Annexure
Pilot Water Audit Report
H1 Hostel Building, IISER Pune - 2023

1. Methodology

Four primary tasks define the procedure for this audit.

1. Developing and installing ultrasonic water level sensors in the four water tanks of the hostel. These sensors help in identifying the instances in time when the water is being supplied. The sensors also make it possible to calculate the net usage of water from the water level of the tank.
2. Developing and installing touch sensors over a small subset of flushes to get a secondary dataset for comparison with the survey.
3. Conducting a behavioural survey of students from the H1 hostel via a Google form to find out specific water usage for various activities such as bathing, flushing, laundry, etc.
4. Analysing water samples used for washing and drinking and comparing the ions and compounds with the recommended safe limits, to check the quality of the water.

All data and codes used for this project have been uploaded at this **location.**

All the students enrolled in the course 'Hydrology ECS3323' contributed to the audit. The students worked in groups of 3, in total 4 groups were formed and divided the work between themselves, each group working primarily on one of the above tasks. In each of the following sections, we discuss the methods and analyse results obtained by executing the above tasks.

Team	Member	Roles played
Group 1	Krishnanand J	Design, creation, calibration, implementation of water level sensors, data analysis, and report compilation
	Raniria Mitra	Creation, calibration, and implementation of water level sensors, water quality assessment
	Athul Suresh	Creation, calibration, and implementation of water level sensors, water quality assessment

Group 2	Medha Murthi	Design, implementation, and data analysis for the behavioural survey
	Shreyas Iyer	Design, Field data collection, and data analysis for the behavioural survey
	Sanket Samal	Field data collection for the behavioural survey
Group 3	Vaibhav Pachaulee	Design, creation, and implementation of flush tank sensors, data analysis, and report compilation
	Paritosh Bhattacharyya	Creation of flush tank sensors, data analysis
	Gopinatha Nayak	Creation of flush tank sensors, data analysis
Group 4	Asish Tanay	Field data collection for the behavioural survey
	Samarpan Mahato	Major cation-anion analysis, Alkalinity test
	Rinuraghavi	Major cation-anion analysis, Alkalinity test and report compilation

*All the students contributed equally in the creation of this presentation which was presented to the water audit team supervisors.

2. Water Tank Dimensions

Tank	Partition	Dimension [LxBxH] (meters)	Volume (litres)
Tank 1	Flush	3.2x1.06x1.17	3,968
	Use	4.57x3.2x1.22	17,110
Tank 2	Flush	4x0.91x1.22	4,441
	Use	4x1.98x1.22	9,662.4
	Drinking	4x0.91x1.22	4,441
	Fire	6.08x4x1.22	29,670.4
Tank 3	Flush	3.26x1.04x1.19	4,034.6
	Use	4.57x3.2x1.19	17,402
Tank 4	Flush	3.04x1.27x1.19	4,594.3
	Use	3.35x3.04x1.19	12,119
	Drinking	3.04x1.22x1.19	4,413.5

The cells highlighted in green are the only dimensions used for the water level calculations. The rest are either unused partitions or tanks with bad data that were discarded.

3. Design and Data related to the Water Level Sensors

Group 1 comprising Krishnanand J, Athul H and Raniria Mitra developed non-invasive ultrasonic water level sensors. The following videos give the demonstration of the design and data retrieval process - Water Level Sensor and Data Retrieval . The water level sensor output gives us the travel time of the ultrasonic pulse to travel from the sensor mounted on top of the tank to the surface of the water. Distance travelled by sound pulse = Speed of sound (m/s) x time of travel (seconds). Since this distance is to and fro travel distance, we need to divide by 2 to get the actual distance.

Distance of water surface from the top of the tank, D (meters) = Speed of sound (meters/seconds) x time of travel (seconds)/2

The water level of the tank was calculated as follows:

Water level (litres) = Length (meters)x Breadth (meters) x [Height (meters) - D (meters)] * 1000

A median filtering algorithm was implemented in python to clean the data, and further analysis was done in python (code attached).

Error Analysis: Sources of errors are travel time measurement and speed of sound variation with temperature.

Typical sound travel time for a 1.2-meter-deep tank: **3500 ± 3 microseconds**
Typical temperature in Pune: 300 ± 10 K
Maximum distance measured =1.2 meters

Speed of sound, $v = \sqrt{\frac{\gamma RT}{M}}$

$$\Rightarrow \frac{\Delta v}{v} = \frac{1}{2}\frac{\Delta T}{T} = \frac{1}{2}\frac{10}{300} = 1/60$$

Distance is velocity times time,

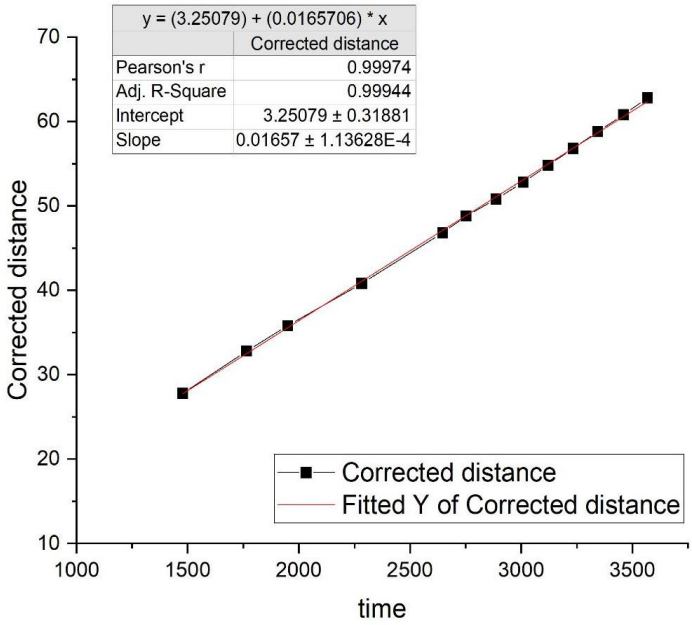
$$D = vt$$

$$\Rightarrow \frac{\Delta D}{D} = \frac{\Delta v}{v} + \frac{\Delta t}{t} = \frac{1}{60} + \frac{3}{3500} \approx 1/60$$

Maximum error , $\Delta D = D/60 = 120cm/60 = 2\ cm$
Corresponding error in volume , $\Delta V = \Delta D \times 3.35 \times 3.04 \times 1000\ litres = 198\ litres$
Maximum error in per heard usage $= 198/200\ litres/heads = 0.99\ litres\ per\ head$

The sensors were first calibrated against a meter stick, and then tested in the water tanks. These sensors were installed in each of the four water tanks on the roof of H1 Hostel Building with help of staff members Shivaji, Bhushan, and Milindh.

Calibration and Setup



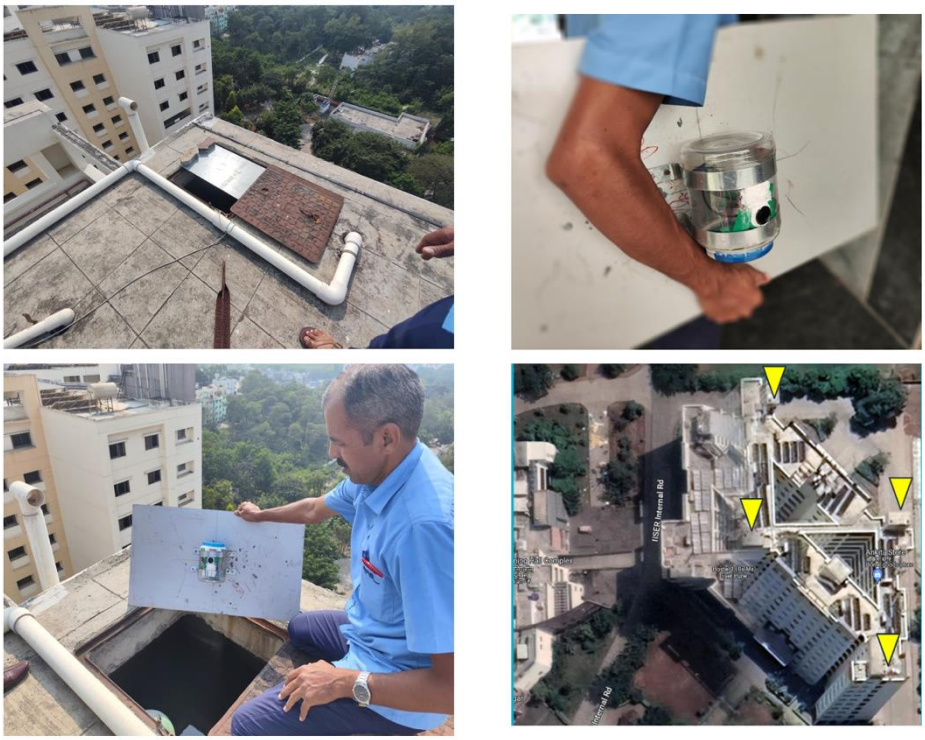
Water Level Sensor Design and Calibration of distance sensor against meter stick

- Plot distance versus measured travel time of sound, and find speed of sound.
- Plot is a straight line, and slope gives speed of sound/2 (due to two-way travel time)
- Accuracy of 1 mm achieved.

Initializing the Sensor

Instructions to start the data recording. Upload esp_deepsleep.ino code. Records the water level every minute.

Installation of Water Level Sensors



Water Level sensors installed in each of the four water tanks on the roof of H1 Hostel Building

Retrieving the Data

Instructions for retrieving the recorded data using a USB cable. Upload the open_data_waterlevel.ino. Touch the data retrieval jumper wires together. Get the data, in serial monitor of computer.

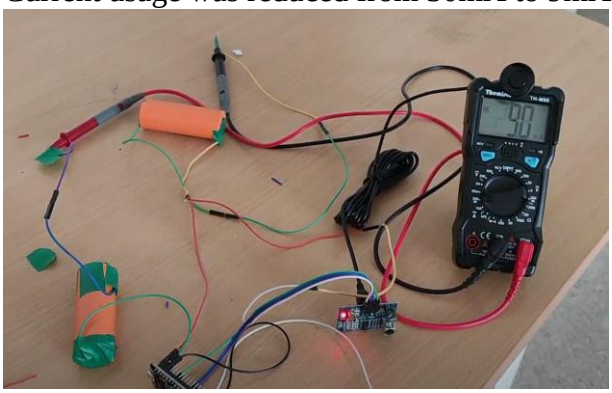
Testing the Water Sensors

Trial 1: Testing the Circuit

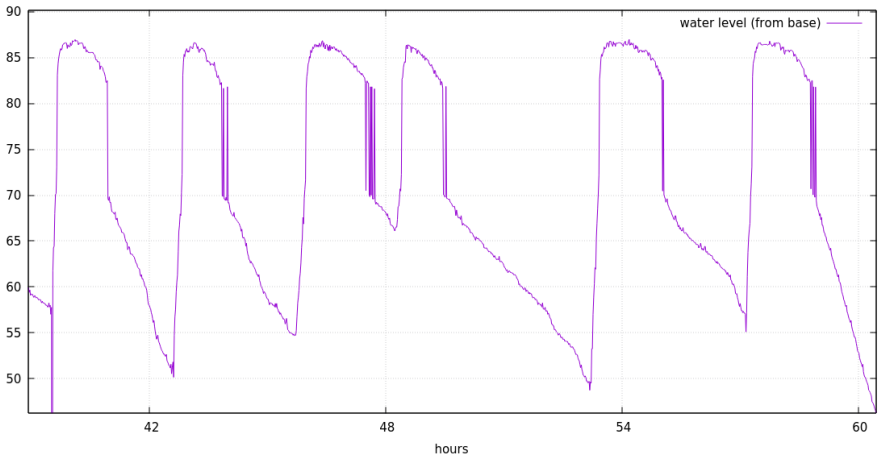
- Deployed the sensor for the first time in the water tank.
    - 16th October 5:30 pm: Recording started.
    - 17th October 12:30 pm: Water level sensor attached.
    - 18th October 12:51 am: Recording stopped; battery drained out.
- Challenge: Battery drained out in 31 hours

Trial 2: Reducing Power Consumption

- 23rd October 2:30 pm: Recording started.
- 27th October 10:40 am: Recording manually stopped.
- Improvements:
    - Implemented deep sleep mode
    - Current usage was reduced from 30mA to 9mA.



    - With a battery of capacity 4000 mAh, this gives around 444 hours of lifetime. (LiPo batteries have an efficiency 95-98%)
    - We tested for 91 hours, and still had plenty of battery left
- New challenge: Data had jumps, due to the interfering float ball.



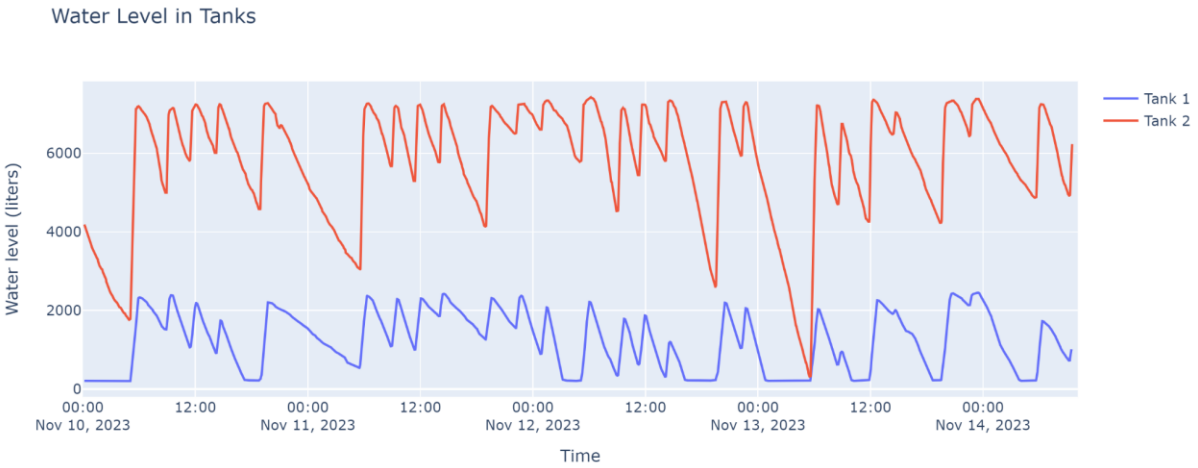
Graph highlighting the problem of Data Jumping

Final Test

- Placed 4 sensors on each of the 4 tanks of H1 Hostel building.
    - 9th November 5:00 pm: Recording started.
    - 15th November 10:00 am: Sensors retrieved.
- Out of 4 sensors, 2 sensors gave good data, one sensor gave constant reading, and one sensor recorded for 3 days and died of short circuit.
- Improvements:
    - Placed sensor away from float balls
    - Got clean data without jumps
- New challenges:
    - One sensor short circuited due to water leaking inside.

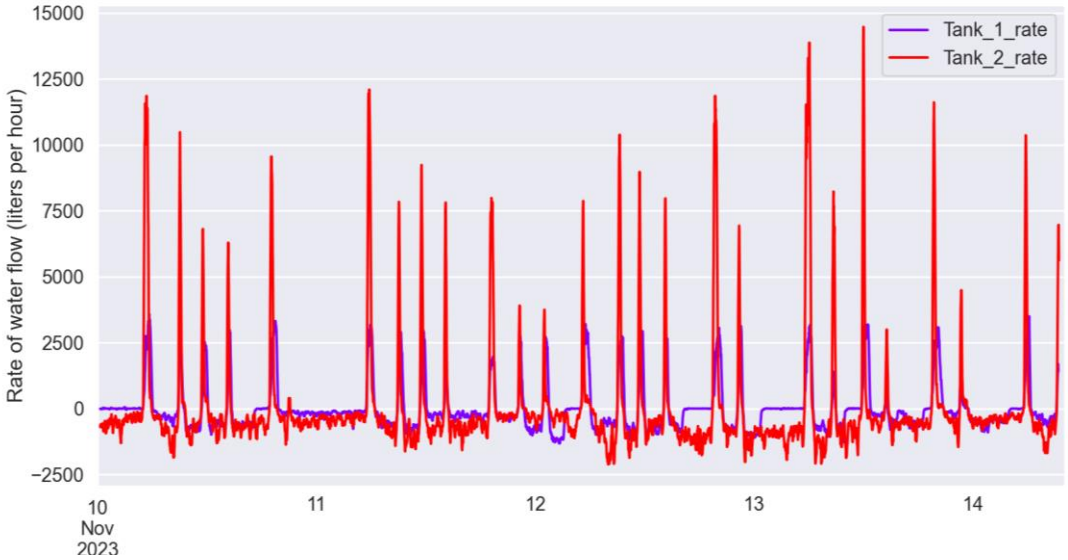
After a set of trials and optimizations, the final data collection occurred from 9/11/2023 at 5:00 PM till 15/11/2023 at 10:00 AM. During Trial 2, the float in the water tank led to a jump in the sensor data whenever the water level reached the float (explained in the video: Float Ball Issue: Water Level Sensor). This was taken care of in the subsequent trials, and in the Final Test the sensors were placed away from the float's position to correct this anomaly.

Due to a sudden rainfall episode, two of the sensors malfunctioned during the final data collection period. The retrieved data from the remaining two sensors was analysed by the group, the inflow periods were delineated for the usage during the inflow period.

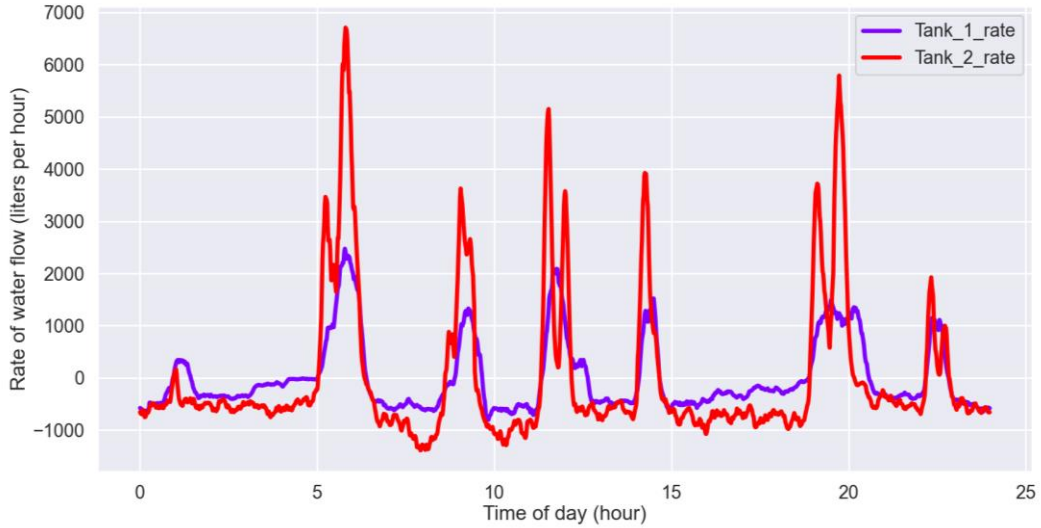


Detailed time series of water level, with one-minute resolution.

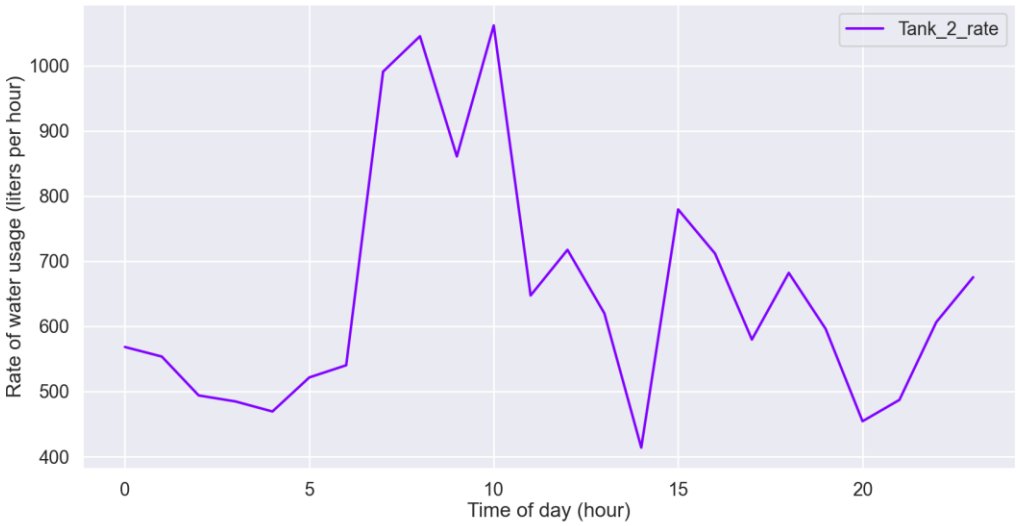
Average water usage per head in litres per day: 80.8 for T3, 139.4 for T4
Average water usage per head on working days: 93 and 148
Average water usage on weekends: 67 and 117
Possible leakages: At no point, does the water level remain at rest. Here, the numbers show the water outflux in litres per hour. Even at midnight hours, there is a decrease in water level of 163 litres± 1 $litre\ \ per\ head\ per\ hour$.



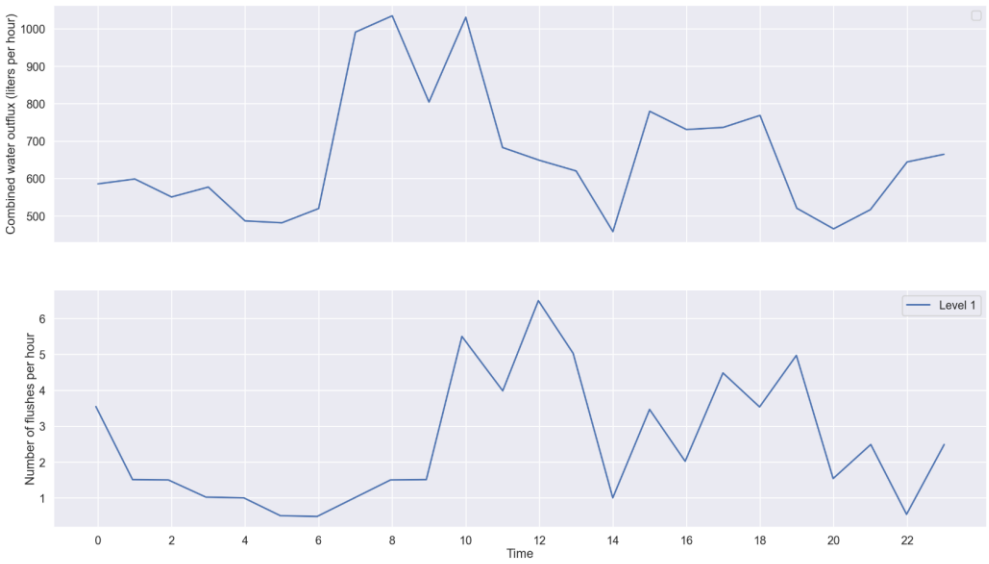
Water usage rate was calculated by taking the time derivative of the 10-min smoothed water level plot



Mean minutely water flow rate. Positive peaks indicate average times when water is pumped into the tanks. Notice that there is no point of time when water is not being used.



Mean hourly water outflux
(removed the positive usage rates when water is getting pumped)



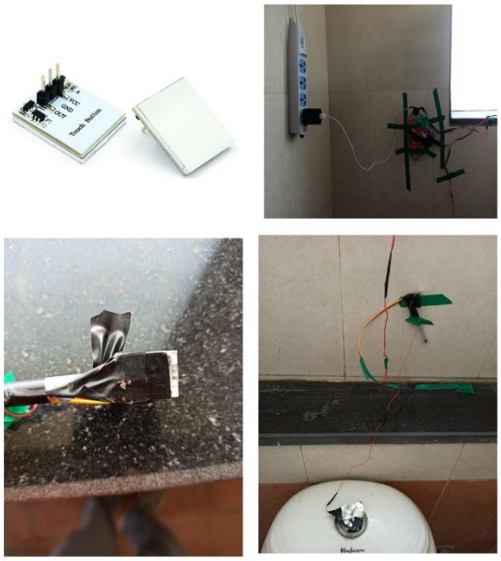
Flushes recorded at each hour of the day(hour 0 = 12:00 AM), and water usage rate detected from the water tank sensor plotted alongside (multiply second plot by 375 to get litres per hour, (750 residents / 20 residents * 10 litres per flush). Note: students are only using half of the washrooms available on average. The first peak in water outflux rate is not visible in the flushing rate, which likely points at that peak happening due to bathing.

Normalised Bathing Index= (Outflux rate - Flush rate) / (Outflux rate + Flush rate)

4. Design and Data related to the Flush Tank Sensors

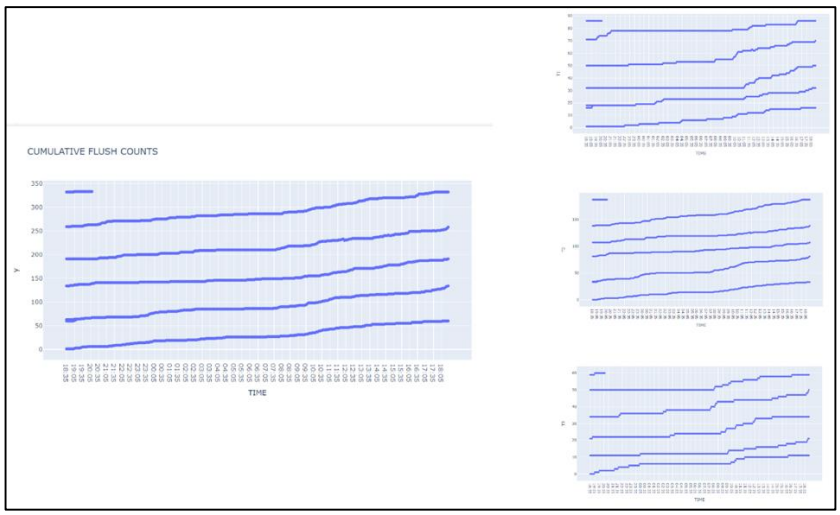
To get a parallel measurement of water used in flushing and compare the reliability of the methods used in the survey, touch sensors were placed over a toilet complex consisting of three functioning toilets on the first floor of H1 Hostel Building. Group 3 consisting of Vaibhav Pachaulee, Gopinatha Nayak and Paritosh Bhattacharyya created the touch sensors using NodeMCU and readily available materials. The touch sensors recorded the presence of a touch of the flush button every five minutes, and logged it as a single flushing event (the flush tank capacity was measured to be about 10 litres).

Installation of the Touch Sensors

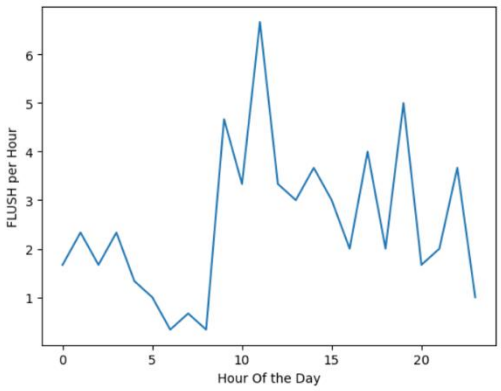


Installation of the touch sensors for recording the total number of toilet flushes during the day.

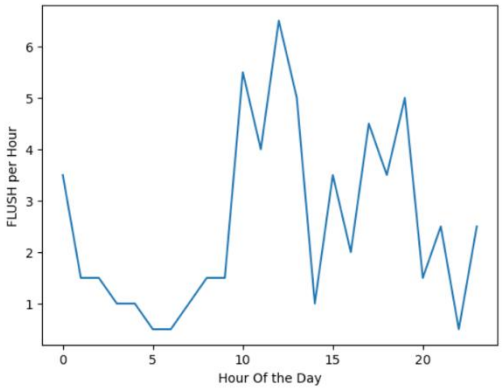
Retrieved Data



Data as retrieved from the Flush Touch Sensors



Weekdays (Average flushes = 60.66)



Weekend(Average flushes = 61)

Graphs showing flushes recorded at each hour of the day (hour 0 = 12:00 AM) on weekdays and weekend.

Calculated Consumption and Analysis

Average Residents per floor = 749/9 = 83
Average Residents using one toilet complex = 83/4 = 21
Average Daily Flush rate = 61 flushes per day
Water used per flush = 10 L

Total water used by 21 people in flushing = 610 Litres/day
Total water flushed by H1 daily = 22000 L
Water flushed daily = 29L/person
% of water gone to flushing = 22000/82356 = 26.7%

The sensors recorded data for five days from 9-11-2023 6:30 PM to 14-11-2023 6:30 PM. The first floor where the sensors were installed and the neighbouring floors were surveyed first to ensure that the complex with sensors is serving to its capacity of about 20 hostel residents. From the retrieved data it was found that daily flush rate is about 30 litres per head, and extrapolating it to the total hostel capacity of H1 Hostel Building which is about 750 residents, it is estimated that about 22,000 litres of water is used in flushing daily which is 26.7% of the total water consumed in H1 Hostel Building. This figure matches well with the 22.9% given by the Behavioural Survey.

Usage During / Type of day	0-6 hrs	6-12 hrs	12-18 hrs	18-24 hrs	Total Usage (litres)
Weekends	10.5	20.5	15.8	15.5	62.3
Weekdays	28.5	24.5	18.5	24.5	96
Overall	23.2	22.7	17.5	20.1	83.4

Tabulated above is daily and time-wise per head water usage in litres.

5. Behavioural Survey

In the absence of enough non-invasive flow sensors, surveying the students directly is a straightforward method to estimate water usage habits and activity-wise consumption. This task was primarily carried out by the group of Shreyas, Medha, Sanket and Ashish Tanay. A questionnaire consisting of quantitative questions was composed to get data on how many times a student takes a bath, uses the flush, does laundry etc. 149 students out of 800 (18.6%) from H1 participated in the survey. The Google form had three primary objectives: firstly, to account for water distribution across various activities and calculate individual water usage; secondly, to identify issues with water fixtures in Hostel 1 through resident observations; and finally, to understand habits leading to increased water consumption, suggesting improvements based on these insights.

A. Nature of the Questionnaire

1. Quantifying water used for bathing: time spent showering per shower/number of buckets used per bath/number of baths taken per week
2. Quantifying water used for washing faces/brushing teeth: number of times doing the above activities
3. Quantifying water used for handwashing/flushing: number of times the restroom is used per day
4. Quantifying laundry habits: number of days' worth of clothes given to the hostel laundry service/number of buckets used for handwashing in the hostel
5. Observations of water wastage in the hostel, problems and concerns with the water fixtures

B. Parameters and Assumptions

1. The flow-rates through the showers and taps were measured in the hostel using a timer and bottles with a known capacity (0.149 L/s, 6L/s)
2. The average bottle capacity was assumed to be 750ml (based on casual observation)
3. The capacities of buckets (from Ankita and DMart) were measured and averaged to give about 20 L
4. Time taken to brush teeth/wash hands were measured using a timer for a few people in the hostel
5. The average laundry frequency was assumed to be about once a week
6. Number of residents in H1: 749

The group analysed the data, and attributed the water consumption fractions to various activities like bathing, flushing, laundry, etc. Parameters like flow rates from taps and flush tank capacities were measured to convert raw statistics from the google form to quantified usage in litres. The final results from the survey are visualized through a pie chart (Graph 1). The concerns of the survey respondents and suggested improvements are discussed in the later section.

Graphs representing the responses to the survey questions filled by the respondents.

Drawbacks of the Survey

1. The large uncertainties in calculated parameters (for example, we assumed that the shower runs the entire time of bathing) as well as the respondents' uncertainty of their own habits (common feedback from the respondents was that they did not actively keep track of or notice the quantities we were asking them to report) could make this very inaccurate as an accounting method for anything less than an order-of-magnitude water calculation.
2. The small sample size (only about 19% of H1 residents filled in the survey form) is not indicative of the habits of all respondents.
3. Variation in response with season/day of the week and other factors were not considered.
4. Water used in cleaning the hostels (by the cleaning staff) was not included.

Recommendations for improving the survey analysis

- The survey should be conducted at different times
- Questions need to be more specific
- Value ranges can be shrunk for better resolution of data
- Participants can themselves be encouraged to consciously observe (at least a rough estimate of) how much water they use every day of the duration of the form being open, as it is not something that people usually think about, and would raise awareness about water wastage as well as improve the accuracy of data received in the form.