Design of Grey water & Blackwater treatment plant for a Multi Storey Building in Ropar.

CP301 : DEP

Presented by:

Hardik - 2019CHB1045

Mehak - 2019CH1050

Nalin - 2019CHB1052

Suryansh - 2019CHB1057

Tanesh - 2019CHB1058

Under the guidance of:

Dr. Navin Gopinathan

Dr. Sarang Gumfekar

Introduction

1. The growth of urbanisation has resulted in an alarming decline in the quality of life in India's cities, causing a shortage of water supply and demanding water usage.
2. The volume and kind of trash generated in households are impacted by the residents' behaviour, lifestyle, the standard of living, and the technical and legal environment in which they live.

Table 1: Wastewater types

Wastewater from society	Wastewater generated internally in treatment plants
Domestic wastewater	Thickener supernatant
Wastewater from institutions	Digester supernatant
Industrial wastewater	Reject water from sludge dewatering
Infiltration into sewers	Drainage water from sludge drying beds
Stormwater	Filter wash water
Leachate	Equipment cleaning water
Septic tank wastewater	

By origin and chemical composition, wastewater is divided into

1. **Domestic wastewater** – It is generated from waters used in households – to maintain personal hygiene, flush sanitary facilities, prepare meals, etc. They are very cloudy, have a grey-yellow colouration, a characteristic smell and a slightly alkaline reaction.
2. **Industrial wastewater** – It usually contains a variety of chemical substances that are a byproduct of industrial plant technological procedures. Coking plants, petrochemical facilities, tanneries, pulp mills, dairies, and sugar industries have wastewater problems.
3. **Rainwater** – is sewage arising from atmospheric precipitation, washing away built-up areas. They contain large amounts of organic and inorganic impurities, many in the form of suspensions; similarly to some social and household sewage, they can be treated as greywater and recovered for the aforementioned needs.
4. **Municipal wastewater** – sewage is located in municipal sewage regardless of the source of origin (domestic, industrial, precipitation, meltwater or a mixture of this sewage). The definition of urban wastewater is aimed at distinguishing the responsibility of the owner of the sewage system (local government) for their disposal and the consequences of the failure.
5. **Agricultural wastewater** – formed from water flowing from fields and farms – usually contains artificial fertilisers, pesticides and microbial pollution.

Grey Water

- It originates from non-toilet and food fixtures such as bathroom sinks, laundry machines, spas, bathtubs, and so on. Technically it is sewage that does not contain poop or urine. It is treated differently from blackwater and is suitable for reuse.

Black water

- It is wastewater that originates from toilet fixtures, dishwashers, and food preparation sinks. Blackwater is made up of all the things going down the toilets, baths, and sink drains which include poop, urine, toilet paper and wipes, body cleaning liquids, etc.

Yellow water

- It is urine collected with specific channels and not contaminated with either Blackwater or greywater.

1. There is a shortage of sanitary infrastructure in India's cities, and the wastewater generated is not appropriately controlled.
2. The water quality of aquatic resources has degraded due to insufficient sewage treatment systems.

Fig1 : Substandard conditions of Wastewater treatment facility of IIT Ropar.

Work Approach

-

- Determine the annual blackwater and greywater generation
- Incorporate the rainwater harvesting into process.

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- Study the conventional methods to treat and improvise them.
- Propose a ready to be implemented blackwater treatment plant layout.

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- Perform calculation pertaining to MBR to estimate reactor size and flow rates.
- Introduce Solar trackers to make the process self-sustainable

Results and Discussion

Prudent use of onsite water resources and available site area.

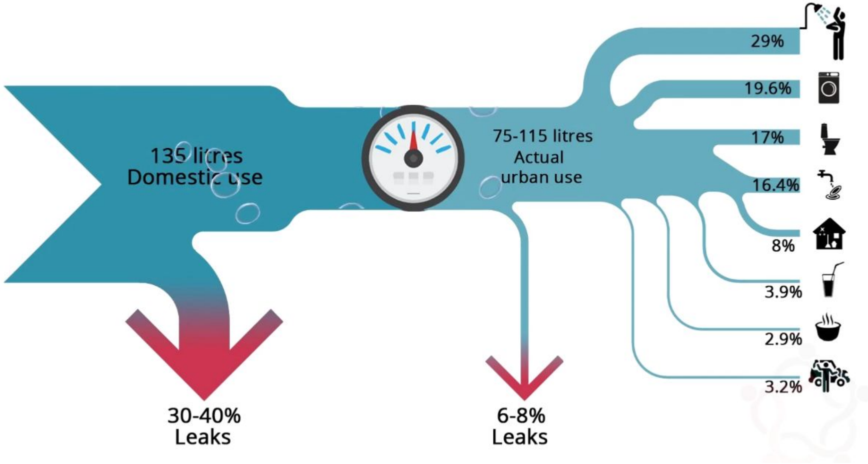
1. **Total occupancy:** 800
2. **Peak occupancy at a time -** 500
3. **BUILT-UP AREA:** 2600 sq. metre
4. **BUILT-UP AREA:** 2483.9 sq.metre
5. **ROOF AREA:** 800 sq. metre
6. **IRRIGATION AREA:** 538 sq. metre

Fig 2 : Building Design (Courtesy: Team Tejaswi, IIT Ropar)

Prudent use of onsite water resources and available site area.

1. **Total occupancy -** 800, **Peak occupancy at a time -** 500
2. **BUILT-UP AREA:** 2600 sq.metre

Per capita per day water use in a residential building for the base case is **135L.**



Occupant's Activity	Percent usage
Bathing	29.0%
Washing	19.6%
Drinking	4%
Cooking	3%
Toilet	17.0%
Cleaning house	8.0%
Washing Utensils	16.4%
Others	3.20%

Fig 3a,b : Breakdown of Household Supply.

Estimating Water Demand and Waste water generation

500 people

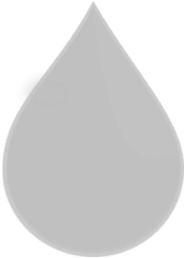
- We assume that 500 people will use the facility daily, and 36% of the total use can be taken care of by non-potable water.

Rainfall

- **Annual Rooftop** 5,75,503.0 L
- **Annual Hardscape** 15,01,567.2 L

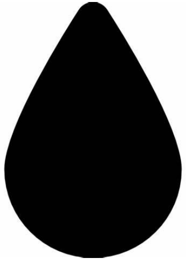
+ve performance

- **Annual consumption** 17,28,536.19L
- **Annual use of alternative** 30,12,310.011L



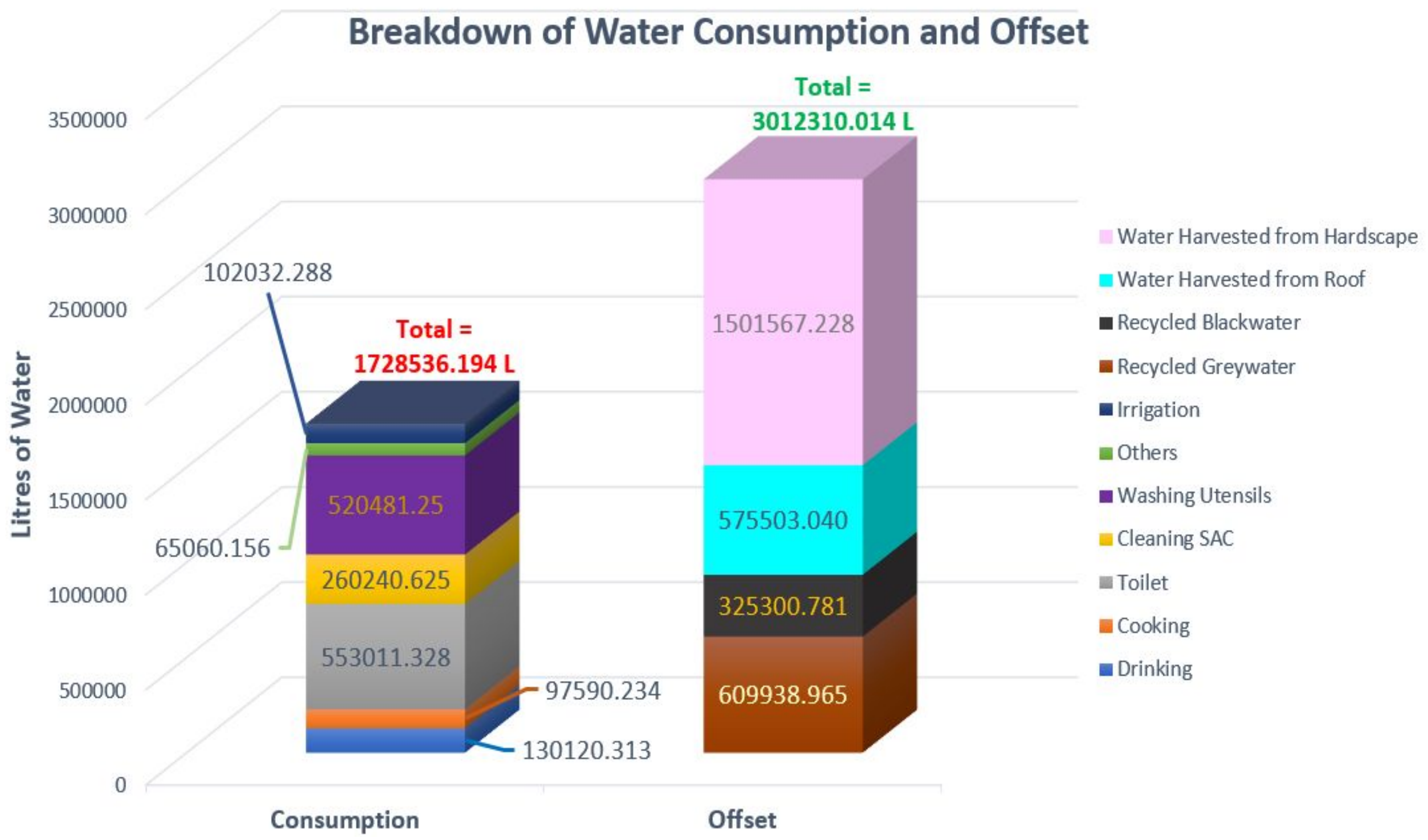
Greywater

7,80,321.875 Litres



Blackwater

5,53,011 Litres


Breakdown of Water Consumption and Offset
Litres of Water
3500000
3000000
2500000
2000000
1500000
1000000
500000
0
Consumption
Offset
Total =
1728536.194 L
Total =
3012310.014 L
102032.288
65060.156
520481.25
260240.625
553011.328
97590.234
130120.313
1501567.228
575503.040
325300.781
609938.965
Water Harvested from Hardscape
Water Harvested from Roof
Recycled Blackwater
Recycled Greywater
Irrigation
Others
Washing Utensils
Cleaning SAC
Toilet
Cooking
Drinking

- **Annual Consumption**- 17,28,536.2 L
- **Annual Rooftop Rainwater Harvesting**- 5,75,503.0 L
- **Annual Hardscape Rainwater harvesting**- 15,01,567.2 L
- **Black water = 5,53,011 Litres**
- **Greywater = 7,80,321.875 Litres**

Rainwater Harvesting

- Rainwater harvesting systems capture, redirect, store, and release rainwater to be used later.

- Rainwater falling on impervious surfaces is collected and transferred into an above or below-ground storage tank (also known as a cistern or rain tank), where it can be utilised for non-potable water and on-site stormwater disposal/infiltration.

- Landscape irrigation, external cleaning (e.g. car washes, building facades, sidewalks etc), flushing of toilets and urinals, fire suppression (sprinkler) systems, and so on are examples of non-potable usage.

- It can be classified into two broad categories: surface runoff harvesting and rooftop rainwater collection.

- **Surface Runoff Rainwater Harvesting**
    - It collects rainwater flowing down the ground during rainstorms and stores it in a tank beneath the ground surface for irrigation and other uses.
    - It is critical to employ efficient and effective water conservation strategies, such as limiting evaporation, while storing rainwater.

- **Rooftop Rainwater Harvesting**
    - It is a method of collecting rainwater from roof catchments and storing it in reservoirs.
    - Rainwater can be collected and stored in sub-surface groundwater reservoirs using artificial recharge techniques to suit residential demands in tanks.
    - In this report, our primary focus will be on **Rooftop Rainwater Harvesting**.

Essential Components of Rooftop Rainwater Harvesting

- **First Flush**
  - The first flush is a mechanism that removes the water from the first shower.
  - To avoid contaminating storable/rechargeable water with impurities from the atmosphere and the catchment roof.
- **Roof Washer**
  - Roof washers filter tiny material from rainwater collected from roof surfaces and are situated just before storage tanks.
  - Roof washers have a tank with leaf strainers and a filter with apertures as fine as 30 microns, usually between 25 and 50 gallons in size.

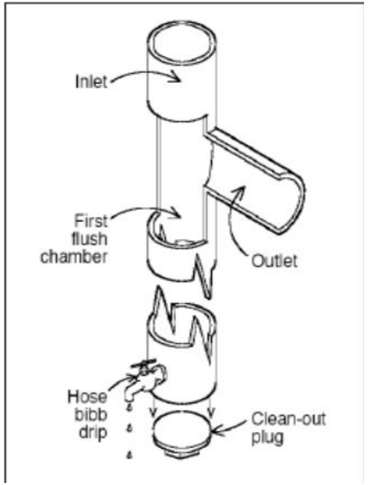


Fig-4 First Flush

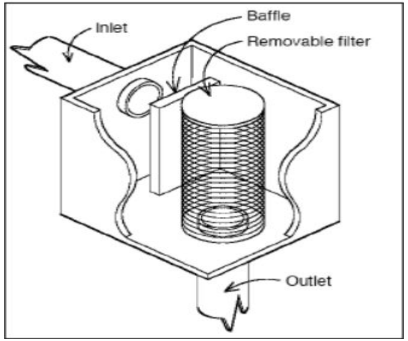


Fig-5: Roof washer

Rainwater Storage and Filtration

Now to store and transport the rainwater, we need to have a proper design and water filters of required efficiency.
So let's have a look at the filters that are used for the treatment of water to effectively remove turbidity, colour, and microorganisms.

- **Sand Gravel Filter**
  - Coarse sand which is of the range 1.5 to 2 mm in size, is preferred at the top.
  - Followed by gravel which are 5 to 10 mm in size.
  - Then boulders which are 5 to 20 cm in size are placed at the bottom.
  - Each layer should have a thickness of roughly 0.5 m.

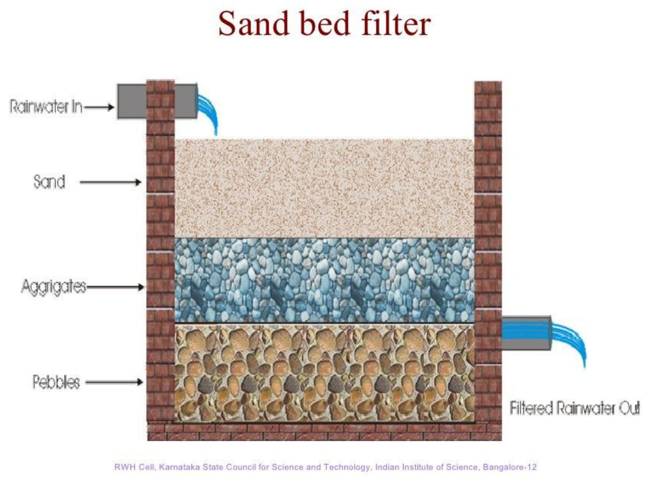


Fig-6: Sand Bed Filter

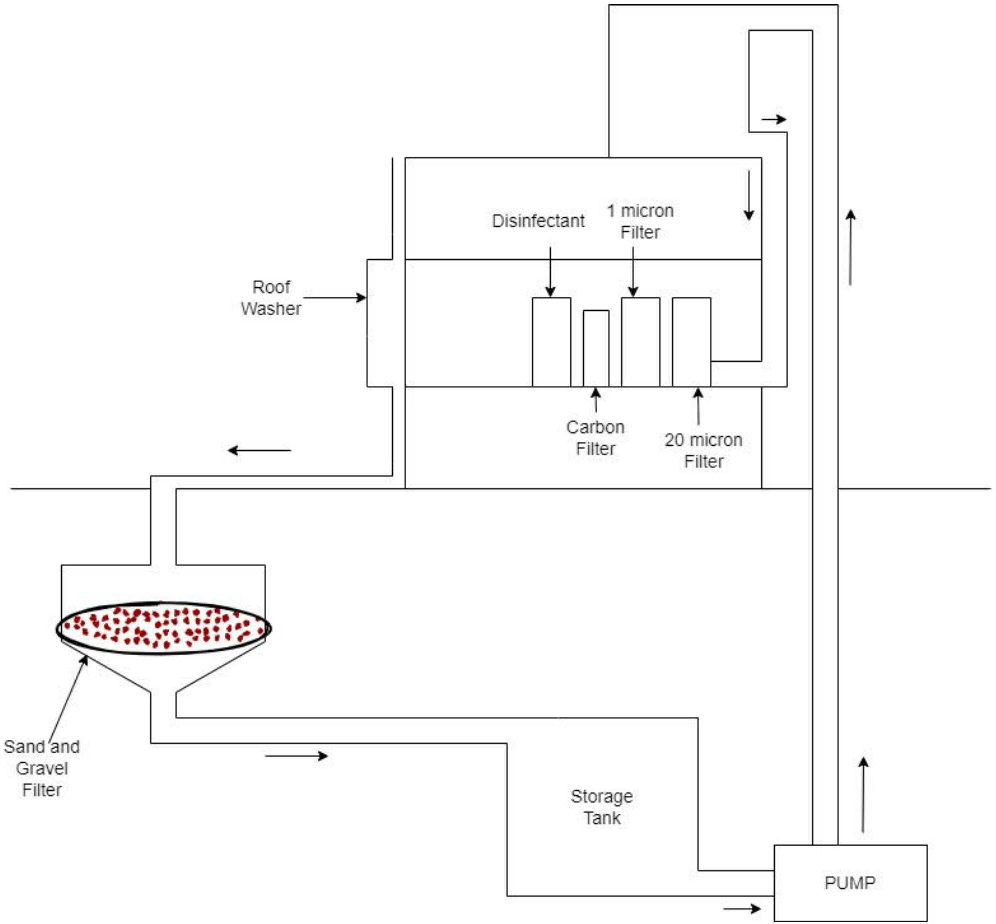
Rainwater Storage and Filtration

- **Charcoal Filter**
  - In situ or in a drum, charcoal filters can be manufactured.
  - The drum or chamber should be filled with pebbles, gravel, sand, and charcoal.
  - If there is any scent, a thin layer of charcoal is utilized to absorb it.
- **Disinfectant:** We will use Chlorine and Chloramine as our primary disinfectants.
- **1 micron and 20-micron filters**
  - Particulate filters allow for considerably finer filtration.
  - Nowadays, such filters are usually in the form of a sealed housing with a cartridge that catches every minute particle to offer even clearer water.
  - More advanced versions have a stainless steel element with a 23 'backwash' function – to enable easy cleaning.

Fig-7: 1 and 20 micron filters

Proposed Design for Rooftop Rainwater Harvesting

Fig-8: Proposed Rooftop Rainwater Harvesting Design



Greywater Treatment

- Greywater emerges from plumbing systems other than toilets, such as hand basins, washing machines, showers, and bathtubs.
- The adaptation of popular green walls can be incorporated to treat greywater.
- Green walls require lightweight media due to their vertical location on the wall, which reduces the strain on their supporting structures.

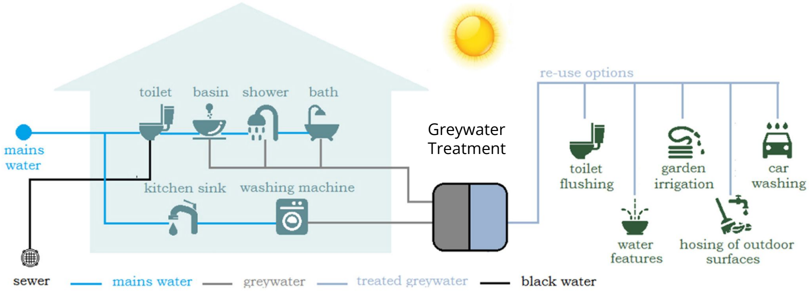


Fig-9: Sources of greywater

Green Walls

Green walls can also be used for greywater treatment. We can consider this method to treat greywater in compact space.

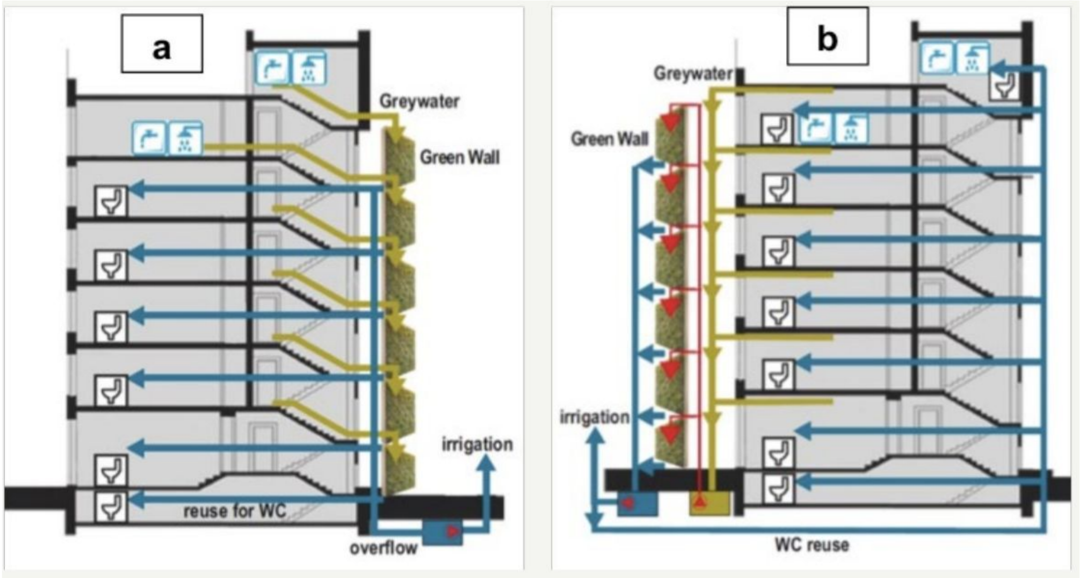


Fig-10: Possible implementation schemes for greywater collection, treatment, and reuse in the same building with green walls: a) floor-by-floor and b) unified.

Materials Involved

Fig-11: Coconut coir

Fig-12 : Perlite

Fig-13:LECA (Lightweight expanded clay aggregate)

Coco coir provides water retention which gives enough time for denitrification processes hence removing the pollutants from the greywater. Uses a biological process for removal.

An amorphous volcanic glass that has a relatively high water content. Perlite provides lower retention times or fast hydraulic. Pollutant removal is through physicochemical processes.

Leca is a growing medium, like soil, in which you can grow your plants. Leca is a collection of baked clay balls that expand when you soak them in water.

Materials Involved

- Mixing these two materials with different hydraulic behaviour allows, on one hand, to limit clogging issues, and, on the other hand, to increase the treatment efficiency, providing enough time for biological processes.

- So for optimum treatment of greywater, a mixture of coco coir and perlite will be used with 25% perlite to 75% coco coir or a ratio of perlite to coco coir of 1:2 along with light expanded clay aggregates (LECA).

- Plants used - Abelia, Wedelia Portulaca, Alternanthera, Duranta, and Hemigraphis.

Fig-14: Abelia

Fig-15: Wedelia Portulaca

Fig-16:Alternanthera

Average impurity removal when using coco coir along with LECA

Impurity	Percentage removal
Total nitrogen (TN)	70
Total phosphorus (TP)	23
E.coli	60
Total suspended solids (TSS)	90
BOD_5 (five-day biochemical oxygen demand)	54
COD (Chemical Oxygen Demand)	55

Table : Average impurity removal

Blackwater treatment

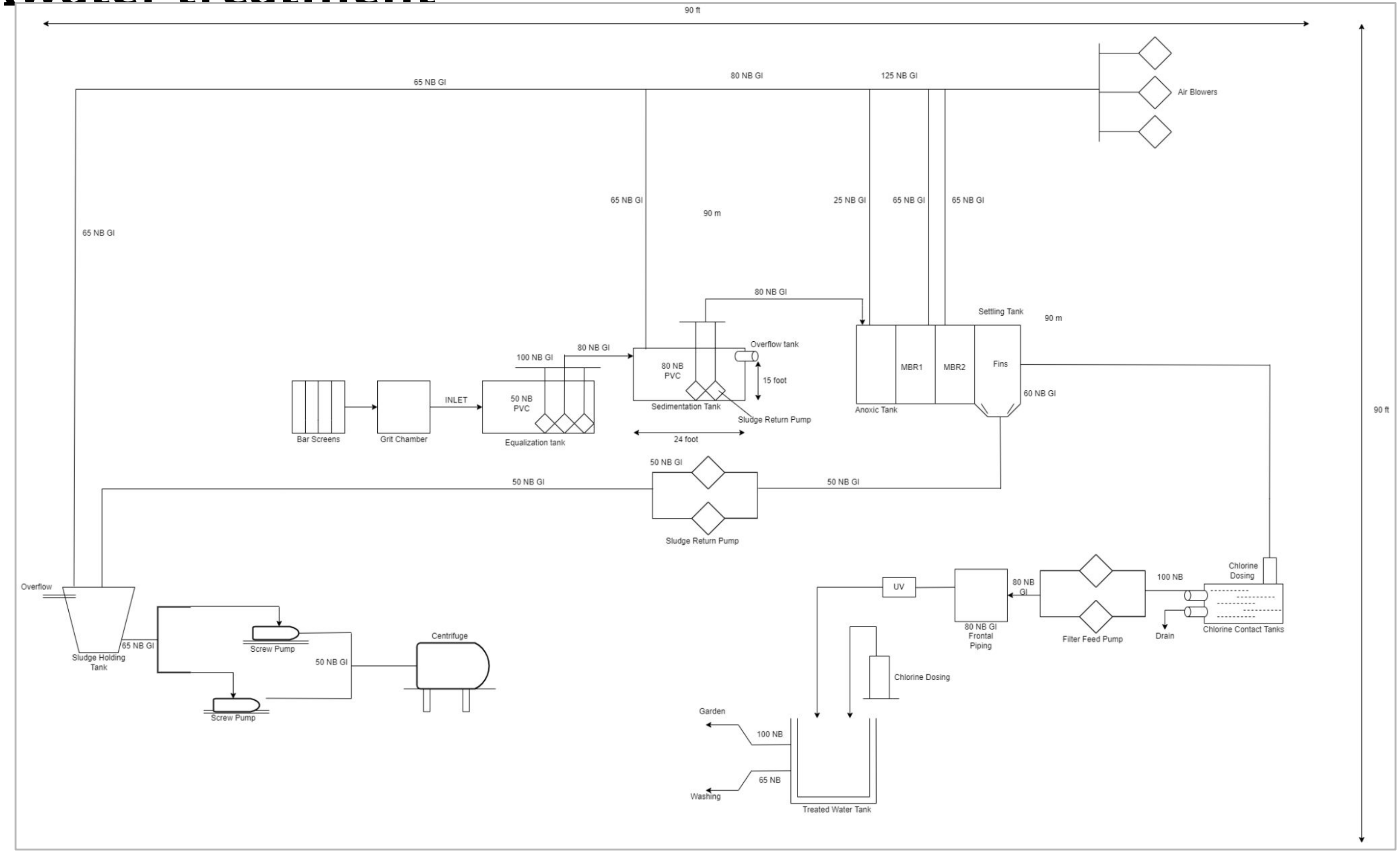


Fig-17: Blackwater treatment Model

Component in black water treatment plant

Bar screens Grit Chamber Equalisation tank Anoxic tank

Sludge holding tank Disinfectant tank Settling tank

Centrifuge tank Treated water tank

Blackwater treatment Process

Primary:

Material that will float or settle out by gravity is removed during the primary treatment.Screening, grit removal, and sedimentation are all examples of physical processes. Long, narrow metal bars are used to construct screens.

Secondary:

The soluble organic matter that escapes basic treatment is removed in secondary treatment. It also eliminates a higher percentage of suspended solids. Biological procedures are typically used to remove organic pollutants, with bacteria consuming them as food and converting them to carbon dioxide, water, and energy for their own growth and reproduction.

Blackwater treatment Process

Tertiary:

Effluent from secondary treatment is further treated through the tertiary treatment which includes disinfectant (chlorination) in the CCT tank then effluent further goes through the filters and then finally treated using UV.

Fig-18 Black water treatment

Black water treatment with Membrane Bioreactor:

Membrane bioreactor (MBR) is the combination of a membrane process like ultrafiltration with a biological wastewater treatment process.

Membrane Bioreactor is operated in a similar way as to operate in a conventional activated sludge process but it does not require secondary clarification and tertiary treatment like sand filtration.

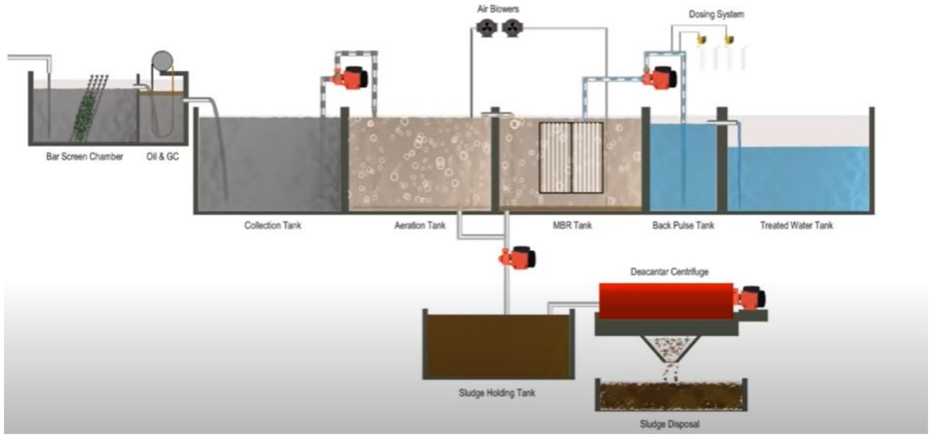


Fig 24: Membrane bioreactor technology

- Membrane bioreactors replace clarifiers, media filters and reduce reactor size by combining physical membrane barriers with biological treatment.

- Aeration brings water and air in close contact in order to remove dissolved gases and to oxidise dissolved metals, including iron, hydrogen sulphide, and volatile organic chemicals (VOCs).

- MBR is also suited for increasing the capacity and treatment efficiency of a wastewater treatment plant among limited land use in areas with a dense population and construction of underground wastewater treatment plants.

Membrane Characteristics

- Membrane Material: The fouling tendency of a membrane in an MBR is influenced by the material it is constructed of.

- Membrane Surface Roughness: Membranes with a higher surface roughness foul more quickly

- Membrane Pore Size: Fine particles have an easier time entering and becoming caught in the membrane pores. Large particles quickly form a top layer on the membrane with smaller pores and capture the smaller particles.

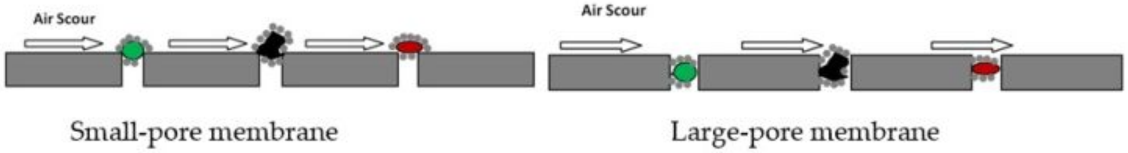


Fig 25: Small and Large pore membrane

- Process design calculations:

Design Membrane Flux:

$J = 0.4056T_{ww} - 5.7278$

$= 25.5\ L/hr/m^2$

Spec. Aer. Demand, SAD = 0.3 m3 air/hr/m2 membrane

Membrane Area $Am = Q_0/J = 100\ ft^2$

Membrane Module Vol. $Vm = Am/density = 3\ ft^3$

Scouring Air Flow Required: $Am*SAD = 2\ ft^3/min$

1. **Calculate the Biomass Production Rate :**

$bCOD_o = 1.6*BOD_o = 400$ mg/L
kd at Tww = $kd,20*\Theta^{Tww-20} = 0.146$ lb VSS/d/lb VSS
$S = Ks[1+(kd)SRT] / [SRT(\mu m - kd) -1] = 0.34$ mg bCOD/L

Biomass Production Rate=
$Px,bio = QY((S_o -S)(1+kd*SRT)) + fd*kd*QY*(S_o -S)SRT(1+kd*SRT) + QYn(NOx)(1+kd*SRT)$
$= 1$ lb VSS/day

1. **Determine the Amount of Nitrogen Oxidized to Nitrate:**

Calculated amount of nitrogen oxidized to nitrate, NOx =
$NOx = TKN - N_e - 0.12*Px,bio/Q$
$= 25.4$ mg/L

1. **Determine the Production Rate and Mass of VSS and TSS in the Aeration Basin:**

$bpCOD/pCOD = (BOD_o - sBOD_o)/(COD_o - sCOD_o)$
$= 0.8$
$nbVSS = [1-(bpCOD/pCOD)VSSo]$
$= 12$ mg/L

BOD And COD Removal:

Influent BOD, BODo	250	mg/L
sBOD, $sBOD_o$	125	mg/L
Influent COD, COD_o	500	mg/L
sCOD, $sCOD_o$	250	mg/L
rbCOD, $rbCOD_o$	135	mg/L
Influent TSS, TSS_o	250	mg/L
Influent VSS, VSS_o	60	mg/L
Influent TKN, TKN_o	40	mg/L
TKN peak/ave factor , FS	1.5	
Influent NH4-N, $NH4\text{-}N_o$	25.0	mg/L
Aeration WW Temp., Tww	77	^oF

Wastewater parameters

BOD_e	10 mg/L
TSS_e	10 mg/L
$NH_4\text{-}N_e$	0.5 mg/L
DO in Aer. Tank, DO_O	2 mg/L
Influent TKN, TKN_o	40 mg/L
MLSS in Aer. Tank, XO	10000 mg/L
Initial Estimate of NOx	28.9 mg/L
MLSS in Waste Sludge, XW	10000 mg/L

Target effluent concentration

Aeration Tank VSS Production Rate = Px,vss = Px,bio + Q(nbVSS)
= 2 lb VSS/day

Aeration Tank TSS Production Rate, P_x,TSS = Px,vss + Q(TSS_o - VSS_o)
= 4 lb VSS/day

Mass of MLVSS = Aeration Tank VSS Production Rate*SRT
= 8 lb VSS

Mass of MLSS = Aeration Tank TSS Production Rate*SRT
= 20 lb TSS

4. Calculate Aeration Tank Volume and dimensions:

Flow rate =0.033 m^3/s

Over flow rate = 800L/day-ft2

Area = 780321.87/800 = 90.67m2

Volume V = Q*t = 0.033*2*60*60 = 237.6m3

Depth(d) =V/A = 2.6m

Width (w) = 4.77 m

Length(l) = 19m

5. Oxygen/Air Requirement and Blower Calculations (for the Aeration Tank):

O_2 needed per kg BOD	1.00 lb O_2/lb BOD
O_2 needed per kg NH4-N	4.40 lb O_2/lb NH4-N
SOTE as Function of Depth	2.00% % per ft depth
AOTE/SOTE	0.33
Press. Drop across Diffuser	12.0 in W.C.
Depth of Diffusers	14.5 ft
Standard Temperature	68 ^{o}F
Standard Pressure	14.7 psi
Atmospheric Pressure	14.7 psi
Air Density at STP	0.075 lbm/SCF
O2 Content in Air	0.0173 lbm/SCF

Air requirement and blower calculations

Press. at mid depth, PD = P_a□□ + γ(Diffuser Depth/2) = 17.8 psi

BOD Removal Rate = (Q_o*(BOD_o - BOD_e)) = 0.125 lb/hr

NH_3N Removal Rate = (Q_o*($NH3N_o$ - $NH3N_e$))

Oxygen Requirement = (BOD removal rate)(lb O2/lb BOD)+(NH_3N removal rate)(lb O_2 /lb NH_3N) = 0.2 lb/hr

SOTE = (SOTE %/m depth)(Diffuser depth) = 29%
AOTE = SOTE(AOTE/SOTE) = 9.6%

Air requirement = (O_2 requirement/AOTE)/(O2 content in air)
= 2 SCFM

Blower Outlet Pressure = P_a□□ + Pressure drop across diffuser + γ(Diffuser Depth
= 21.4 psia

Pump systems

Number of pumps -

2 air blower - 12.5hp each

2 Sludge loading and 2 sludge return - 3hp each

3 drainage - 2hp each

1 chlorine dosing - 2hp

1 backwash - 5hp

2 gardening and 2 flushing - 5hp each

2 filter feed and 3 raw sewage relift - 5hp each

- Calculate Size of Pump having following Details
- Static Suction Head (h2)=0 Meter
- Static Discharge Head (h1)=12 Meter.
- Required Amount of Water (Q1)=2.2 Liter/Min.
- Density of Liquid (D) =1200 Kg/M3*
- Pump Efficiency (pe)=80% *
- Motor Efficiency(me)= 90% *
- Friction Losses in Pipes (f)=30% *

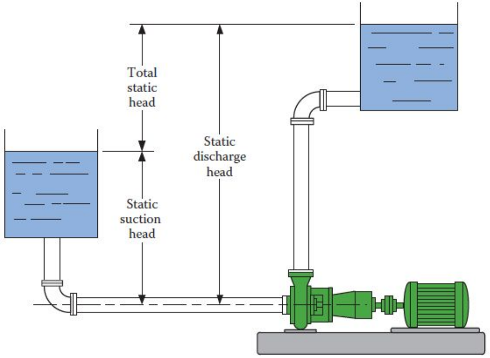


Fig 26: Static Suction and Discharge Head

- Flow Rate (Q) =2.2x1.66/1000 =300×1.66/1000= 0.003652 M3/Sec
- Actual Total Head (After Friction Losses) (H) = (h1+h2)+((h1+h2)xf)
- Actual Total Head (After Friction Losses) (H)=50+(50×30%)= 15.6 Meter.
- **Pump Hydraulic Power (ph) = (D x Q x H x 9.87)/1000**
- Pump Hydraulic Power (ph) = (10000 x 0.009652 x 85 x9.87)/1000 =**2.21 KW**
- Motor/ Pump Shaft Power (ps)= ph / pe = 2.21 / 80% = **2.76 KW**
- Required Motor Size: ps / me = 2.76 / 90% = **3.06 KW**

Introduction to Solar Tracker

1. The power from the sun interrupted by the earth is approximately $1.8*10^{11}$MW, which is thousands of times larger than the current consumption rate on the earth of all commercial energy sources.
2. The current technology is capable of capturing only 30 – 40% of all falling radiations.
3. The solar panels works at maximum efficiency only during a specific period in a day when the radiation are inclined at an angle of 90^0.

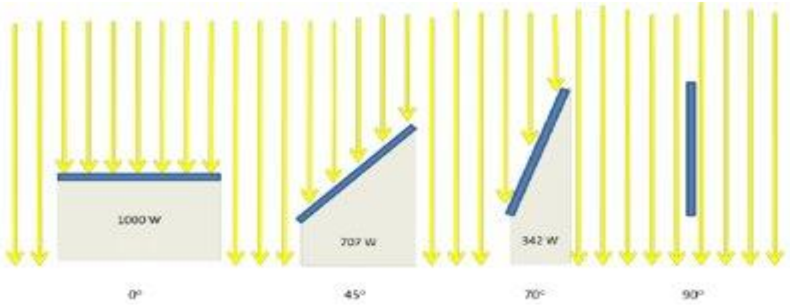
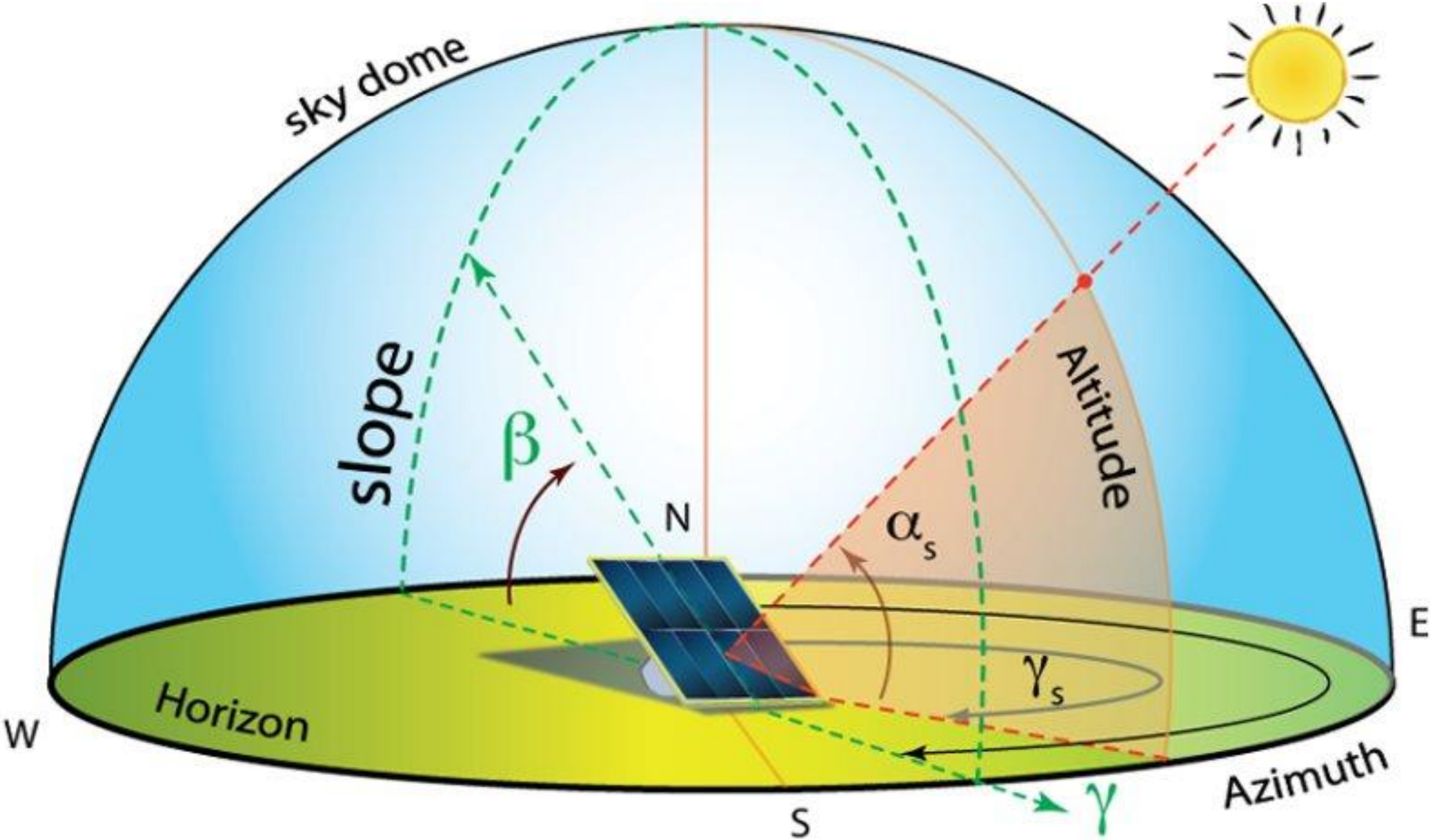


Fig 27: Energy produced vs the angle of elevation



sky dome
slope
β
N
Altitude
α_s
E
γ_s
W
Horizon
S
γ
Azimuth

Solar Tracker

➔ **Ideation and Solution**

- *Phototropism* : The phenomenon by which the plant bends in the direction of light.
- *Proposed solution:* Solar Tracker is a Device which follows the movement of the sun as it rotates from the east to the west each day.

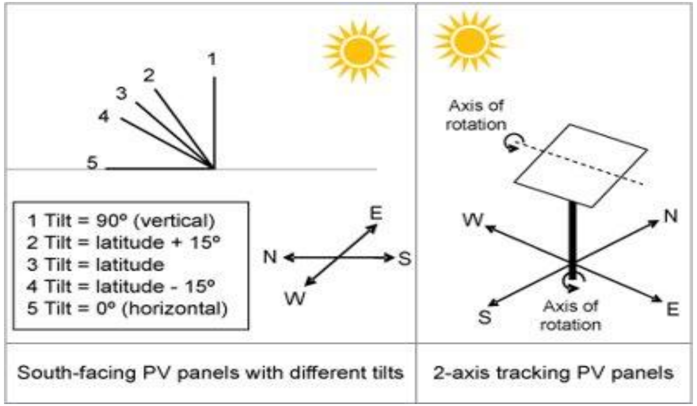


Fig 28: Dual axis Solar Tracker

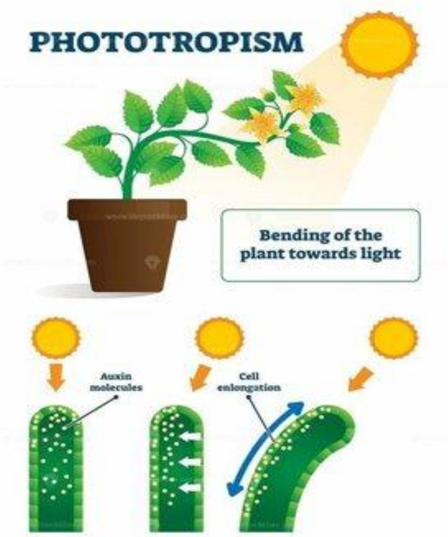


Fig 29: Phototropism

Solar tracking system

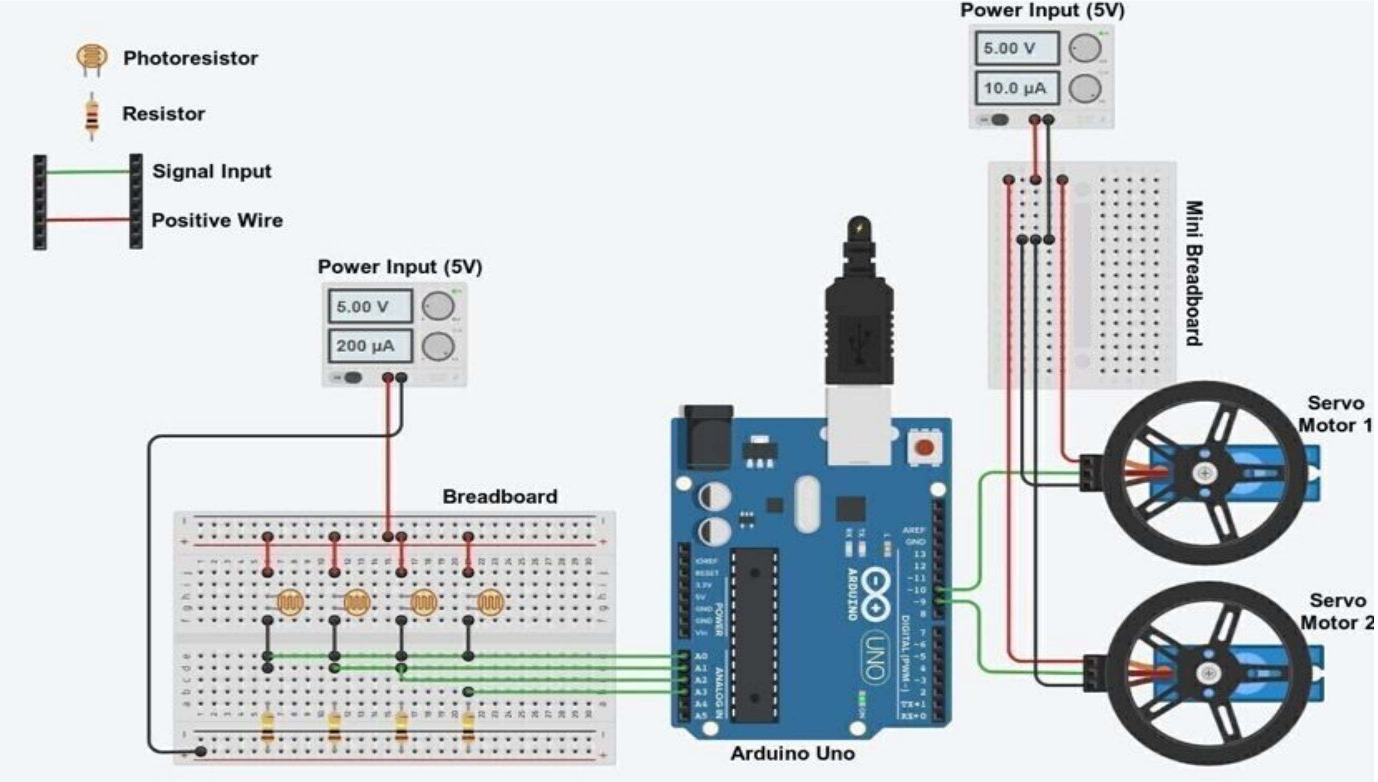


Fig 30: Circuit Diagram

Expected Results

- It is estimated that a solar tracking system will increase the output of solar panels by **30-40%**.
- Static solar panels provide about 300 Watts/hour on a normal day with 10 hr of sunlight and between 250-400 Watts/hour in general.
- Solar tracking panels will provide about **405 Watts/hour** on a normal day with 10 hr of sunlight and between 337.5-540 Watts/hour in general depending on the number of hours of sunshine received.

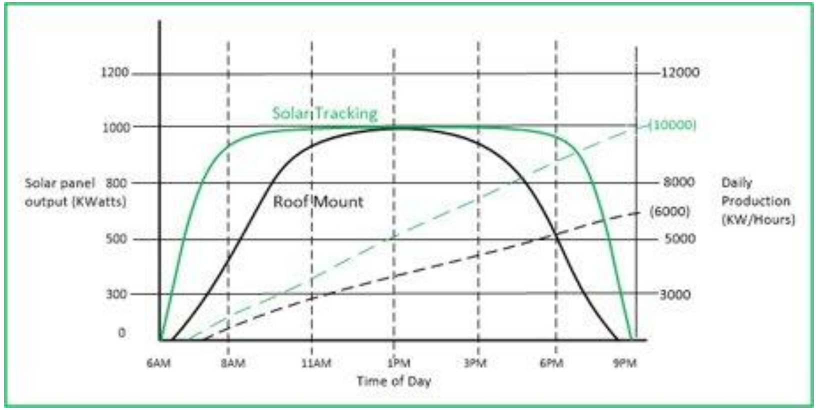


Fig 31 : Energy Generated by Tracking vs Fixed Solar Mounts

Estimating energy consumption

- ➔ Total energy = 95 hp
- ➔ Estimated average operating time of pumps - 5.1 hrs/day
- ➔ Energy required per day -
  70.84 kW ✖ 5.1 ✖ 3600 = **1.3 ✖ 10^9 Joules or 361.11 kWh**
- ➔ After adding solar trackers, energy produced = 4.05kWh/day
- ➔ No. of solar panels required = 361.11/4.05 = about 80-90 solar panels.
- ➔ Area required to to setup 1 kWh solar panel = 5.25 m^2
  Area required = 361.11 ✖ (5.25 ✖ 0.65) m^2 = 1232 m^2
  Approximate area of plant(obtained from on-site visit) = 8100 ft^2 or 752.5 m^2 approx.

Conclusions

1. To start with the water part, we achieved a net positive water performance cycle without depending on offsite consumption.
2. We then prepared a diversified flow diagram of rooftop rainwater harvesting to capture 5,75,503 litres of water annually. Next, we successfully calculated the annual generation of Black and Greywater.
3. To begin with the treatment, we first discussed the treatment of Greywater using effective natural remedies such as Coco hair, Perlite, LECA, Abelia, etc. which gave an average removal of 60% and 90% from Ecoli & TSS respectively.
4. Next, we calculated the biomass generation rate in MBR, followed by its dimensions (19m x 4.77 x 2.6m) and the oxygen air requirement for the aeration tank. Calculating the capacity of 15 pumps proved to be a real challenge.
5. We then integrated the plant with Arduino Powered Solar trackers to make it self-sustainable. To produce an equivalent power, the number of solar panels came out to be 80-90, occupying a 752.5 m2 area.
6. It proved to be a perfect fit for our building, with a rooftop area of 800m2, hence validating all of our calculations.

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Thank you