300mm.

(8) For the vegetation layer, local plants should be adopted, and their waterlogging or emerging time should be longer than 36 hours. Considering that Zhuhai is the prevailing period of typhoons from July to October, wind resistance should also be considered. In this scheme, Haitong (shrub, belonging to the family Haitong, tolerant to cold and heat, resistant to sea tide and wind, with strong adaptability), hibiscus (shrub, malvaceous family, tolerant to cold and light, tolerant to drought and pruning), Phoronyx (ground bark, belonging to the family Sedulaceae, extremely tolerant to drought and barren, slightly tolerant to cold), and forbido (grass, grass, tolerant to light and semi-shade, strong and resistant) are selected.

After calculation, the roof area of the study object is 1278.9 square meters, then set garden planting green roof.

$$S_r = 1278.9 \times 60\% = 767.34m^2$$

$$S_e = 1278.9 - 767.34 = 511.56m^2$$

$$S_p = 767.34 \times 85\% = 652.239m^2$$

$$S_i = 767.34 \times 12\% = 92.08m^2$$

$$S_g = 767.34 \times 3\% = 23.02m^2$$

In the formula:  $S_r$ -- green roof area;

$S_e$ -- roof equipment area;

$S_p$ -- roof area of green planting;

S<sub>1</sub>-- paved garden road area;

S<sub>g</sub>-- the area of garden ornaments;

Figure 7-8 shows the green roof design scheme of the dormitory building.

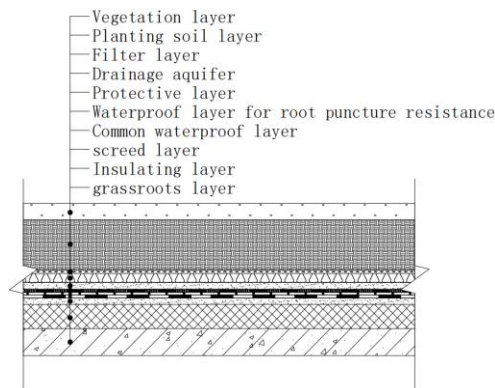


Figure 7: Dormitory building green roof basic structure level

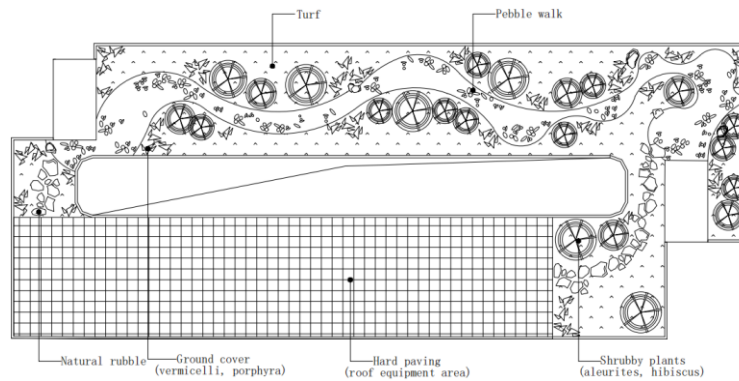


Figure 8: Dormitory green roof plane design scheme

### 3.3 Study on rainwater harvesting and utilization system

The traditional roof rainwater collection system consists of abandonment filtration system, water storage system and purification system. One of its disadvantages is that the transportation of miscellaneous water in the indoor water tank needs to be laid from the surface of the additional pipeline pressure pumping, the cost increases; The second disadvantage is that water tank and municipal water supply can not be fully automated, can not ensure the sustainable water supply; In addition, the lack of overflow device can not solve the problem of flooding plants caused by heavy rainfall<sup>[7]</sup>.

#### 3.3.1 Double flow path

The first path of the system is that rainwater penetrates through the planting soil layer and flows into the indoor water storage tank along the pipe. The second flow path is mainly used when the rainfall is too large. A rain hopper is set on the side 50mm above the vegetation layer to prevent the vegetation layer from being flooded by rain. The rainwater bucket is connected with the riser, and the overflow pipe in the first diameter meets the riser, and eventually leads to the underground sump.

#### 3.3.2 Double filtration

In order to meet the water quality standards of residential miscellaneous water, a double filtration scheme is proposed, and after coarse filtration through the roof soil layer, another industrial filter is set for fine filtration, so as to ensure the quality of indoor water storage tank is up to standard.

As shown in Figure 10, the rainwater of the first diameter flows into the indoor storage tank after being coarse filtered through the roof along the pipe. A pre-filter is installed at the front of the storage tank to separate impurities from the rainwater after coarse filtered. The initial rain in the first 3-5mm contains more pollutants and cannot be stored, so the initial rainwater abandonment device is installed between the rain pipe and the water storage tank. With the increase of rainfall, the water level rises. When the set water level is reached, the rain will end the abandonment and enter the indoor water

storage tank through the rain pipe. When the initial rainwater does not reach the set water level, it is discharged into the sewage network, and the sewage in the underground sump also needs to be discharged into the sewage network. In addition, a disinfection and dosing device is installed between the storage tank and the initial rainwater abandonment device to remove the elements with odor, and then the rainwater treated in the storage tank is pressurized by the water supply pump and disinfected by the ultraviolet sterilizer before being supplied to the water reuse pipe network.

In order to prevent the rain water of the second flow path from flowing into the pipe, a simple filter is set up on the side of the parapet wall. When the rainfall is too large, the upper clear rainwater will be directly discharged into the initial rainwater abandonment device through the pipe. The rainwater overflow from the first and second flow paths is set up again near the ground to reach the standard of miscellaneous water, and flows into the underground catchment pool.

WISY rainwater recovery filter is the specific material selected for the filter and the initial rainwater abandonment device. It requires no maintenance and can separate rainwater from impurities and mix a lot of oxygen with rainwater to prevent the water inside the tank from getting smelly and maintain good water quality.

### 3.3.3 Double collection

The indoor water tank is provided with a liquid level gauge, when the water in the tank is submerged, that is, when the water level is high, the liquid level gauge output signal to the main control chip, control the municipal water pipe solenoid valve closed, rainwater recovery system solenoid valve opened; When the water level drops, the liquid level gauge will output a signal to the main control chip, which controls the solenoid valve of the rainwater recovery system to close and the solenoid valve of the municipal water pipe to open, realizing the automatic switching of water source (FIG. 9). The rainwater flowing into the indoor storage tank is mainly used to flush the toilet, while the water in the underground catchment tank is used to irrigate vegetation and wet the road surface [8].

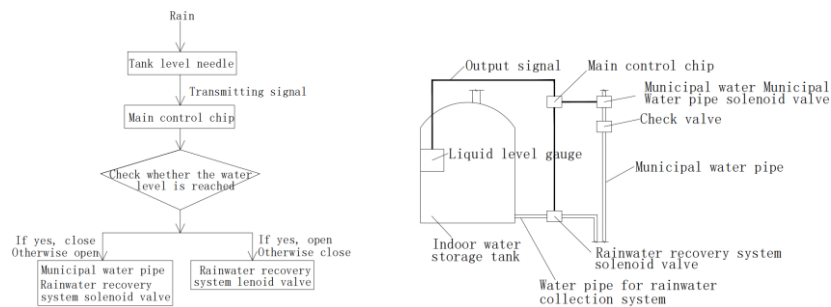


Figure 9: Switch water automatic specific process

### 3.4 Rainwater collection and utilization system scheme

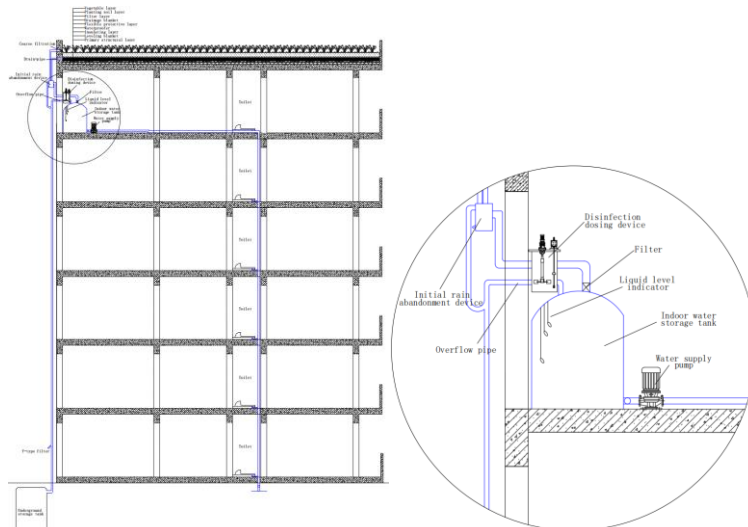


Figure 10: Schematic diagram of rainwater collection and utilization system in dormitory building

The water storage tank in this scheme is located in the service room on the sixth floor of a university dormitory building in Jinwan District, Zhuhai. The specific arrangement is shown in Figure 10 (the underground catchment tank is an existing one on campus).

#### 4. Data analysis of green roof rainwater collection and utilization system

##### 4.1 Water consumption analysis of a university dormitory building in Jinwan District of Zhuhai

A university dormitory in Jinwan District of Zhuhai has introduced recycled water from the municipal pipe network for flushing toilets, and digital water meters are set in the recycled water main channel of each toilet. Through monitoring and analysis of the data of flushing water in four student dormitory buildings from April to June in summer, as shown in Table 1, the maximum average flushing water consumption in male dormitory and female dormitory is 27.39L/(person ·d) and 27.59L/(person·d), respectively, based on the average value from Monday to Thursday in this scheme.

*Table 1: Per capita daily water consumption for flushing in each dormitory*

Time	Water consumption/L/(person·d)			
	Boys dormitory 1 building	Boys dormitory 2 building	Girl dormitory 1 building	Girl dormitory 2 building
Monday	24.62	26.54	24.12	27.45
Tuesday	25.41	25.62	32.10	24.62
Wednesday	26.85	28.76	25.41	26.84
Thursday	24.87	28.65	22.36	31.48
Friday	27.63	25.87	26.12	27.41
Saturday	28.54	28.62	28.36	30.54
Sunday	28.12	26.75	31.25	29.65
Average value from Monday to Thursday	25.43	27.39	25.9	27.59
Average value from Friday to Sunday	28.09	27.08	28.57	29.21

Taking the female students' dormitory building with more maximum average water consumption per flushing day from Monday to Thursday as the research object, there are 4 students in one dormitory, 32 dormitories in each floor from Floor 2 to Floor 6, and 11 dormitories in the first floor. Assuming that the dormitories are fully occupied, the total number of floors is 6.

$$Q_u = Q_p \times N \times F \tag{1}$$

In the formula:  $Q_u$ -- water consumption of the whole building (L);

$Q_p$ -- Per capita daily water consumption for flushing (L/(person ·d));

$N$ -- The number of users (persons);

$F$ -- general floor;

$$Q_u = 27.59 \times (4 \times 32 \times 5 + 11 \times 4) \times 10^3 \approx 18.871 \text{m}^3$$

To sum up, it is known that its daily water consumption is about 18.871m<sup>3</sup>, and the average annual duration of college students is about 240 days, so the average annual flushing water consumption of the dormitory :18.871m<sup>3</sup>×240d=4529.04m<sup>3</sup>.

##### 4.2 Analysis of rainwater collection

Zhuhai is a subtropical monsoon humid climate, with no severe cold in winter and no severe heat in summer. The rainfall from April to September accounts for about 80% of the annual total. According to the analysis of the total monthly rainfall data of Jinwan District of Zhuhai in January-December 2022 (provided by Jinwan Airport Observation Station of Zhuhai), as shown in Figure 11, the rainfall in January, April and December is less than or equal to 50mm, and that in May, June and August is more than or equal to 250mm, among which the rainfall in May is the highest, reaching 727.2mm. The average annual precipitation is about 214.9mm.



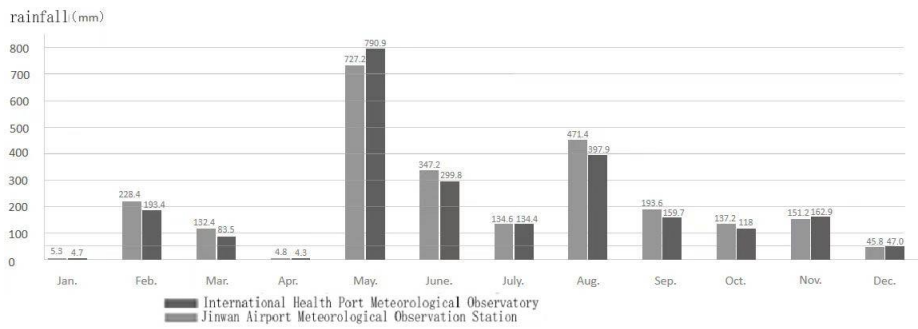


Figure 11: Statistical chart of total monthly rainfall in Jinwan District from January to December 2022

Taking the dormitory building of a university in Sanzao Town, Jinwan District, Zhuhai City as the research object, the relevant data are estimated.

1) Calculation of annual rainwater collection

$$Q = h \times F \tag{2}$$

In the formula: Q -- Rainwater collected, m<sup>3</sup>;

h -- Average annual rainfall, mm;

F -- catchment area, square meters;

After consulting relevant data, we know that the average annual precipitation in Jinwan District of Zhuhai over the years is about 214.9mm, and the available roof area within a dormitory building of a university in Sanzao Town, Jinwan District of Zhuhai is about 767.34m<sup>2</sup>.

Then annual rainwater collection:

$$Q = 214.9 \times 767.34 = 16490 \text{ m}^3$$

Since  $Q = 16490 \text{ m}^3 > 4529.04 \text{ m}^3$ , the annual rainwater collection amount of this dormitory building can meet the annual flushing water consumption of one dormitory building.

According to the layout characteristics of the area and the requirements of rainwater recycling, part of the roof rainwater in the area was collected, with a total collection area of 1278.9 square meters (see Figure 4). According to Article 4.2.1 of "Technical Code for Rainwater Utilization Engineering of Buildings and Residential Areas" GB50400-2006, the formula of total rainwater design runoff is calculated:

$$W = 10 \Psi_c h_y F \tag{3}$$

In the formula: W -- total designed runoff of rainwater, m<sup>3</sup>;

F -- catchment area, h square meters;

h<sub>y</sub> -- designed rainfall thickness, mm;

Ψ<sub>c</sub> -- runoff coefficient, the roof is green roof, then the coefficient of roof is 0.5;

According to the literature, the daily maximum rainfall in the one-year and two-year return periods of the major monitoring stations in China is calculated according to the annual maximum rainfall method and the return period formula, so the calculated rainfall thickness in Zhuhai is 43.6mm<sup>[9-10]</sup>. It can be calculated that the total rainwater design runoff in the green roof area of the dormitory building is about  $W = 10 \times 0.5 \times 43.6 \times 1278.9 \times 10^{-4} = 27.88 \text{ m}^3$ .

According to Article 4.1.4 of "Technical Specifications for Rainwater Collection, Storage and Utilization Engineering" GB/T50596-2010, the total amount of rainwater that can be collected:

$$W' = W a - W_w \tag{4}$$

In the formula: W' -- recoverable water amount of rainwater, m/a;

W -- total rainwater runoff, m<sup>2</sup>/a;

a -- seasonal reduction coefficient, 0.85;

$W_w$  -- initial rain water runoff, m<sup>3</sup>.

Therefore, the total amount of rainwater that can be collected by the rainwater system of this project during a rainfall period is:

$$W' = \frac{27.88 \times 0.85 - 10 \times 0.5 \times 3 \times 1278.9}{10000} = 21.7797 \text{m}^3$$

### 4.3 Analysis of rainwater collection box

The rainwater collection box is generally fully enclosed, with minimal evaporation and leakage losses. Therefore, the water balance equation of the rainwater collection box can be expressed as:

$$R_t = \begin{cases} Q_t & Q_t + S_t - D_t \leq V \\ V - S_t + D_t & Q_t + S_t - D_t > V \end{cases} \quad (5)$$

In the formula:  $R_t$  is the rain water quantity held in the reservoir for  $t(t \geq 1)$  days, m<sup>3</sup>;

$Q_t$  is the rainwater quantity that can be collected in the catchment area on the  $t$  day, m<sup>3</sup>;

$S_t$  is the amount of water stored in the storage pool at the beginning of the  $t$  day, m<sup>3</sup>;

$D_t$  is the water demand on day  $t$ , m cubed

$Q_t$  can be calculated by pressing:

$$Q_t = \begin{cases} 0 & H_t \leq \delta \\ 10\psi(H_t - \delta)F & H_t > \delta \end{cases} \quad (6)$$

In the formula:  $H_t$  is the rainfall on day  $t$ , mm.

The water storage ( $S_t$ ) of rainwater collection tank can be calculated as follows:

$$S_t = \begin{cases} 0 & Q_{t-1} + S_{t-1} - D_{t-1} \leq 0 \\ Q_{t-1} + S_{t-1} - D_{t-1} & 0 < Q_{t-1} + S_{t-1} - D_{t-1} \leq V \\ V & Q_{t-1} + S_{t-1} - D_{t-1} > V \end{cases} \quad (7)$$

In the formula:  $S_{t-1}$  is the water storage capacity of the reservoir at the beginning of the first day, m<sup>3</sup>;

$Q_{t-1}$  is the rainwater quantity that can be collected in the catchment area on day  $t-1$ , m<sup>3</sup>;

$D_{t-1}$  is the water demand on day  $t-1$ , m<sup>3</sup>.

Rainwater retention rate  $\eta$  is one of the important indexes to measure the effectiveness of rainwater collection and utilization projects in alleviating urban waterlogging problems. It can be calculated by the following formula:

$$\eta = \frac{\sum R_t}{10\psi F \sum H_t} \cdot 100\% \quad (8)$$

The replacement rate of tap water  $W$  is an important index to measure the effectiveness of rainwater collection and utilization projects in alleviating urban water shortage, which can be calculated by the following formula:

$$w = \frac{\sum R_t}{\sum D_t} \cdot 100\% \quad (9)$$

Water supply guarantee rate  $g$  is an important index to evaluate the water supply capacity and reliability of rainwater collection and utilization projects. The formula is as follows:

$$g = \frac{N - U}{N} \cdot 100\% \quad (10)$$

In the formula:  $N$  is the total number of days included in the calculation period,  $d$ ;

U is the number of days when the water storage capacity of the reservoir cannot meet the water demand of the day, d;

Based on the daily rainfall data of Jinwan meteorological Station in Zhuhai from 2010 to 2020, the same runoff coefficient and initial discharge are adopted as designed rainstorm method [Yue Tongjia. Effect of rainfall and water use on optimal volume of urban rainwater collection and utilization system. Beijing Forestry University, 2021.], According to equations (5) ~ (7), the daily water balance of rainwater reservoir was continuously simulated. Formulas (8) ~ (10) were used to calculate the rainwater interception rate, replacement rate of tap water, water supply guarantee rate and benefit-to-cost ratio corresponding to the volume of rainwater collection box under different scenarios of irrigation water for flushing and greening, and their variation curves were drawn.

In this water consumption scenario, the curves of rainwater interception rate, tap water replacement rate, water supply guarantee rate and benefit-cost ratio are shown in Figure 12. When the volume of rainwater collection box is less than 20m<sup>3</sup>, the benefit-cost ratio is greater than 1, among which, when the volume of rainwater collection box is 7m<sup>3</sup>, the benefit-cost ratio reaches the maximum 2.05. Therefore, considering only economic benefits, the volume of rainwater collection tank under this water use scenario should be no more than 20m<sup>3</sup>, and the optimal economic volume is 9 m<sup>3</sup>. Considering the rainwater management benefit, water supply reliability and economic benefit comprehensively, the optimal design volume of rainwater collection box under this water use scenario is 19m<sup>3</sup>, the benefit-to-cost ratio is 1.10, and the rainwater interception rate, tap water guarantee rate and water supply warranty rate are 66.94%, 21.71% and 17.48%, respectively.

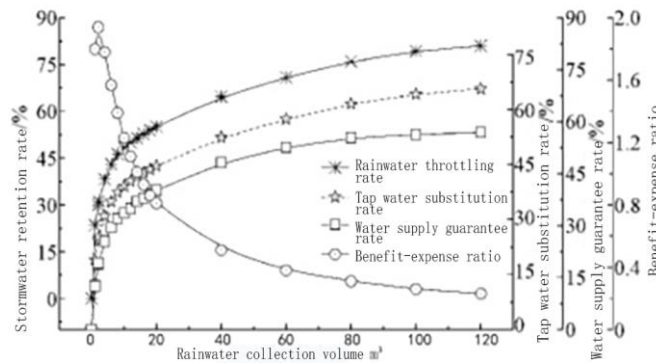


Figure 12: Variation curve of each index under comprehensive water use scenario

To sum up, the volume of rainwater collection box in dormitory building should be  $V = 19\text{m}^3$ , the size is  $3.0\text{m} \times 2.5\text{m} \times 2.7\text{m} = 20.25\text{m}^3$ , the effective volume is  $19\text{m}^3$ , and the effective water depth is 2.5m. Overflow pipe is set at the water level of  $18\text{m}^3$  to direct the rest of the rainwater to the underground catchment tank.

According to the "building structure load code" GB 50009-2012 strong provisions, dormitory floor active load should take  $3.5\text{KN}/\text{m}^2$ , water tank covers an area of  $8.1\text{m}^2$ , water density  $\rho=1$ ;

Then the floor needs to carry:  $N_n = 19000\text{N}$ .

According to the floor active load is  $3.5\text{KN}/\text{m}^2$ , the water tank covers an area of  $8.1\text{m}^2$ , the floor can bear:

$$N = 3.5 \times 8.1 \times 1000 = 28350 \text{ N}$$

As  $N > N_n$ , it can be known that the water tank can be reasonably placed in the service room of the dormitory building.

#### 4.4 Benefit analysis of rainwater harvesting

(1) Increased regulation and storage capacity.

The designed storage capacity of the building is  $21.7797\text{m}^3$ , while its daily flushing water consumption is  $18.871\text{m}^3$ . The storage capacity is much larger than that of the equivalent sponge city construction scheme, which provides a feasible scheme for saving sponge city construction investment in the process of university construction<sup>[11]</sup>.

(2) Obvious effect of water saving and emission reduction.

According to the specification<sup>[12]</sup>, Green watering with water amount of  $1 \sim 3L/(m^2 \cdot d)$ ;

Where,  $Q_{\text{overflow}} = W \cdot 18.75 = 3.029m^3$ .

Assuming that  $2L/(m^2 \cdot d)$  is required for greening watering, the overflow of  $3.029m^3$  water can water  $1514.85m^2$  of green space in that day.

(3) The campus operation cost is significantly reduced.

The price of local water in Jinwan District of Zhuhai is  $1.38 \text{ RMB}/m^3$ , and the annual rainwater collected is  $164,901m^3$ . Assuming that the daily flushing water consumption of the dormitory is unchanged, the annual water demand is  $4,529.04m^3$ . The extra rainwater is used for irrigation and greening, and the annual cost can be saved up to  $227,500 \text{ RMB}$ , with significant economic benefits.

## 5. Summary

Advantages and promotion of this scheme:

1) Easy to collect and use, rainwater is collected to the water tank on the roof, and the water level difference is used to supply downstairs. There is no need to lay pipes from the surface to pressurize pumping, saving manpower and material resources.

2) The indoor water collection tank is equipped with a water level sensor, which can realize the automatic switch between the municipal water supply and the indoor water supply tank, so as to ensure the continuous water supply.

3) The "double flow path" of the water system in this scheme is equipped with an overflow device to solve the problem of large rainfall amount and prevent rainwater from flooding the planting layer.

4) The planting layer selects wind-resistant, cold-tolerant and drought-tolerant plants, mostly ground cover and shrubs of no more than 3m, to prevent the coming of extreme weather such as typhoon and heavy rain.

Colleges and universities have large resident population, large land area, large water consumption, large rainwater confluence area, and great potential for energy and water saving. Strengthening the recycling and reuse of rainwater on campus is an important content of sponge city and green campus construction<sup>[13]</sup>. By exploring the green roof rainwater collection and utilization system of campus buildings, we see the possibility and popularization of green roof rainwater collection and utilization system of residential buildings and other types of buildings, which has great social benefits.

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