# Sustainable Sanitation Block for Student's Mall: A Feasibility Study

University of Abomey-Calavi, Benin

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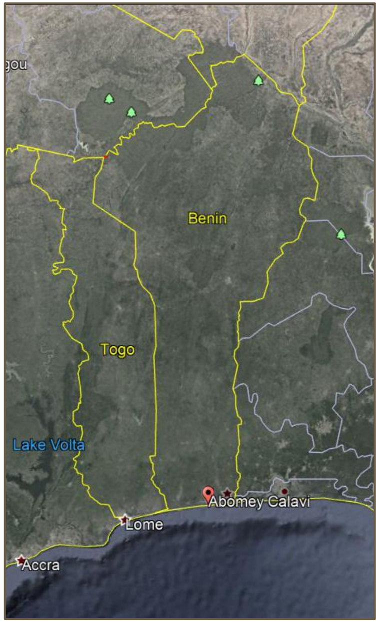
# Introduction & Outline

| Background | Final Project Definition | Methodology | Sector Results | Conclusion/ Recomendations |
|---|---|---|---|---|
| Benin | Project Statement | Evaluative Matrix, | Interior Environment | |
| University of Abomey-Calavi | Goals | SWOT Analysis, | Rainwater Collection | |
| | | Project Framing | Energy | |
| | | | Wastewater Management | |

# Background



- A student mall on the University of Abomey-Calavi (UAC) campus lacks adequate sanitation resources
- Over 45,000 students attend UAC
- Approximately 500 people visit the mall each day

# Project Statement

- Dr. Charlene Gaba, a researcher at UAC, requested a feasibility study on implementation of a sanitation block within the student mall

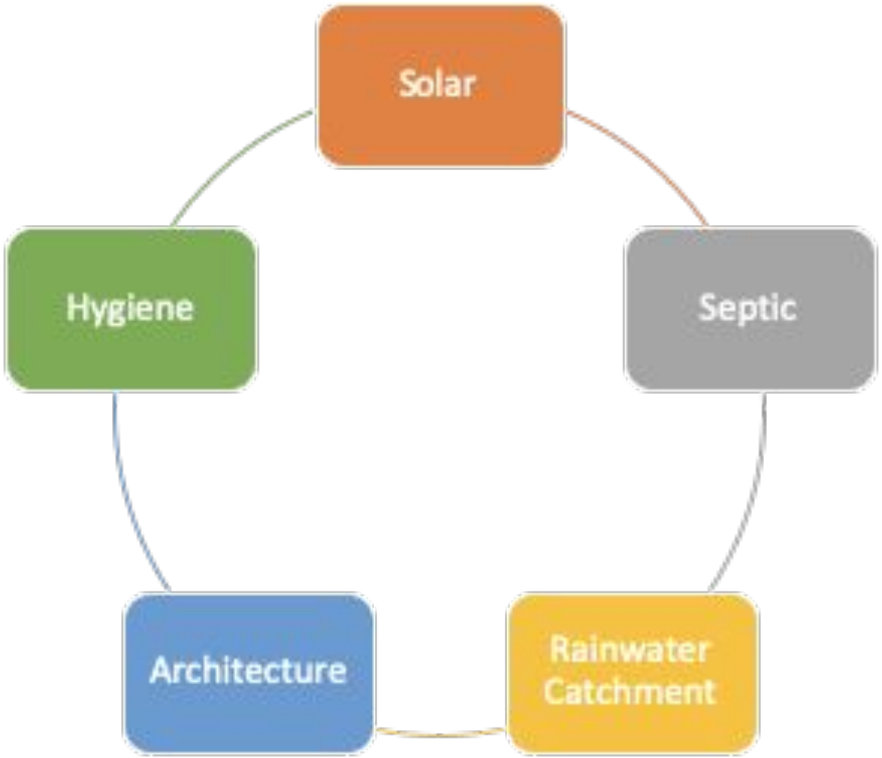
- We evaluated installation of a system utilizing:
    - Touchless, solar-powered sinks and toilets
    - A septic system for wastewater management
    - Rainwater catchment as a backup source to UAC-provided water

# Methodology - SWOT Analysis

| Strengths | Weaknesses |
|---|---|
| - Land already acquired<br>- Demand for sanitation<br>- Many resources are available on alternative water systems design | - Touchless faucets can be unreliable<br>- Financial resources are unknown |
| **Opportunities** | **Threats** |
| - Obvious need to improve hygiene and sanitation resources<br>- Learning opportunity for students on sustainable, off-grid resources | - Sourcing material and hardware may be challenging<br>- Maintenance requirements<br>- Cultural preferences for a bathroom are likely different than those in the U.S. |

# Design Considerations

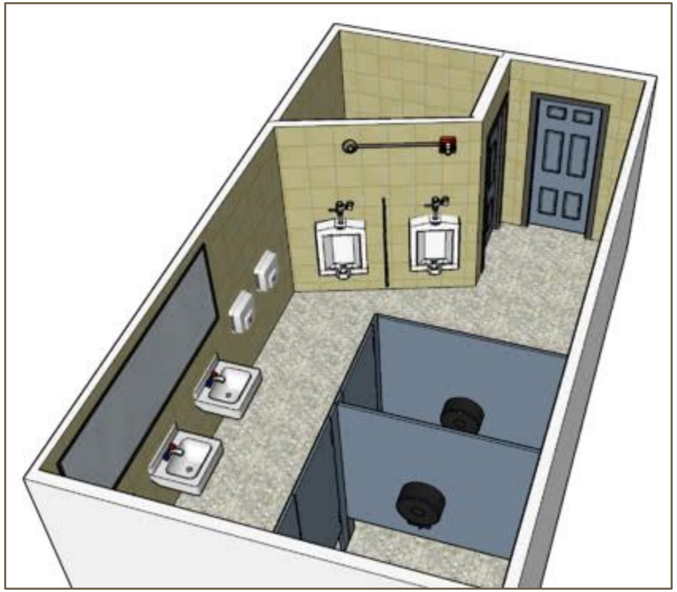
- Four lenses of sustainability:
  - Environmental
  - Social
  - Technical
  - Financial



# Indoor Environmental Quality Results

**Areas**

1. Air Quality
   a. Air quality can impact respiratory health
   b. Ventilation lowers health risks
2. Lighting
   a. Natural and Artificial
3. Hand Hygiene
   a. Hand washing and drying
4. Accessibility



Courtesy of Sketchup

# Indoor Env. Quality Results

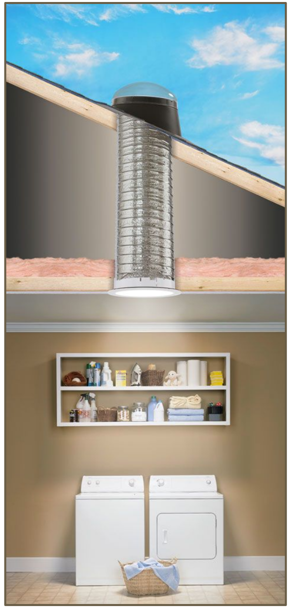
## Ventilation Standards

| Ventilation System | Relevant Codes | Specification |
|---|---|---|
| Mechanical | ICC Mechanical Code 401, 403<br><br>ASHAE/ANSI 90.1-2007 | cfm = 662 $ft^3$/min (1125 $m^3$/hr)<br>Bph = 24 + (cfm-20000) ×0.0012<br>Pfan= bhp × 746 / $E_{motor}$<br>→ ½ **HP (425 W) blower motor** |
| Natural | ICC Mechanical Code 401, 402 | 7600-15,000 L/min - $m^2$ |
| Hybrid | Combination of above | 1/3 HP blower motor<br>& 7,600 L/min - $m^2$ |
| ICC = International Code Council<br>ASHAE = American Society of Heating and Air-Conditioning Engineers<br>ANSI = American National Standards Institute | | |

# Indoor Env. Quality Results

## Temperature/Lighting Standards

| Facility System | Relevant Codes | Specification |
|---|---|---|
| Temperature | ICC Building Code S 1203 | Maintain indoor temperature around 20°C (68°F) |
| Lighting | ICC Building Code Section 1204,<br>ICC Mechanical code 402 | Artificial light (107 lux at 30-in height)<br>Natural light |
| Hand Hygiene | ICC Building Code Section 402, 604 | Automatic faucets and hand-dryers |
| ICC = International Code Council | | |

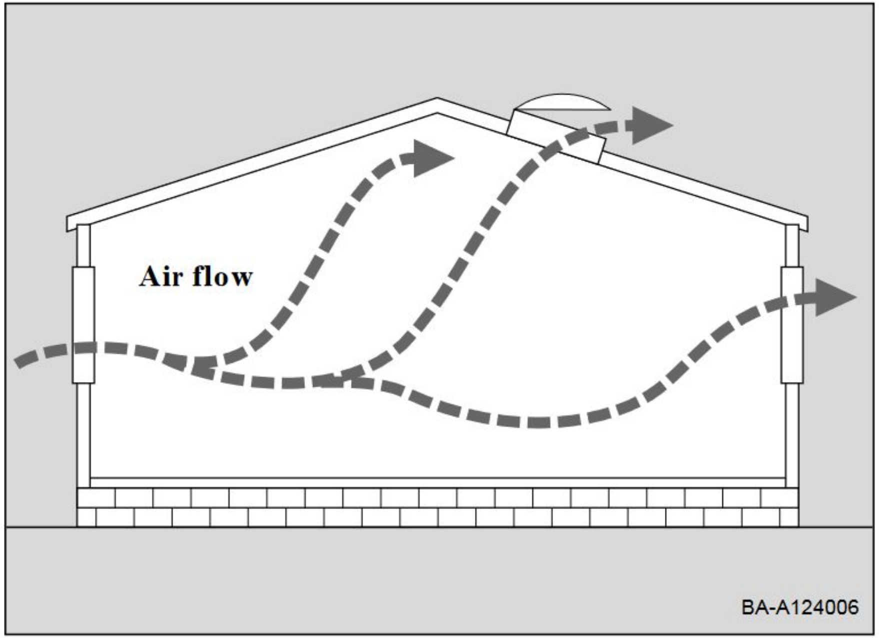


Sun Tunnel

solarskylights.com

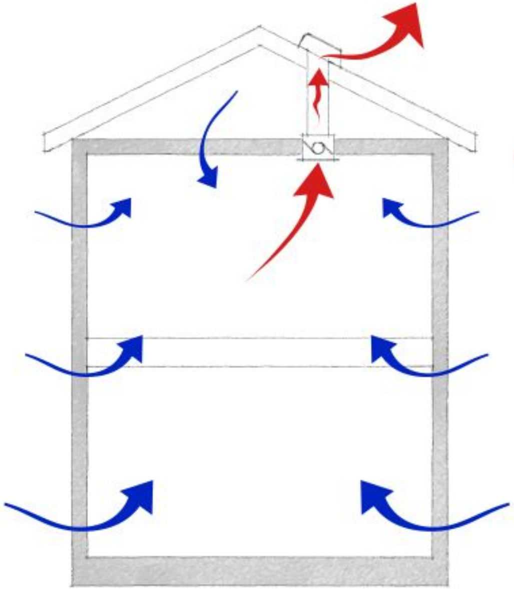
# Indoor Env. Quality Results

Natural Ventilation




Department of Energy. (1994). *Cooling Your Home Naturally* (No. DOE/CH10093-221). Retrieved from Department of Energy website: https://www.nrel.gov/docs/legosti/old/15771.pdf

Mechanical Ventilation



Upblast Fan

Alibaba

Alfano, S. (2016, July 19). Whole-House Mechanical Ventilation, an Overview. Retrieved June 6, 2019, from Pro Remodeler website: http://www.proremodeler.com/whole-house-mechanical-ventilation-overview

# Indoor Env. Quality Results

## Accessibility

| Facility Type | Relevant Codes | Specification |
|---|---|---|
| Restroom | ICC A117.1 Accessible and Usable Buildings and Facilities | Grab bars, sitting toilet clearances, ramp design, flat even floors |
| ICC = International Code Council | | |

Specified clearances for accessible toilets

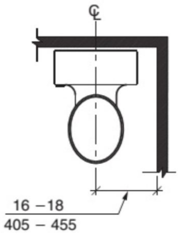



FIGURE 1103.11.2.4(A)
WATER CLOSETS IN TYPE A UNITS - WATER CLOSET LOCATION

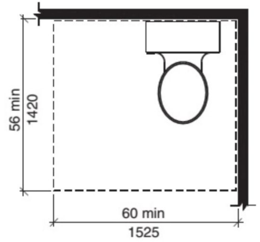



FIGURE 1103.11.2.4(B)
WATER CLOSETS IN TYPE A UNITS - MINIMUM CLEARANCE

# Indoor Env. Quality Results

Lighting & Hand Hygiene

| Components | Unit Cost | Total Quantity | Total Cost |
|---|---|---|---|
| LED Lights | $0.90 | 20 | $18 |
| Natural Light Fixtures (sun tunnel) | $150 | 4 | $600 |
| Hand Dryers (electric) | $75 | 4 | $300 (~$150/yr) |
| Faucets (automatic) | $25 | 4 | $100 |
| | | **Total** | $1240 |

*Paper towels* $3,700/year = ($0.01/towel X 365 days X 500 people/day x 2 towels/person)

Ventilation Options

| Options | Unit Cost | Total Quantity | Total Cost |
|---|---|---|---|
| Mechanical | $500 | 2 | $1000 |
| Natural | $550 | 2 | $1100 |
| Hybrid | $675 | 2 | $1350 |

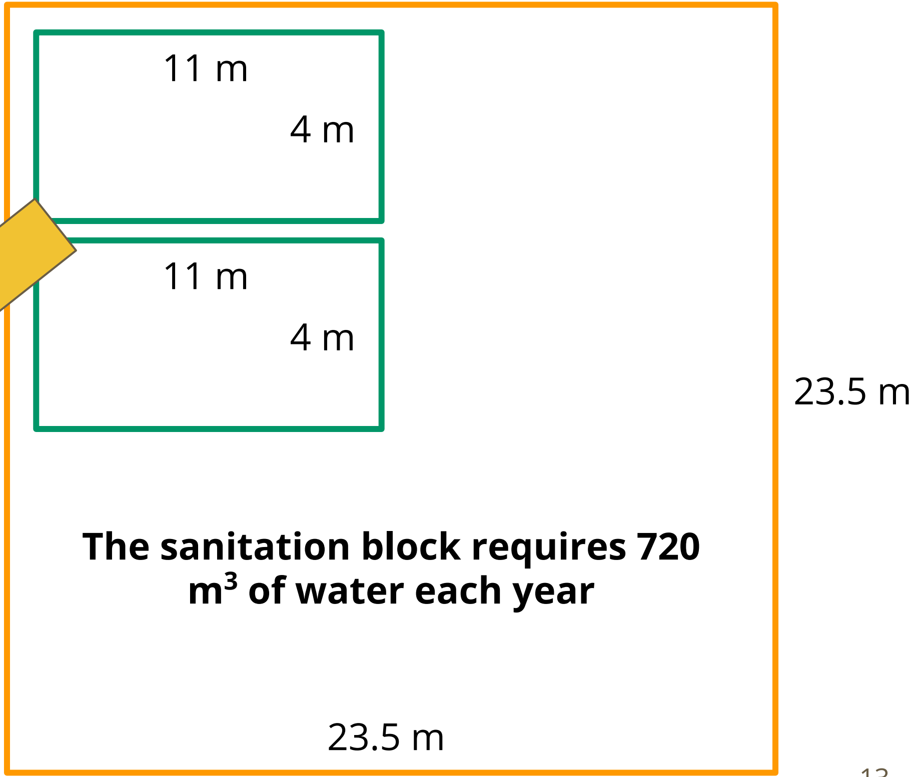
**$2590**

# Sector 2 - Rainwater Catchment Results

*Collection Volume = Efficiency × Rainfall × Surface Area*

- Abomey-Calavi gets ~1300 mm rainfall/year
- Efficiency = 85%
- Roof surface area must be determined

**Two 4 m by 11 m roofs will collect 90 $m^3$ water each year**

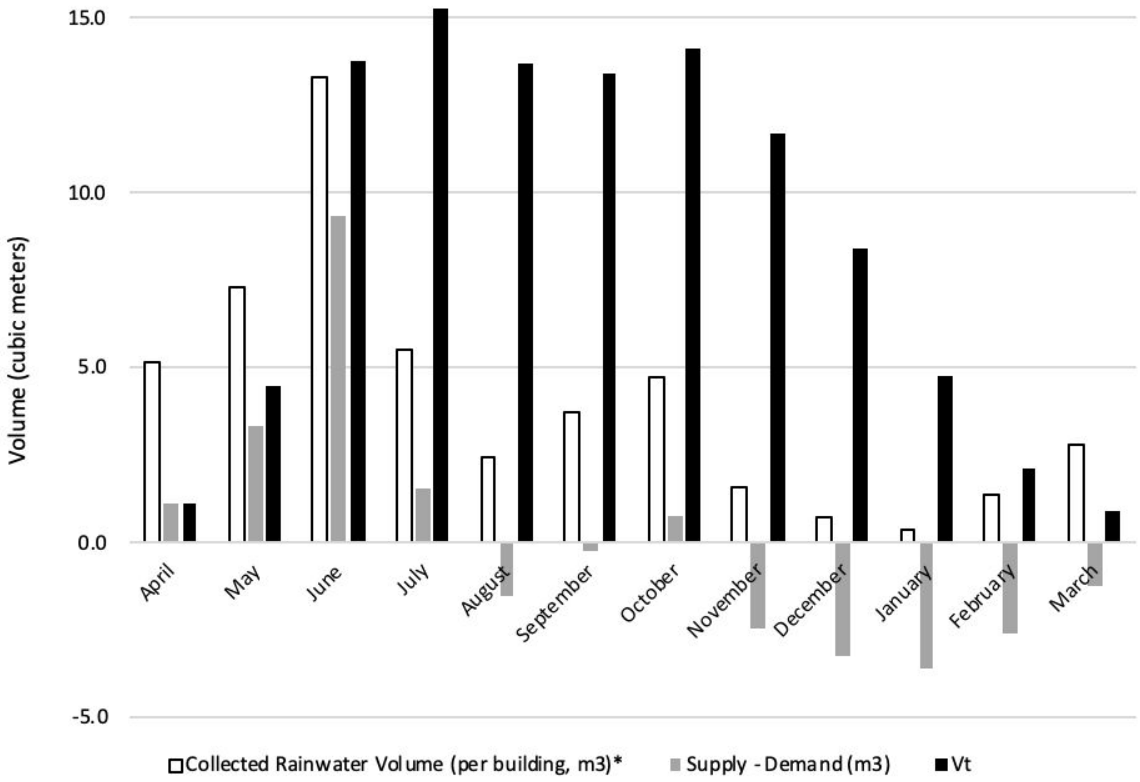


# Rainwater Catchment Results - Sizing

$V_t = V_{t-1} + Supply - Demand$

- $V_t$ = water volume remaining
- $V_{t-1}$ = water volume remaining from previous month
- *Demand* = 4 $m^3$ (average monthly rainfall)

**15 $m^3$ tank volume required per building**

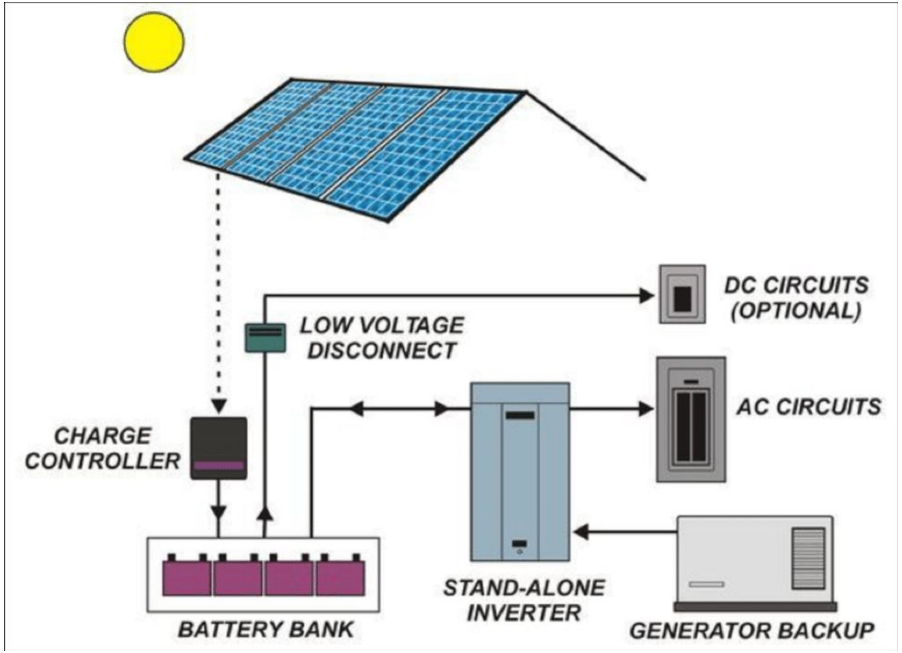


# Rainwater Catchment Results - Costs

| | Unit Size | Dimensions (Diameter x Height, m) | Apprx. Cost (USD) | No. of Units Required per Building | No. of Buildings | Total Cost (USD) |
|---|---|---|---|---|---|---|
| Storage tanks | 15 $m^3$ | 2.6 x 3.25 | $2,670 | 1 | 2 | $5,340 |
| | 7.6 $m^3$ | 2.3 x 2.1 | $900 | 2 | | ***$3,600**** |
| | 5.1 $m^3$ | 1.8 x 2.2 | $780 | 3 | | $4,680 |
| Gutters (PVC) | 11 m | NA | $180 | 2 | | $720 |
| First Flush Diverter | 1.4 L | NA | $40 | 1 | | $80 |
| Pumps | 140 L/min | NA | $500 | 1 | | $1,000 |
| NA = Not applicable | | | | | **TOTAL** | **$5,400** |

# Sector 3 - Energy

- Solar energy system
- Optimum Tilt:
  - Fixed or adjust: 2 seasons, 4 seasons
- The facility will use solar energy to power the following:
  - Light bulbs
  - Touchless faucets
  - Squatting toilets/Urinals
  - Energy storage
  - Ventilation Fan




Energy Sage. (2019). *Storing Solar Energy: How solar batteries work.* Available from: https://www.energysage.com/solar/solar-energy-storage/how-do-solar-batteries-work/

# Energy Results- Steps

1. Determine the energy consumption of electric devices powered by the solar panels
2. Select the rated power(watts) of solar panel
3. Determine the Daily, Monthly, and Annual Use
4. Find the Peak Sun Hour (PSH) of your region
5. Determine the off-grid PV System Capacity (kWp)
6. Determine the off-grid PV System Capacity (kWp)
7. Determine the off-grid PV System Yield (kWh/kWp) (i.e. system expected output)
8. Determine the number of needed modules
9. Determine the space needed for the amount of panels

$$\text{Off-grid PV System Capacity (kWp)} = \frac{Daily\ Energy\ Use\ (kWh)}{Peak\ Sun\ Hours\ (hours)} \quad (1)$$

$$\text{Off-grid PV System Yield (kWh/kWp)} = \frac{Annual\ Energy\ Use\ (kWh)}{PV\ System\ Capacity\ (kWp)} \quad (2)$$

$$\text{Number of needed modules} = \frac{System\ Capacity\ (kWp)}{Module\ Rated\ Power\ (kW)} \quad (3)$$

$$\text{System Expected Output} = \text{PV System Capacity} * \text{PV System Yield} \quad (4)$$

$$\text{Space needed} = \frac{Roof\ Size\ (m2)}{10} * kWp \quad (5)$$

# Energy Results- Power Output

| Parameter | Units | Minimum | Maximum |
|---|---|---|---|
| Rated Power | Watts | 200.00 | 400. |
| Daily Energy Use | kWh | 11.0 | 53.8 |
| Monthly Energy | kWh | 328.78 | 1615 |
| Annual Energy Use | kWh | 3945.40 | 19378 |
| Peak Sun Hours (PSH) | Hours | 4.00 | 4.90 |

| Parameter | Units | Minimum | Maximum |
|---|---|---|---|
| Daily Energy Demand | kWh | 11.0 | 53.8 |
| Off-grid PV system capacity | $kW_p$ | 2.74 | 11 |
| Off-grid PV system Demand | kWh/year | 3945 | 19378 |
| Off-grid PV System Yield | $kWh/kW_p$ | 1440 | 1764 |
| Number of PV modules needed | Each | 14 | 27 |

- In total solar power system will  provide **3,945 kWh annually, .**
- The men’s building will have four urinals and three squatting toilets and the women will have seven squatting toilets. The total daily energy demand for both facilities is **21.92 kWh.**

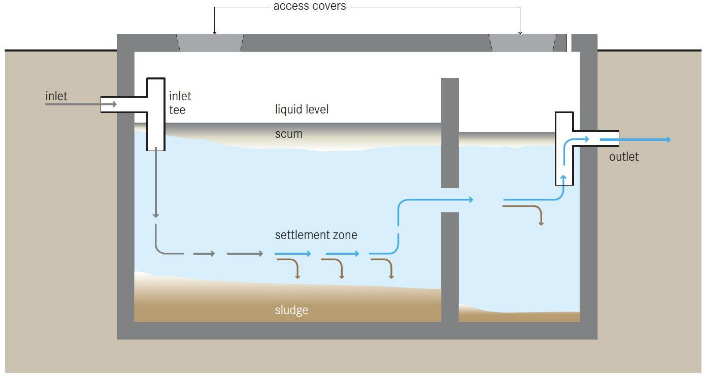
# Energy Results - Cost

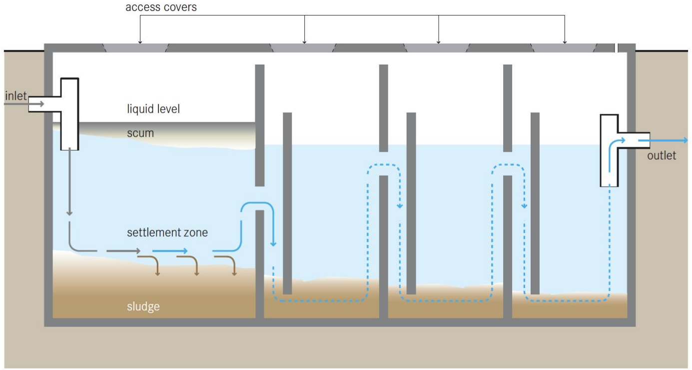
Total Cost: $34,912

| | Elements | Quantity | Min. Cost ($) | Max. Cost ($) |
|---|---|---|---|---|
| Energy System | Solar Panels | 14 | 500 | 700 |
| | stand-alone inverter | 1 | 200 | 1000 |
| | charge controller | 1 | 20 | 100 |
| | Low voltage disconnect | 1 | 60 | 130 |
| | AC/DC circuits | 1 | 100 | 300 |
| Facility Elements | Energy Storage | 1 | 8,500 | 15,500 |
| | LED Light Bulb | 5 | 8 | 12 |
| | Touchless Faucets | 2 | 28 | 33 |
| | Squatting Toilets | 3 | 200 | 400 |
| | Urinals | 4 | 200 | 400 |
| | Ventilation fans | 2 | 40 | 100 |
| | **Total** | | **$ 17,456** | **$ 29,956** |

# Decentralized Wastewater Treatment

- Primary and Secondary Treatment Technologies
- Parameters
  - 7 L/use
  - 500 users
  - Q = 3.5 L/day
- Primary
  - Septic Tank
  - Holding Tank
  - Anaerobic Baffled Reactor (ABR)
- Secondary
  - Drainage Field
  - Constructed Wetlands



# Septic and Holding Tanks

HRT = 1 day

Desludge every year

University already has multiple septic tanks

**Holding Tank**

- 4 times the size of a septic tank
- 194.4 $m^3$
- Desludge every year

| Unit | Value |
|---|---|
| Max Capacity for 24 hr Retention (L) | 3500 |
| Volume for sludge accumulation (L) | 35000 |
| Working Tank Volume $m^3$ | 39 |
| Water Depth | 1.5 |
| Total Depth | 1.8 |
| Width | 3 |
| Length Compartment 1 | 6 |
| Length Compartment 2 | 3 |
| Total Length | 9 |
| Designed Tank Volume $m^3$ | 48.6 |

# Anaerobic Baffled Reactor

- Baffles create a longer HRT
- Longer HRT for smaller footprint
- Better BOD removal 90% vs 25%

| | |
|---|---|
| HRT (days) | 2 |
| Working Volume (m3) | 7 |
| Peak Upflow Velocity (m/hr) | 0.54 |
| Design Upflow Velocity (m/hr) | 0.3 |
| Number of Compartments | 5 |
| Hanging Baffle Clearance (m) | 0.2 |
| Upflow to downflow area ratio | 3 |
| Compartment width to length ratio | 3 |
| Reactor Depth (m) | 2 |
| Reactor width (m) | 1.4 |
| Reactor Length (m) | 2.3 |
| Volume (m3) | 6.44 |
| Sludge Accumulation rate (L/cap yr) | 1.5 |
| Sludge Accumulation (m/yr) | 0.7 |
| Desludge Rate (yr) | 1.4 |

# Drainage Field

- Large Area
- Potential groundwater pollution
- University uses ground water wells

| Unit | Value |
|---|---|
| Infiltration (L/$m^2$ day) | 50 |
| Wall Area ($m^2$) | 70 |
| Depth | 0.6 |
| Length (m) | 116.7 |
| Enough space for two trenches (m) | 58 |
| Width (m) | 0.4 |
| Volume of gravel ($m^3$) | 28.1 |
| Area ($m^3$) | 46.68 |

# Constructed Wetlands

Deguenon et al. 2009

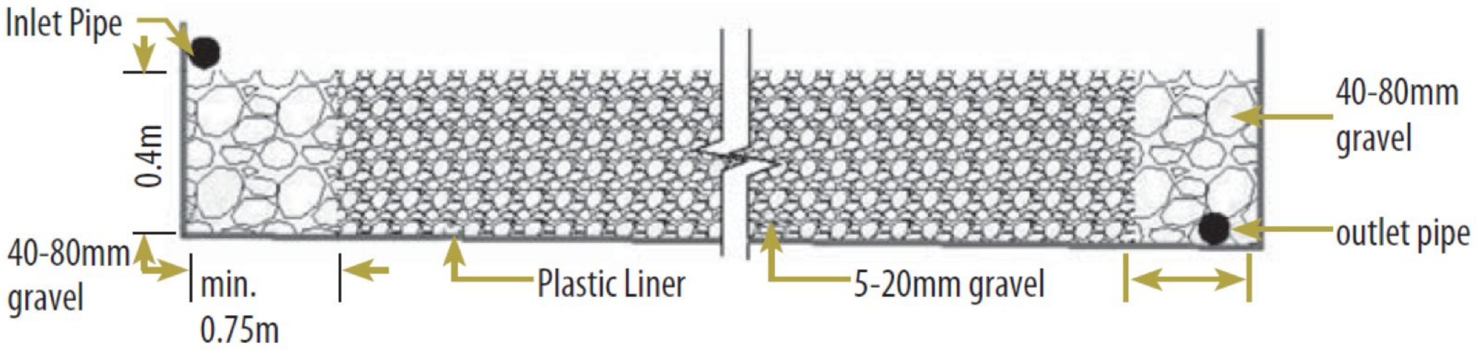
- VF CW using Phragmite reeds at the University

Reed's Method

- calculate surface area based on BOD removal
- cross sectional area based on conductivity

Horizontal Subsurface Flow

| Unit | Value |
|---|---|
| Cin | 134 |
| Ce | 30 |
| Surface Area ($m^2$) | 18 |
| Slope (dH/dS) | 0.01 |
| Cross-sectional Area ($m^2$) | 5 |
| width (m) | 12.5 |
| Length (m) | 3.6 |



| | Vault | Septic Tank + Drainage Field | Septic Tank + Constructed Wetlands | ABR + Drainage Field | ABR + Constructed Wetlands |
|---|---|---|---|---|---|
| **Capacity ($m^3$)** | 194.4 | 48.6 | 48.6 | 6.44 | 6.44 |
| **Foot Print ($m^2$)** | 97.2 | 46.68 | 45 | 49.9 | 21.22 |
| **HRT (days)** | N/A | 1 | 1 | 2 | 2 |
| **BOD Removal** | 10% | 25%% | 90% | 90% | 90% |
| **Pathogen Removal** | 0% | 0% | N/A | 0% | N/A |
| **Sludge Removal Interval (years)** | 1 | 1 | 1 | 1.4 | 1.4 |
| **Maintenance** | Periodically Desludging | Periodically Desludging | Periodically Desludging + Maintaining Health of Wetlands | Periodically Desludging | Periodically Desludging + Maintaining Health of Wetlands |
| **Total Capital Cost[1]** | $ 3,600 | $ 12,300 | $ 3,7 | $ 11,400 | $ 3,315 |
| **Operational Cost/year[1]** | $ 3,524 | $ 811 | $ 811 | $ 117 | $ 117 |

# Final Details


- Rainwater catchment will provide ~4 $m^3$ of water per month
- Indoor environmental quality will be maintained with an active or hybrid ventilation system
- Solar energy will used to power faucets, toilets, lighting, and a fan for ventilation
- Decentralized WW management will be achieved with ABR-Constructed Wetlands system
- Final cost = $46,000