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Design and Cost Economics of Rooftop Rainwater Harvesting System for College and Hostel Buildings of CAE Campus, Bapatla

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ABSTRACT

Water is a life-blood of the environment and it is a limited universal solvent, which is essential for all forms of growth and development of human, animal and plants to sustaining the basic need for their economic activities. However, water is a renewable resource which is gift from nature because of its availability in space and time and is limited by climate and hydrological condition. Hence an attempt is made to design and evaluate the cost economics of roof top harvesting system. The total rooftop surface area of College building and UG boys' hostel building were 1061.9 m^2 and 608.74 m^2 respectively. The total cost for the installation of the rooftop rainwater harvesting structure for College and UG boy's hostel buildings were Rs. 55385.18 and Rs. 33241.14 respectively. The benefit cost ratio for the installation of the rooftop rainwater harvesting structure for College and UG boy's hostel buildings were 1.58 and 1.50. The Net present worth for the installation of the rooftop rainwater harvesting structure for College and UG boy's hostel buildings were Rs. 73283.39 and Rs. 38604.56.The Payback period for the installation of the rooftop rainwater harvesting structure for College and boys' hostel buildings were 0.58 and 0.51.

Key Words: Cost economics, Rooftop surface area, Rooftop rainwater harvesting system.

Water is a life-blood of the environment and it is a limited universal solvent, which is essential for all forms of growth and development of human animal and plants, to sustaining the basic need and for their economic activities. Though water is a renewable resource, which is free gift from nature.

Now a days the availability of water in urban areas has become a problem; therefore to meet the water requirement, one of the best option is rooftop rain water harvesting. The national drinking water mission constituted in 1986 has suggested this is one of the viable technologies for solving water related problems in our country. Hence a comprehensive study was initiated on broad aspects of rooftop rainwater harvesting. If we adopt this method there is rise in ground water levels, increases availability of water from well, reduction in the energy for pumping water and consequently the cost of a one meter rise in water level saves about 0.49 KWH of electricity, helps to save the money on monthly water bills, reduces in flood hazard and soil erosion.

Rooftop rainwater harvesting is the process of collecting and storing rainwater in a scientific and controlled manner for future use. To meet the ever-increasing agricultural and domestic water demand effective water management techniques such as harvesting rainwater, recharging underground aquifer also lessens local erosion. The rooftop water harvesting involves a simple collection of rain that falls on a building. This encompasses the components like catchment area, conveyance system, filters, storage tanks and distribution system.

Omwenga (1984) stated that a survey in Kissi and Kenya showed that 33 per cent of households collected water in oil drums compared with 17 per cent, which had permanent tanks. Most of the remaining families collected some runoff from roofs in pots, pans, and buckets placed under caves during storms. The oil drums can also be used for rainwater collection with a capacity of 2,000 liters. Mohan Rao (2000) conducted that the experiment on roof water harvesting in Dewas. The prescribed Dewas roof water harvesting filter consists of a standard PVC pipe (4 kg/m^2 pressure) of size 1.2 to 2 m in length and diameter depends on the roof area. He recommended that for the roof area up to 136m^2, the diameter of the filter pipe should be 15 cm and for roof area more than 136 m^2, the diameter of the filter pipe should be 20 cm. The filter media should consist of pebbles of size 6 mm to 40 mm. The entire cost of the filter media and other filtering varies from Rs. 800 to Rs. 1,200. This system not only increased the water level of the deep aquifer but also reduced the hardness of the groundwater.

Murthy et al. (2000) worked out that the total quantity of water that could be harvested from ARS Taluka office building at Gouribidanur, Karnataka.

The roof area was about 900 m^2 and the total annual rainfall was 650 mm. The total quantity of water that could be harvested or recharged during a year was worked out to be 585 cubic meters. The water from the roof was collected through drain pipes and made to pass through a common pipe connecting a settling tank for arresting the impurities; the collected water was then passed to the recharge pit. Ravikumar and Anand (2002) conducted that the experiment on rooftop rainwater harvesting in civil engineering block, Bangalore, University, J.B campus, Bangalore, Karnataka. The annual average rainfall of this campus is 860 mm and rainwater harvesting is necessary since the campus population depends solely on ground water. They adopted the rainwater collection from the rooftop, in an area of 5500 sq.m. The total water consumed was estimated to be 2, 25,600 liters per year. The rainwater was conveyed by gravity flow through 22.5 cm pipes, which was approximately 700 m length to sumps. From the sumps water was conveyed to an existing tank, which was given a revetment and thus clean water was collected. The rooftop rainwater collected worked out to be 47,80,000 liters which can be stored for more than a year with suitable measures.

MATERIAL AND METHODS

The present investigation on rooftop rainwater harvesting was carried out during 2008-2009 at the College of Agricultural Engineering (CAE) campus, Bapatla. Bapatla is situated in the Coastal Zone of Andhra Pradesh state at $15^0 54^1$ N latitude and $80^0 30^1$ E longitude with an altitude of 5.49 m above the mean sea level. The average annual rainfall of College of Agricultural Engineering campus is 998.33 mm.

Description of the Study Area

The College is the main building in the CAE Campus which is situated near to the main road [Bapatla to Karlapalem road] consists of a two-store building with flat terrace roof surface. Water is supplied from a circular overhead tank which is located on top of the building and about 175 members are working in this building. The roof top area of this building is 1061.91 m^2. The UG boy's hostel building is two store building with the flat terrace roof surface, which is located about 250 meters from the left side of the CAE building. Water is supplied from two circular overhead tanks which are located on top of the building. Nearly 66 members are staying in this building. The roof top area of this building is 608.74 m^2.

Layout and Design of the Rooftop rainwater harvesting structure

The various components in the design of rooftop rainwater harvesting structures are as follows;

1) Rooftop surface area
2) Down pipe
3) P.V.C pipe
4) Detention basin
5) Filtration basin
6) Storage tank

1. Rooftop surface area

Flat roofs normally with RCC have water proofing as a surface finishing. This top surface is provided with a slope towards down water pipes. This type of roof will minimize the pipe length to the storage system.

Whole roof terrace surface area of this hostel was divided into a number of rectangular parts and each area was calculated by using the basic formula as given below

Where,

A = Area of rectangle [m^2]

L = Length [m]

B = Breadth [m]

After adding all these area of rectangles the total rooftop area contributing the rainwater was obtained and was 1670.65 m^2 (Table 1).

2 Down pipe

The down pipes also called transmitters are another important component in the rainwater harvesting system. The down pipe should be connected to the holes at top surface of roof to collect water which falls on it. The pipe should be made up of PVC, HDPE, galvanized steel or cement available in different sizes can be used for transporting rainwater collected from roofs to the filtration systems before storing. The size of the down pipe varies depending on the roof area and rainfall intensity. The down pipe should be at least 100 mm diameter. Normally 1 square inch of down pipe is enough for every 100 square feet of roof area. The down pipes are fitted inside the wall during construction of wall of the building. 3-4 down pipes are sufficient for 1000 to 1200 square feet area. The number of down pipes present in college and UG boy's hostel buildings and their heights are represented in Table 2.

Table 2 Number of down pipes present and their heights for both buildings

Based upon the maximum intensity of rainfall the diameter required for down pipe was calculated by using the following formulae:

Volume of water harvested (Q) =
Rooftop area X Rainfall intesity X
Runoff Coefficient .... (i)

Q = A X Vm ------------------- (ii)

Where,

Q = Flow in channel, m^3/s

Vm = Velocity of flow in channel, m/s

A = Cross sectional area, m^2

Where,

$$A = \left(\frac{\pi d^2}{4}\right) ----------(iii)$$

d = Diameter of the down pipe, m

Where,

$$Vm = \sqrt{\frac{H \times d \times g}{2 \times f \times l}} --------(iv)$$

H = Available head causing flow, m

g = Acceleration due to gravity, m/s^2

f = Darcy's roughness coefficient

l = Length of the pipe, m

Substituting equations (i), (iii) and (iv) in equation (ii) we get

$$Q = \left(\frac{\pi d^2}{4}\right) \times \sqrt{\frac{H \times d \times g}{2 \times f \times l}}$$

3. P.V.C pipe

The PVC pipe also called as conveyance system by which the water is received from the down pipe and was diverted through P.V.C pipes to the detention basin. By using number of joints like L bends and T bends at necessary places, all underground and above ground pipes are joined in the line. The PVC pipes are commonly used instead of others because of low initial cost, ease of application, resistant to inside pipe corrosion and much lighter than metal pipe. The conveyance piping from the gutter system to the cistern or filter should be 4 inch diameter. More than 45-degree angle bends should not be exceeded in horizontal pipe and a minimum slope of ¼-inch per foot shoud be provided. The total lengths of P.V.C pipe required from down pipe end to detention tank were measured for all buildings, which are presented in Table 3.

Based on the maximum rainfall intensity, the pipe design was made. The pipe diameter required for supplying water was calculated using the following formulae:

Volume of water harvested (Q) =
Rooftop area X Rainfall intesity X
Runoff Coefficient .... (i)

Where,

Q = Flow in channel, m^3/s

Q = A X Vm ------------------- (ii)

Vm = Velocity of flow in channel, m/s

A = Cross sectional area, m^2

$$A = \left(\frac{\pi d^2}{4}\right) ----------(iii)$$

Where,

d = Diameter of the down pipe, m

$$Vm = \frac{1}{n} \times R^{\frac{2}{3}} \times S^{\frac{1}{2}} ------(iv)$$

Where,

n= Manning's roughness coefficient

R = Hydraulic radius = d/2

S= Slope factor

Substituting equations (i), (iii) and (iv) in equation (ii) we get

$$Q = \left(\frac{\pi d^2}{4}\right) \times \left(\frac{1}{n} \times \left(\frac{d}{2}\right)^{\frac{2}{3}} \times S^{\frac{1}{2}}\right)$$

4. Detention basin

The purpose of this basin is to reduce the speed of the rainwater that comes out of the P.V.C pipes and to settle down the larger impurities present in the rainwater. The treatment is to be recommended for contaminated water to make it

Table 1 Rooftop surface areas of different buildings

Sl.No.	Buildings	No. of members/ building	Rooftop surface area (m^2)
1	College	175	1061.91
2	U.G boy's hostel	66	608.74

Table 1 Number of down pipes present and their heights for both buildings

Sl.No.	Buildings	No. of down pipes present	Height of each down pipe (m)
1	College	20	8.20
2	U.G boy's hostel	20	7.10

Table 3. Length of the PVC pipe required for College and UG boy's hostel buildings up to detention basin.

Sl.No.	Name of the Buildings	Pipe length required(m)				
		63mm	75mm	90mm	110mm	140mm
1	College	-	-	83	57	41
2	U.G boy's hostel	44	71	25	6	-

potable or fit for drinking purposes. These detention tanks settle the inorganic impurities and makes water fit for the next process of filtration. These basins are usually located near filter unit. From the P.V.C pipe, the water can be let into the detention basin. In case of intense rain this structure has got a great utility in dissipating the velocity of rainwater.

Maximum quantity of water harvested (Q) =
Total depth of rainfall X Rooftop area X Runoff coefficient

For the laying of foundation bed and for the construction of walls for detention basin the cement concrete 1:5:10 and II class chamber burnt bricks with cement mortar 1:5 are used and the inner walls are plastered by 1:5 cement mortar of 12 mm thickness. Maximum rainfall intensity calculated does the design of this structure. The size of the detention basin and the velocity required for settlement were calculated by using the following formulae:

Stoke's Law to calculate time taken to settle the particles

$$T = \left[\frac{0.03 \times \eta \times Dv}{(Dp - D) \times 4 \times r^2} \right]$$

Where,

T = Time taken for particles to fall vertical distance D, s

Dv = Vertical distance through which the particle falls , m

r = Radius of the particle, m

Dp = Particle density, g/cc

D = Density of water, g/cc

Table 4. The diameter of down pipe and PVC pipe and dimensions of detention basin, filtration tank, storage tank of College andUG boy's hostel buildings

SI.NO	Items	College	UG boy's hostel
1	Diameter of down pipe, mm	90	63
2	Diameter of PVC pipe, mm	90,110,140	63,75,90,110
3	Detention basin		
	a) Length, m	1.6	1.3
4	b) Breadth, m	1.1	1.0
	c) Depth, m	1.0	1.0
5	Filtration tank		
	a) Length, m	2.9	3.0
	b) Breadth, m	1.9	2.0
	c) Depth, m	2.0	1.0
	Storage tank		
	a) Length, m	6.0	4.5
	b) Breadth, m	4.0	3.0
	c) Depth, m	2.0	2.0

Table 5. The total cost for the installation of the rooftop rainwater harvesting structure for College & UG boy's hostel buildings

S.No	Parameters	College	Hostel
1	PVC pipe	Rs. 20262.30/-	Rs. 9110.62/-
2	Various fittings	Rs. 2170/-	Rs. 1960/-
3	Detention basin	Rs. 2290.00/-	Rs. 2021.75/-
4	Filtration tank	Rs. 8151.57/-	Rs. 5252.70/-
5	Storage tank	Rs. 22511.30/-	Rs. 14896.07/-
6	Total cost	Rs. 55385.17/-	Rs. 33241.14/-

5. Filtration basin

The rainwater collected on the roof is very pure and clean. But there are many substances they get mixed up with this pure water on roof like leaves, bird droppings, dust etc. The best strategy is to filter and screen out the contaminants before they enter the storage tank. These contaminants need to be filtered before the rainwater is stored. Filtration is the important process in the purification of water for drinking purposes. The first rainwater will get cleaned away any contaminants using a roof washer. The function of roof washer is to isolate and reject the first water after rain and then direct the rest of rainwater to the storage tank. Instead of wasting the water, the first flush can be used for non-potable uses such as irrigating the garden. There are many methods used for filtration as discussed below.

Sand bed filter:

The sand bed filter in which coarse riverbed sand, pebbles and aggregates in the ratio of 1:1:1 inches are filled as layer one above the other in a confined masonry structures. Then the rainwater is allowed at the top from one end and filtered water is drawn from other side.

Pop up filter:

The pop up filter is simple in design and very flexible to install in varying field condition. The pop

Table 6. Cash flows of rooftop rainwater harvesting for College building

Year (A)	Gross expenses (B)	Gross benefit (C)	Dis-counted factor at 12% interest rate (D)	Dis-counted gross expenses (E)	Discounted gross benefit (F)	Net benefit (G)
1	55385.17	25465	0.8929	49451.04	22736.31	29920.50
2	11077.03	25465	0.7972	8830.54	20300.28	14387.64
3	11077.03	25465	0.7118	7884.41	18125.25	14387.64
4	11077.03	25465	0.6355	7039.66	16183.26	14387.64
5	11077.03	25465	0.5674	6285.41	14449.34	14387.64
6	11077.03	25465	0.5066	5611.97	12901.19	14387.64
7	11077.03	25465	0.4523	5010.69	11518.92	14387.64
8	11077.03	25465	0.4039	4473.83	10284.75	14387.64
9	11077.03	25465	0.3606	3994.49	9182.82	14387.64
10	11077.03	25465	0.3220	3566.51	8198.94	14387.64
11	11077.03	25465	0.2875	3184.38	7320.48	14387.64
12	11077.03	25465	0.2567	2843.20	6536.15	14387.64
13	11077.03	25465	0.2292	2538.57	5835.85	14387.64
14	11077.03	25465	0.2046	2266.58	5210.58	14387.64
15	11077.03	25465	0.1827	2023.73	4652.30	14387.64
16	11077.03	25465	0.1631	1806.90	4153.84	14387.64
17	11077.03	25465	0.1456	1613.31	3708.79	14387.64
18	11077.03	25465	0.1300	1440.45	3311.42	14387.64
19	11077.03	25465	0.1161	1286.12	2956.62	14387.64
20	11077.03	25465	0.1037	1148.32	2639.84	14387.64
21	11077.03	25465	0.0926	1025.29	2357.00	14387.64
22	11077.03	25465	0.0826	915.43	2104.46	14387.64
23	11077.03	25465	0.0738	817.35	1878.99	14387.64
24	11077.03	25465	0.0659	729.78	1677.67	14387.64
25	11077.03	25465	0.0588	651.59	1497.92	14387.64
		Total		126439.55	199722.95	315382.76

Net present worth= F-E	73283.40
Pay Back period= Net present worth/ E	0.58
B-C ratio =G/F	1.58

Fig 1. Layout and Design of Rooftop Rainwater Haryesting Systems of College Buliding.

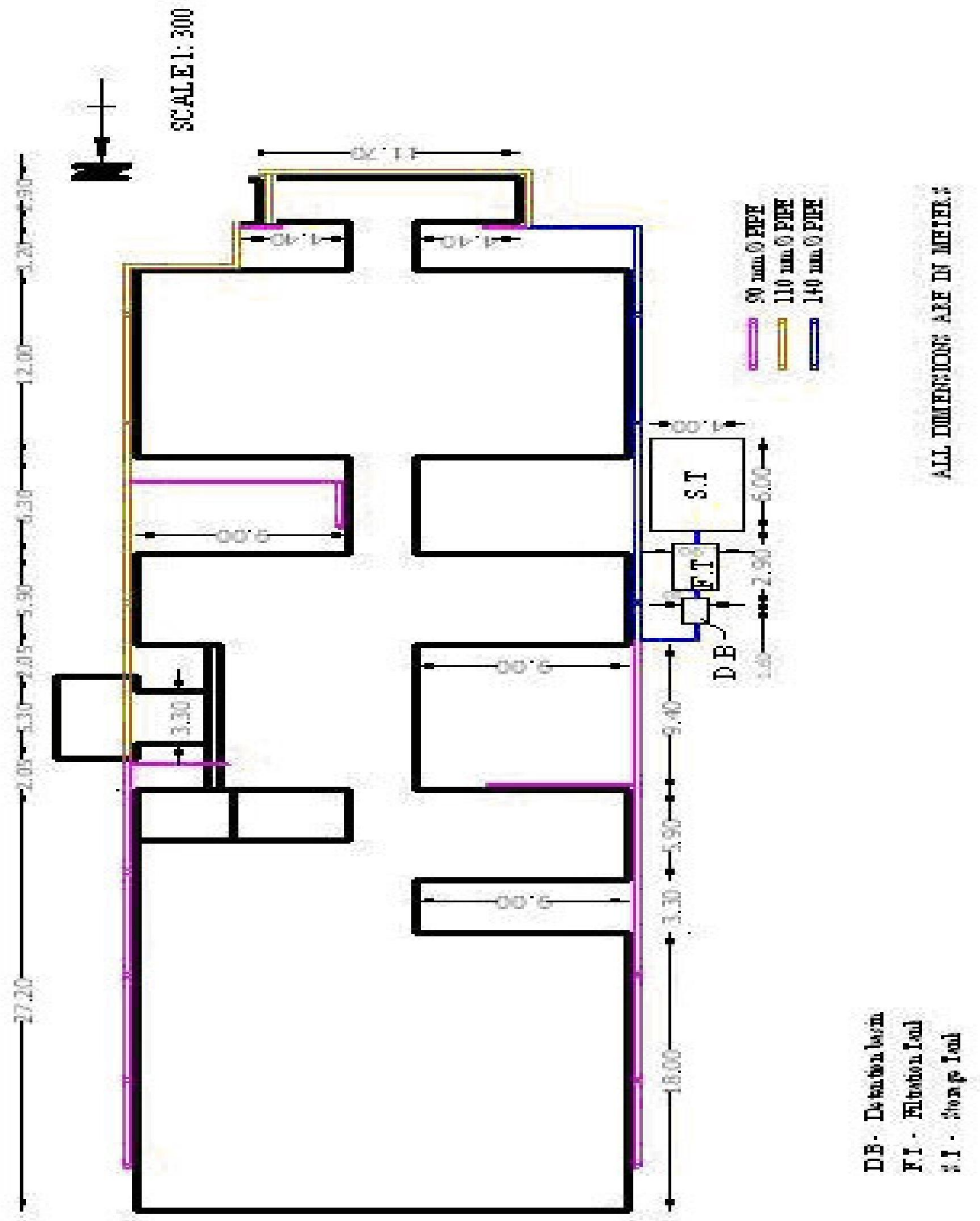
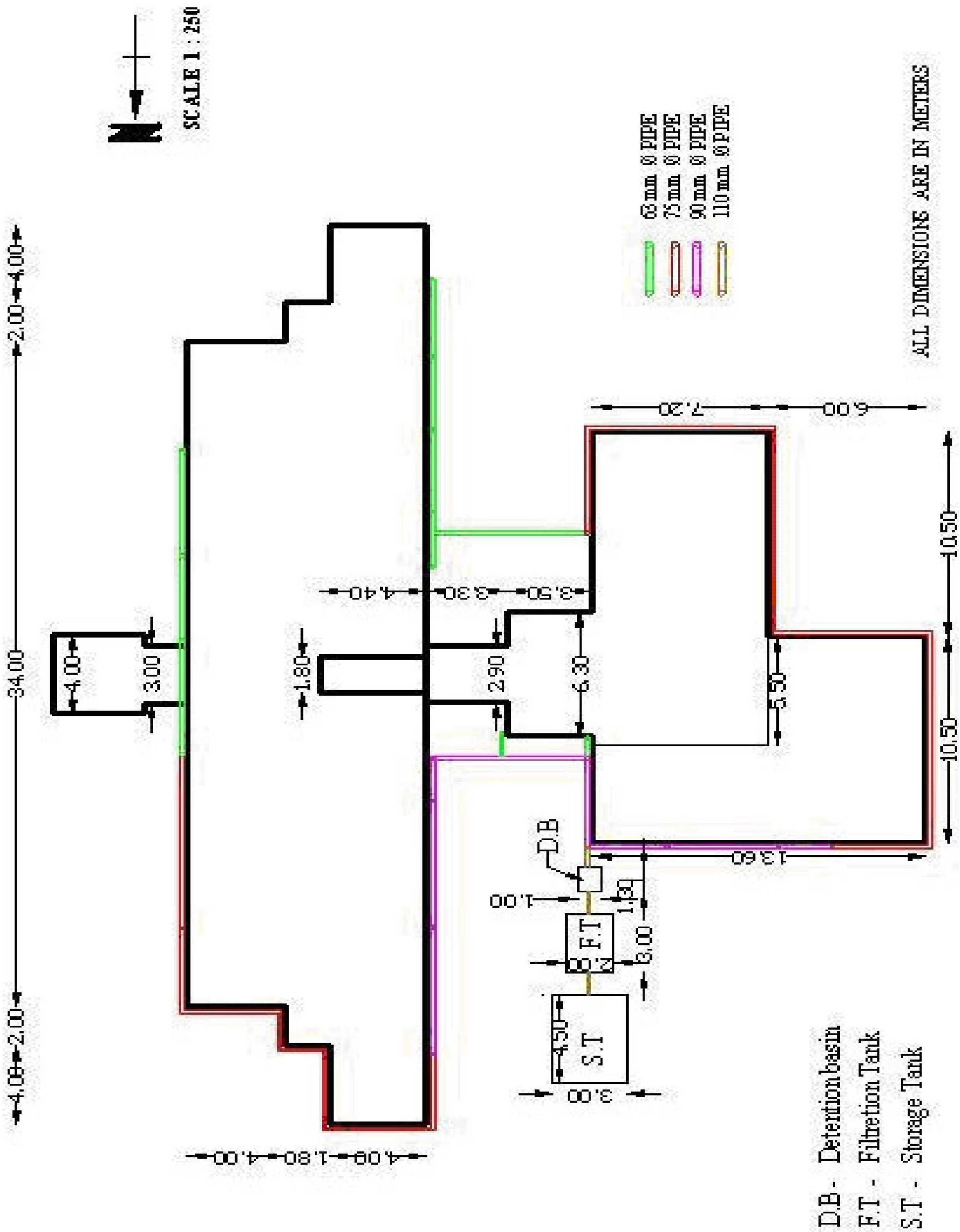


Fig 2. Layout and Design of Rooftop Rainwater Haryesting Systems of Ug Boys Hostel Buliding.



up filter has three components like rainwater receptor, flush valve and filter element. Rainwater receptor is allowed to flow from down pipe and a flush valve is provided to flush the first flow of rainwater along with leaves, dust etc. Finally rainwater is passing through the filter element which can be led to storage device.

Stabilization tank:

In this system, the rainwater is allowed to flow through a series of small tanks and by providing an entry and exit for water at strategic position. Heavier impurities will get trapped in the first two tanks as the water flows out at the higher level. Lighter and floating impurities get trapped in the third and fourth tanks as the water flows out at the bottom or lower level. For the laying of foundation, construction of walls and for plastering of walls same materials were selected as in the case of detention tank. Using maximum rainfall intensity the design was worked out with following formulae:

$$\text{Total surface area required (A)} = \text{Maximum discharge/Rate of filtration}$$

6. Storage tank

In Rooftop rainwater harvesting system, storage device is the single most expensive component. The tanks may be constructed on the surface as well as in underground by utilizing the local material. These storage tanks range in size made from a simple barrel, drum, fibre glass, galvanized steel, large concrete or wooden storage tank depends upon the availability of runoff water and water demand. Underground tanks are best for storage because the tanks have less chance for contamination and evaporation. To make rainwater available in non rainy days, storage device need to be designed with an optimum capacity to suit the need or requirement. Optimum size of the storage device and cost effective methods to store water are the key issues for a viable rooftop rainwater harvesting system. Ferro cement tanks are the cheapest one compared to others. To design this tank, 10 years weekly rainfall data were collected from Department of Meteorology centre in Bapatla. For computing initial probability, the rainfall data were arranged in descending order and the probability levels of 40, 50, 60, 75, and 90 per cent were calculated. The initial probability is calculated by using the following formula.

$$IP = \frac{S \times P}{100}$$

Where,

IP = Initial probability
S = Sample size
P = Probability required in percentage

Maximum quantity of water harvested from rooftop surface was found by following principle

Maximum quantity of water harvested = Total depth of rainfall X Rooftop area X Runoff coefficient

Based on the maximum quantity of water harvested the size of the storage tank was designed by using the basic formula

$$\text{Volume of tank} = \text{Length} \times \text{Breadth} \times \text{Depth}$$

The layout and design of Rooptop rainwater harvesting system for college and boys' are shown in Fig. 1 and 2.

6. Cost analysis

The cost of this technology varies considerably depending on location, type of material used and level of implementation. The components that need to be cost included like roofing materials, gutters, conveyance pipes, detention basin, filtration and storage tanks including operation and maintenance cost for the CAE Campus Bapatla. The expected life of the construction materials is taken as 25 year. To examine the economic feasibility of investments in rooftop rainwater harvesting the payback period and benefit cost ratio were analysed.

Payback period:

The payback period is a simple method of ranking a project. It is the length of the time required to get back the investment on the project. It was calculated by using the formula.

$$P = \frac{I}{E}$$

Where,

P = Payback period of the project in years
I = Investment of the project in Rs.
E = Annual net cash revenue in Rs.

Table 7. Cash flows of Rooftop rainwater harvesting for boys' hostel building

Year (A)	Gross expenses (B)	Gross benefit (C)	Dis-counted factor at 12% interest rate (D)	Dis-counted gross expenses (E)	Discounted gross benefit (F)	Net benefit (G)
1	33241.14	14598	0.8929	29679.58	13033.59	18643.51
2	6648.23	14598	0.7972	5299.93	11637.14	7949.40
3	6648.23	14598	0.7118	4732.08	10390.30	7949.40
4	6648.23	14598	0.6355	4225.07	9277.05	7949.40
5	6648.23	14598	0.5674	3772.38	8283.08	7949.40
6	6648.23	14598	0.5066	3368.20	7395.61	7949.40
7	6648.23	14598	0.4523	3007.32	6603.22	7949.40
8	6648.23	14598	0.4039	2685.11	5895.74	7949.40
9	6648.23	14598	0.3606	2397.42	5264.05	7949.40
10	6648.23	14598	0.3220	2140.55	4700.04	7949.40
11	6648.23	14598	0.2875	1911.21	4196.47	7949.40
12	6648.23	14598	0.2567	1706.43	3746.85	7949.40
13	6648.23	14598	0.2292	1523.60	3345.40	7949.40
14	6648.23	14598	0.2046	1360.36	2986.96	7949.40
15	6648.23	14598	0.1827	1214.61	2666.93	7949.40
16	6648.23	14598	0.1631	1084.47	2381.19	7949.40
17	6648.23	14598	0.1456	968.28	2126.06	7949.40
18	6648.23	14598	0.1300	864.53	1898.27	7949.40
19	6648.23	14598	0.1161	771.90	1694.88	7949.40
20	6648.23	14598	0.1037	689.20	1513.29	7949.40
21	6648.23	14598	0.0926	615.36	1351.15	7949.40
22	6648.23	14598	0.0826	549.43	1206.38	7949.40
23	6648.23	14598	0.0738	490.56	1077.13	7949.40
24	6648.23	14598	0.0659	438.00	961.72	7949.40
25	6648.23	14598	0.0588	391.07	858.68	7949.40
			Total	75886.64	114491.20	172142.02
Net present worth= F-E						38604.56
Pay Back period= Net present worth/ E						0.51
B-C ratio =G/F						1.50

The preference of a particular project is based on the shorter payback period.

Benefit - cost ratio (B-C ratio)

It is by comparing the present worth of costs with present worth of benefits. The benefit cost ratio will change based on the interest rate. The given project is opted for implementing, among alternatives, based on the highest B-C ratio. This ratio was calculated by dividing present worth of the discounted benefit to the present worth of the discounted cost.

$$\text{BC ratio} = \frac{\sum_{t=1}^{n} Bt \quad (1+i)^{-t}}{\sum_{t=1}^{n} Ct \quad (1+i)^{-t}}$$

Where,

Bt = Benefit in $t^{th\ year}$

Ct = Cost in $t^{th\ year}$

i = Discount rate

RESULTS AND DISCUSSION

Design of Rooftop rainwater harvesting structure

The design incurred for calculating dimensions for roof top area, down pipe, PVC pipe, various fittings (such as elblow, tee, reducers and gate valves etc.,) , detention basin, filtration tank, storage tank. The design of down pipe, PVC pipe and length, breadth, depth of detention basin, filtration tank, storage tank were calculated and represented in Table 4.

Cost Analysis

The cost incurred for different materials such as PVC pipe, various fittings (such as elblow, tee, reduces & gate valves etc.,) earthwork excavation, sand quantity, plain cement concrete, II class brick wall and pump were calculated and presented in Table 5. The total cost for the installation of the rooftop rainwater harvesting structure for College and UG boy's hostel buildings were Rs. 55385.18/- and Rs. 33241.14/-. The cash flows of roof top rain water harvesting for College & UG boys hostel are presented in Table 5 Table 6 and Table 7.

The Net present worth for the installation of the rooftop rainwater harvesting structure for College and UG boy's hostel buildings were Rs. 73283.40/- and Rs. 38604.56/-.The Payback period for the installation of the rooftop rainwater harvesting structure for College and UG boy's hostel buildings were 0.58 and 0.51. The Benefit cost ratio for the installation of the rooftop rainwater harvesting structure for College and UG boy's hostel buildings were 1.58 and 1.50 both more than 1.00.

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