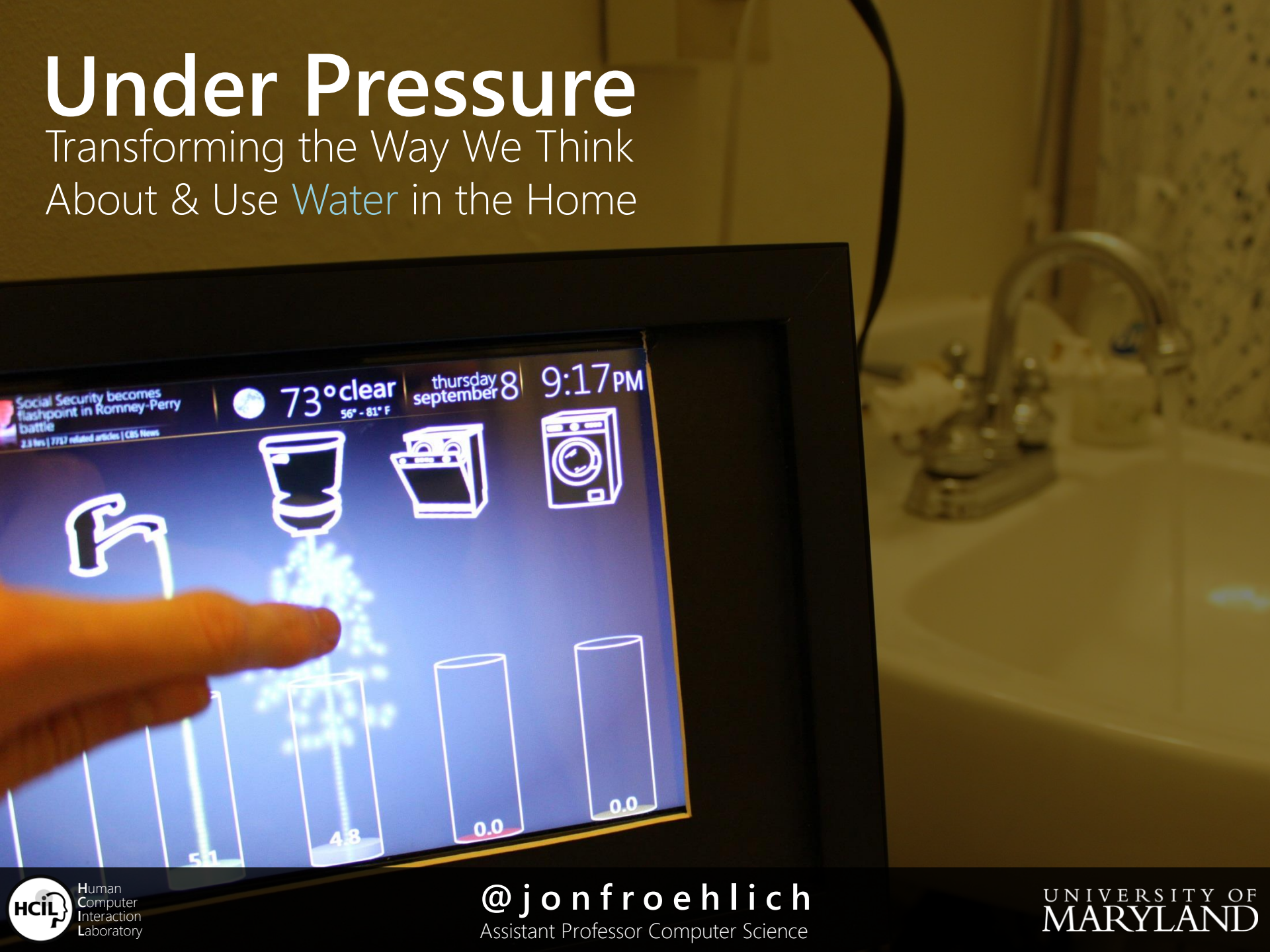
Under Pressure

Transforming the Way We Think About & Use Water in the Home



HCIL Human Computer Interaction Laboratory

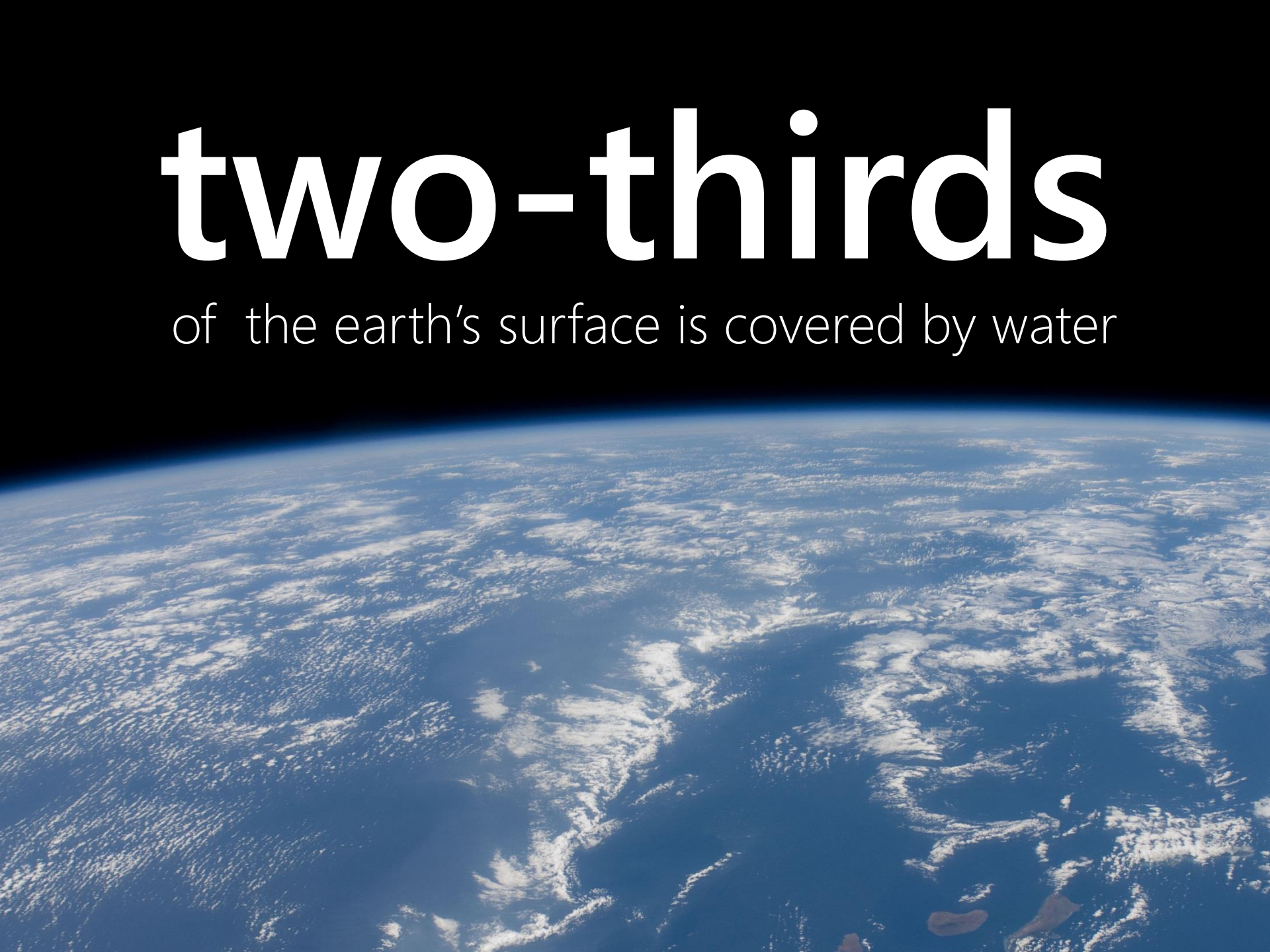
@jonfroehlich

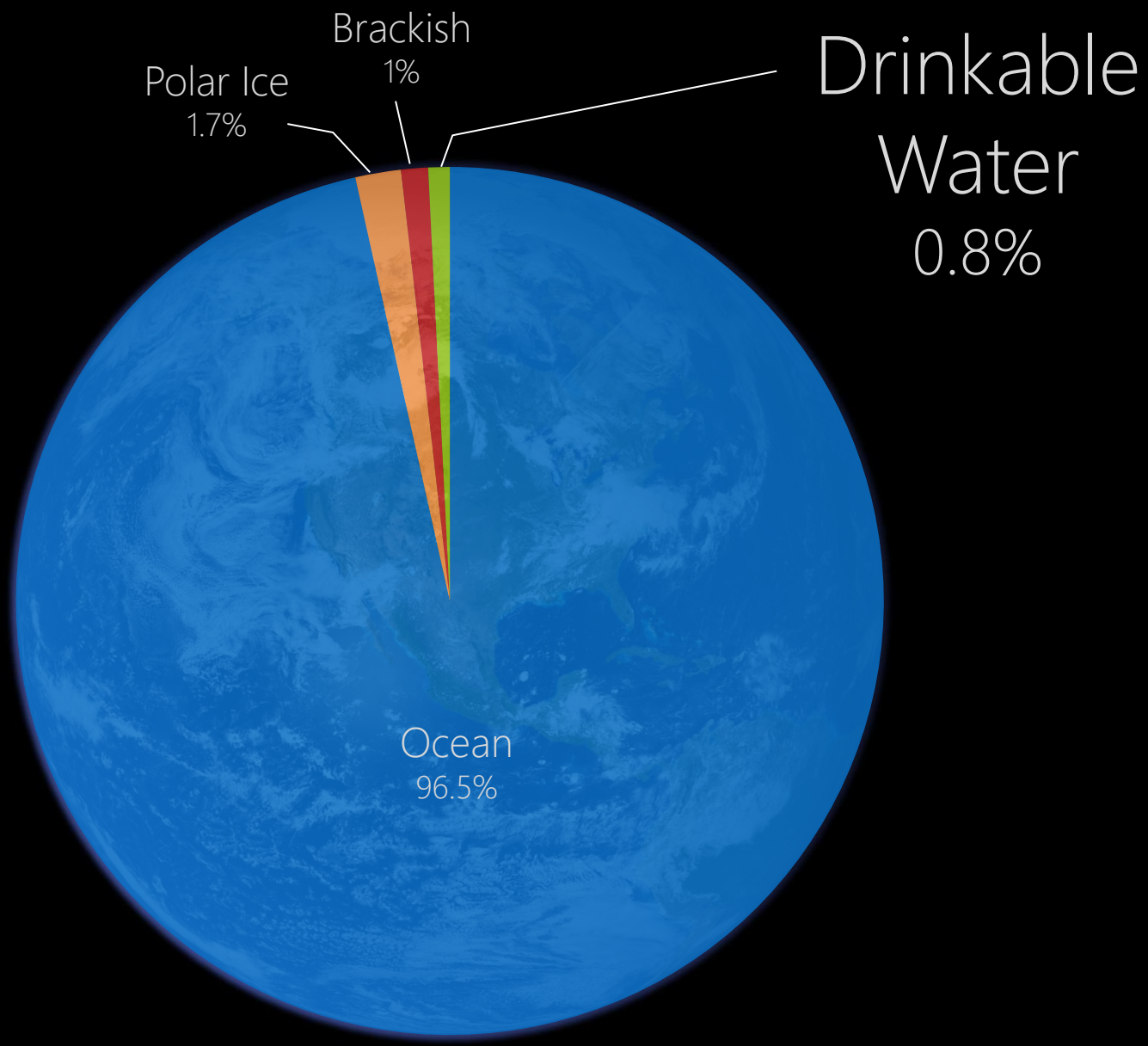
Assistant Professor Computer Science

UNIVERSITY OF MARYLAND

two-thirds

of the earth's surface is covered by water





[Glennon, *Unquenchable: America's water crisis and what to do about it*, 2009; Gleick,*World Policy Journal*, 2009]

The amount of water on earth is not changing

The amount of water on earth is not changing but its **location**, **quality** and **amount per person** is changing

As the  's climate changes…

precipitation patterns

glacial and ice snowpack

surface water availability

[Gleick, *World Policy Journal, 2009*]


As populations grow
per-capita water availability is declining


water availability disproportionately felt in
urban environments

[Barlow, 2007]

This places an enormous strain on drinkable water supplies

[Inman and Jeffery, 2006; Gleick *et al.*, 2008 Vairavmoorthy, 2006]

growing demand

in 2010, water consumption rose to 938 billion gallons in beijing

water supply = 576 billion gallons

[Guardian, Dec 2010]


"china melting snow to meet
freshwater demand"
[Guardian, Dec 2010]

[Bloomberg News, Feb 2009]


new sources of water
more costly to extract


water utilities
governments
shift focus

This is an area where HCI researchers and designers can help

eco-feedback

sensing and visualizing behavior to reduce environmental impact

toyota prius

toyota prius

The Washington Post

washingtonpost.com > Nation > Green

More news on: Environment | Climate | Science

For Hybrid Drivers, Every Trip Is a Race for Fuel Efficiency

By Michael S. Rosenwald
Washington Post Staff Writer
Monday, May 26, 2008

Evan Hirsche averages 43 mpg with his Prius, while Katie Sebastian, shown with her son, Cole, averages 41 mpg. The drivers have friendly rivalry over their mpg scores, fueled by the Prius hybrid's real-time mileage readings. (By Kevin Clark -- The Washington Post)

Buy Photo

Katie Sebastian accuses her friend Evan Hirsche of getting better mileage than she does because he lives in Bethesda and has flatter everyday trips than she encounters in hilly Takoma Park. She suspects the Hirsche family of taking frequent long drives out of town, which also helps them.

"They claim they haven't been out of town in a while," she said, "but I know they have."

Hirsche retorts: "It is well known that Katie is a lead-footer."

Their friendly rivalry stems from the Prius effect. Both drive a Prius, the Toyota hybrid with an elaborate dashboard monitor that constantly informs drivers how many miles per gallon they are getting and whether the engine is running on battery or gasoline power. That can change driving in startling ways, making drivers

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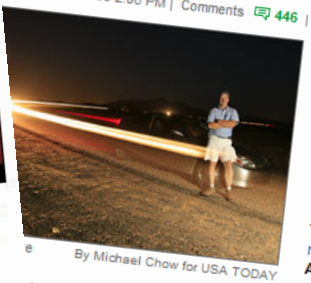
100 mpg? For 'hypermilers,' that sounds about right

Updated 6/27/2008 2:06 PM | Comments 446 | Recommend 103 E-mail | Save | Print | Reprints & Permissions | RSS



By Michael Chow for USA TODAY

in of Gilbert, Ariz., squeezes as much an get from his 2000 Honda Insight.

By Chris Woodyard, USA TODAY

GILBERT, Ariz. — After a 29-mile jaunt from his Phoenix office to his home here, Louis Hudgin proclaimed his gas mileage "pitiful."

He averaged just 88.3 miles per gallon.

MAXIMIZING MPG: What experts think of hypermiler techniques
TELL US: How do you squeeze the most miles out of every gallon?
ACROSS THE USA: Drivers slow down as costs accelerate

Most drivers would take a victory lap if they managed to squeeze that kind of mileage out of increasingly precious gasoline. Even on this, a bad day, Hudgin coaxed 28 mpg more out of his 2000 Honda Insight hybrid than its federal highway mpg rating.

Hudgin's disappointment — he usually averages about 100 mpg this time of year — stems from his pride in being no ordinary driver.

He's a hypermiler, part of a loose-knit legion of commuters who've made racking up seemingly unattainable mpg an art. And a sport.

Hypermilers practice such unorthodox techniques as coasting for blocks with their car's engine turned off, driving far below speed limits on the freeway, pumping up tire pressure far beyond car and tire makers' recommendations, manipulating the

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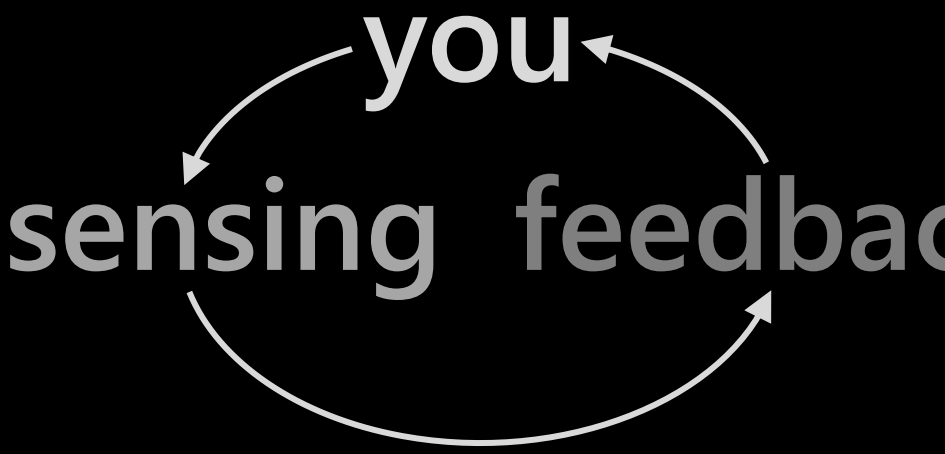
THE DISCUSSION

price of a
ar gasoline
low has
ted you?
sion at
Fuel
stories
g tips
rs.

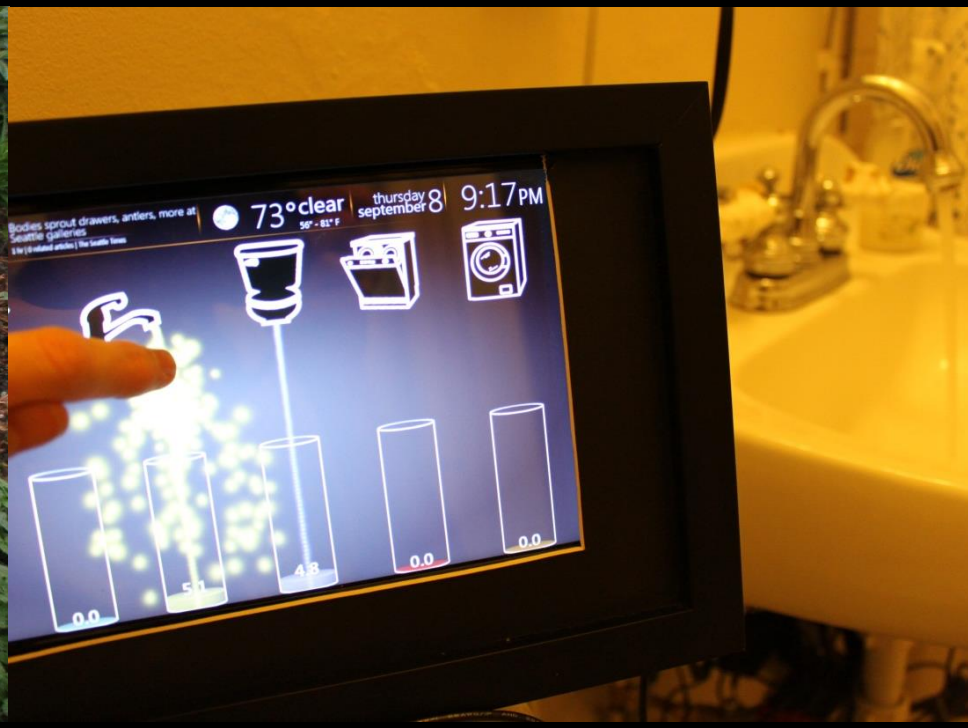
GAS AT A PREMIUM

eco-feedback

sensing and visualizing behavior to reduce environmental impact



HydroSense + **Reflect**$_2$O



sensingfeedback

water sensing

Municipal Services Statement

City of Tempe
P.O. Box 29617
Phoenix, AZ 85038-9617
480-350-8361
480-350-8400 (TDD)

0000127520000000010068700154711 8

LINDER HOLLINQUEST
7450 S KENWOOD DR
TEMPE AZ 85283-4921

Mark if address change requested on reverse side

Account Number: 100687-00154711
Utility Amount Due: 127.52
Voluntary Donation: 1.00
Total + Voluntary Donation: 128.52
Date Due: 1/8/2007
Enter Amount Paid:

Make checks payable to the City of Tempe.

PLEASE FOLD BEFORE TEARING

Return the top portion of this statement with your payment.

Keep the bottom portion of this statement for your records.

See reverse side for important information.

Account Number: 100687-00154711
Current meter reading: 16507
Billing period: 12/2006
Previous meter reading: 16305
Service Address: 7450 S KENWOOD LN
Meter read date: 11/20/2006
Gallons delivered: 20,200
Days of service: 27

Account Activity

Date	Description	Amount
	Payments Received Thank You	100.00
12/12	Water Quality Fee	0.13
12/12	Tempe City Tax	0.61
12/12	State Tax	2.15
12/12	Sewer Service Charge	7.28

Date	Description	Amount
12/12	Water Consumption	20.11
12/12	Water Service Charge	13.99
12/12	1% Delinquent Fee	0.40
12/12	Sewer Charge	11.48
12/12	Residential Refuse	17.41

The due date on this ... applies ONLY to current charges.
... Discover payments accepted, call 480-350-8361

Date Due: 1/8/2007

Previous Balance	Payments	Credits	Net Due	Late Charges	+ Other Debits	=Utility Amount Due
153.96	100.00	0.00	53.96	73.56	0.00	127.52

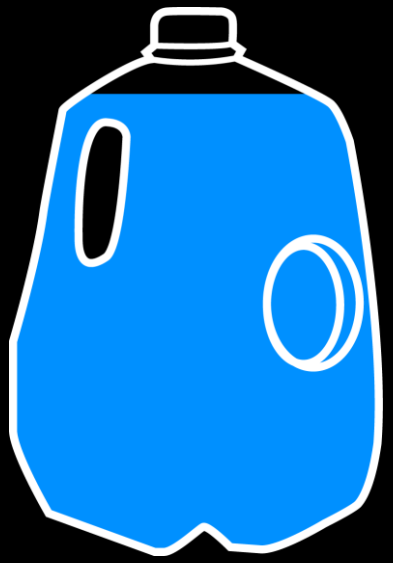
+ Voluntary Donation	= Total Including Voluntary Donation
1.00	128.52

Year to Date Voluntary Donation Thank You: 0.00

Help to Others voluntary donation program makes it easier to help neighbors in need. Help to Others supports essential human service programs for children, families and seniors. If you do not wish to contribute to this program, simply pay only the "Utility Amount Due."

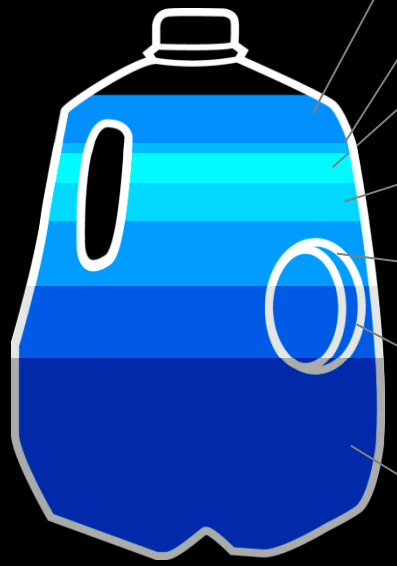
water feedback

10,230
gallons




SAFEWAY
SAVE MORE AT SAFEWAY
GROCERY
SFWY PRTZLE STICK
RegPrice 1.79
CardSav .29
1.50 B
BLKBERY PRES
SFY CANOLA OIL
CEREAL PNT BUTTER
CHILI SAUCE SWT
CHF-B PIZZA
LK GRLC SCE
REFRIG/FROZEN
LUC CHEESE
RegPrice 6.79
SPINACH ARTICHOKE
RegPrice 3.79
3S CRWN VEG RSTD
RegPrice 3.79
2@2.50 SFWY SEL MEDALL FC
RegPrice 7.58
MARGARINE
GEN MERCHANDIS
#SFY BENEHIST TAB
BAKED GOODS
LD COSMIC BROWNIES
1.29 B
OROWEAT RYE
3.14 B
CUSTARD PIE 9IN
4.99 B
RegPrice 5.99
CardSav 1.00
CHOC CREAM PIE
4.99 B
RegPrice 5.99
CardSav 1.00
**** TAX
6.76 BAL
144.25
VF MC XXXXXXXXX
144.25
.00
CHANGE
TOTAL SAVINGS 16.97
NUMBER OF ITEMS = 35
SAFEWAY
SAVE MORE AT SAFEWAY
Month: April 2006
Total Food Units: 1527
Total Price:
$642

10,230 gallons



Other
1248 gals

Dishwasher
102 gals

Faucets
1105 gals

Showers
1176 gals

Laundry
1,524 gals

Toilets
1,872 gals

Outdoor
3,212 gals


waterbot
[Arroyo *et al.*, CHI 2005]


showme
[Kappel & Grechenig, Persuasive 2009]


upstream
[Kuznetsov & Paulos, CHI 2010]

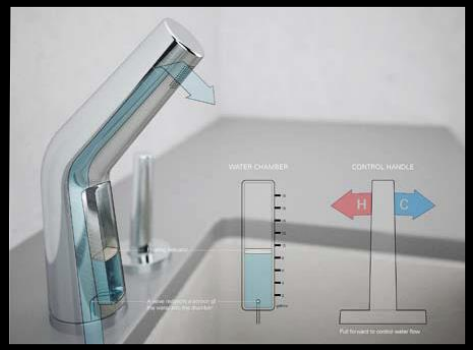
waitek shower monitor

http://www.waitek.co.nz/

Point-of-Consumption Eco-Feedback Displays

sensing and feedback
unit co-located at fixture

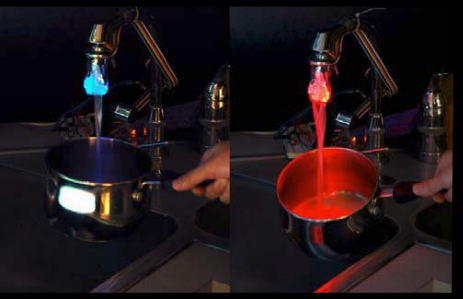
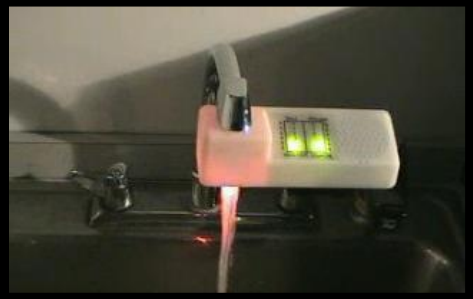
provides real-time
feedback on water usage



WATER CHAMBER
CONTROL HANDLE
H
C

IN SIGHT MIND
see what you're wasting
WEEK
82
WEEK
327



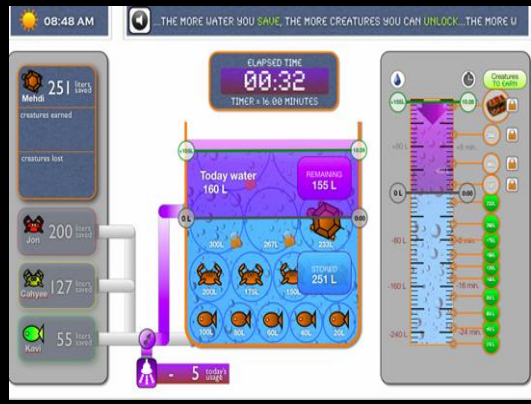

iSAVE
38
iSAVE
855

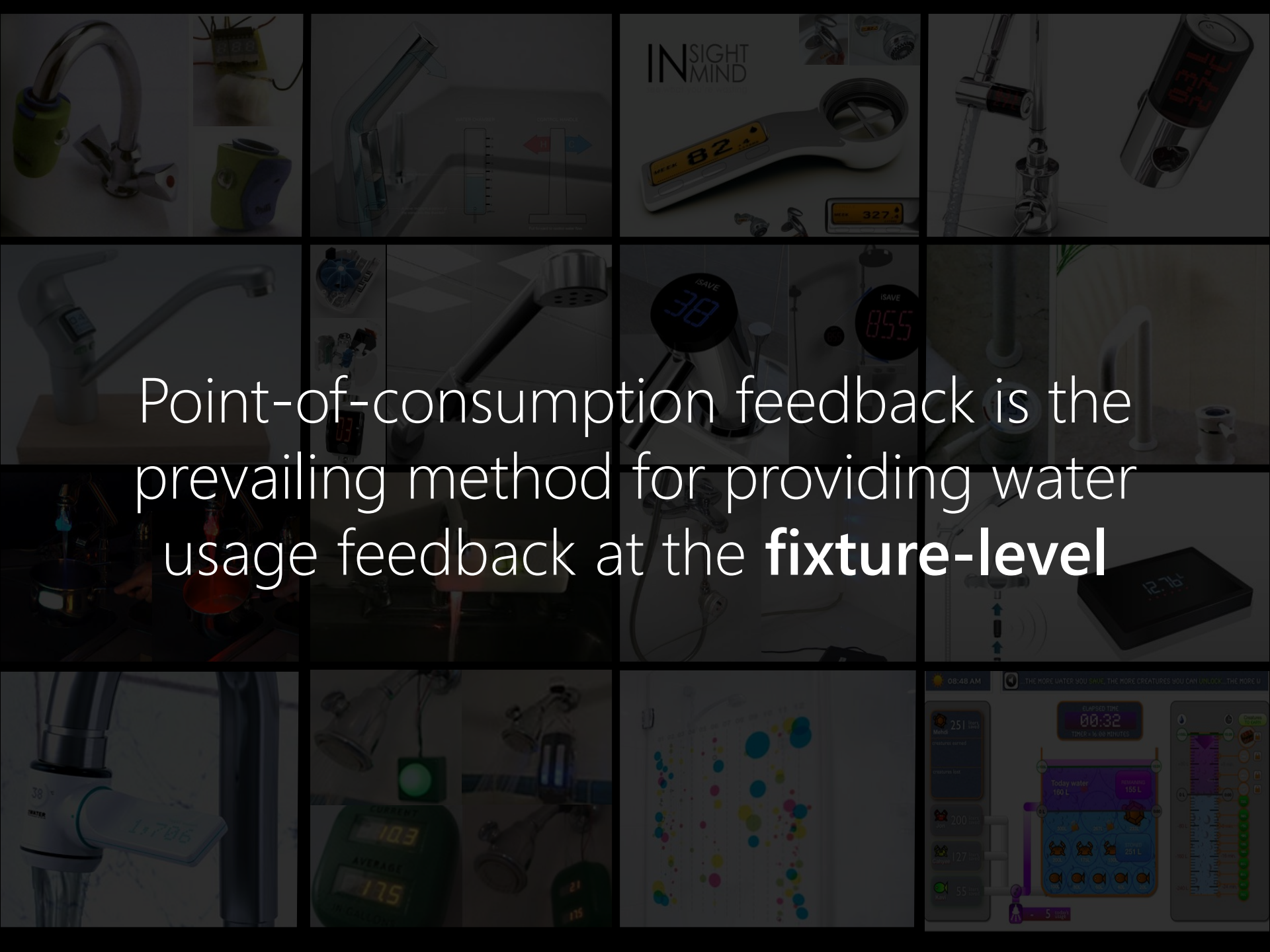





38
1.706

CURRENT
103
AVERAGE
175
IN GALLONS


08:48 AM
...THE MORE WATER YOU SAVE, THE MORE CREATURES YOU CAN UNLOCK...THE MORE U
ELAPSED TIME
00:32
TIMER = 16 00 MINUTES
Mehdi
251 liters saved
creatures earned
creatures lost
Today water
160 L
REMAINING
155 L
Jon
200 liters saved
Cahyee
127 liters saved
Kavi
55 liters saved
STORED
251 L
- 5 today's usage
Creatures To Collect



Point-of-consumption feedback is the prevailing method for providing water usage feedback at the **fixture-level**

Showers and **faucets** account for **~22% of water use** in the average North American home

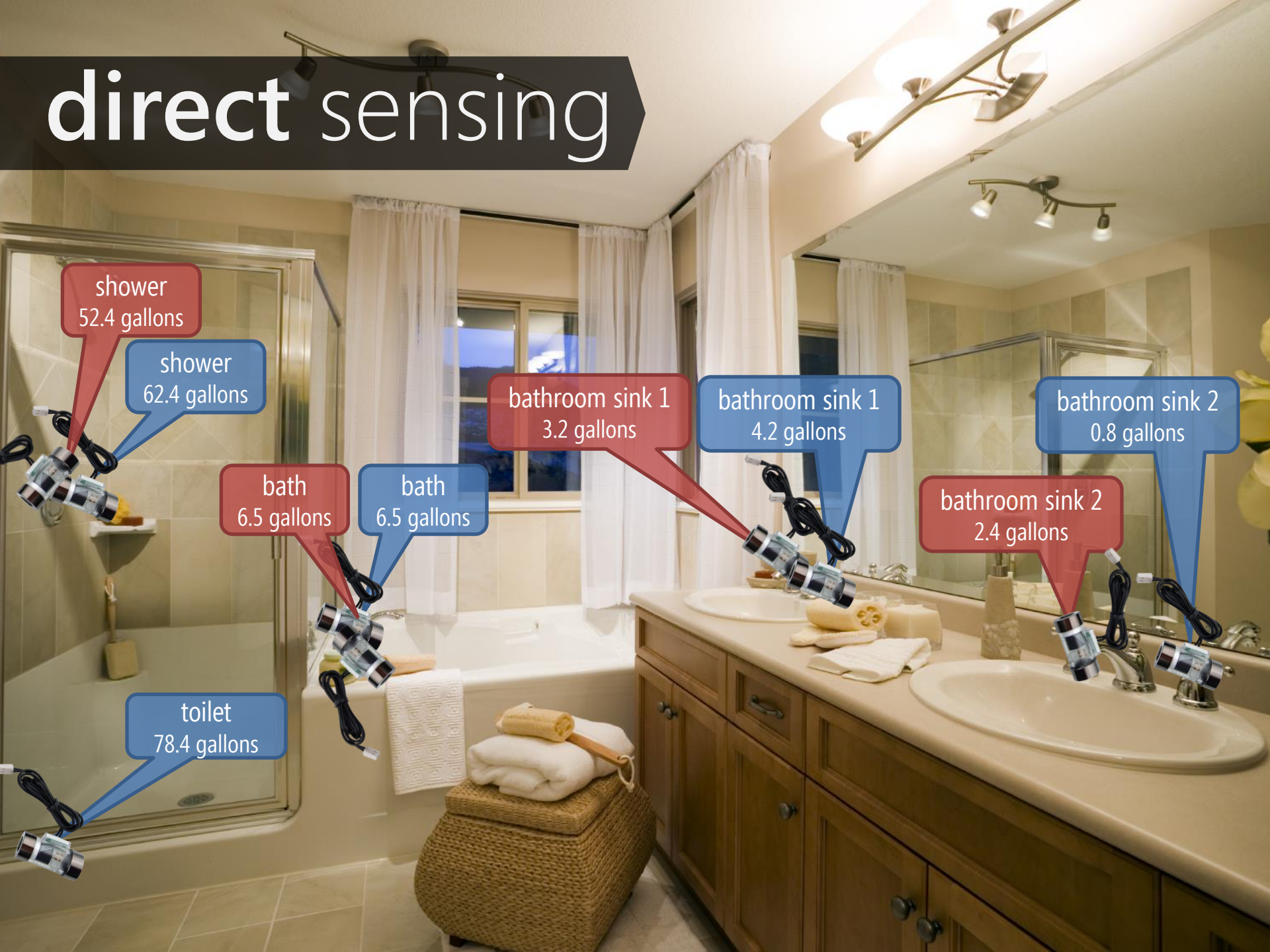
[Vickers, 2001]

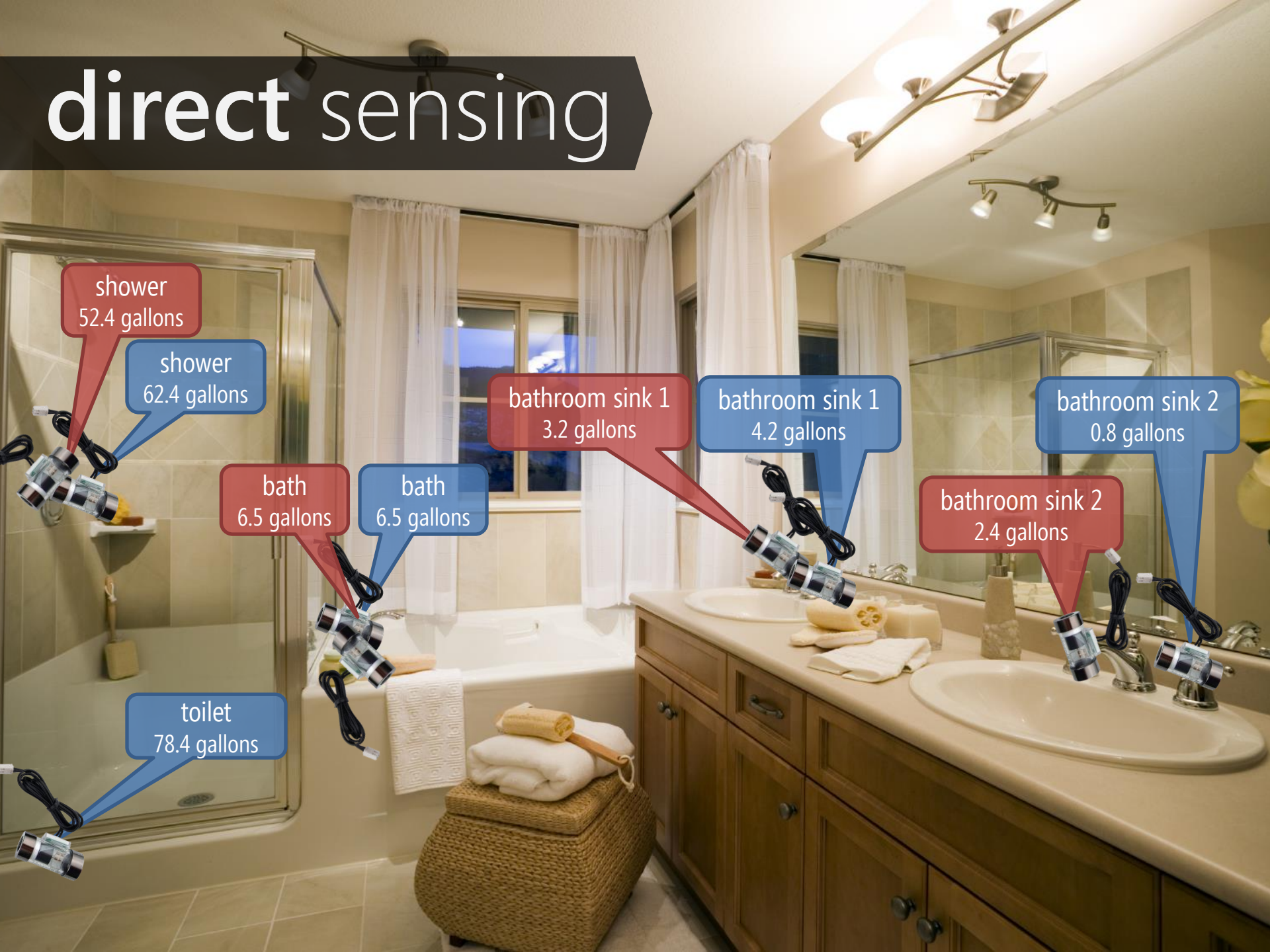
direct sensing

[Teague Labs, Arduino Water Meter, http://labs.teague.com/?p=722]


direct sensing
shower
62.4 gallons
bath
6.5 gallons
toilet
78.4 gallons
bathroom sink 1
4.2 gallons
bathroom sink 2
0.8 gallons

direct sensing




direct sensing
shower
52.4 gallons
shower
62.4 gallons
bath
6.5 gallons
bath
6.5 gallons
bathroom sink 1
3.2 gallons
bathroom sink 1
4.2 gallons
bathroom sink 2
0.8 gallons
bathroom sink 2
2.4 gallons
toilet
78.4 gallons

indirect sensing

shower
52.4 gallons

shower
62.4 gallons

bath
6.5 gallons

bath
6.5 gallons

toilet
78.4 gallons

bathroom sink 1
3.2 gallons

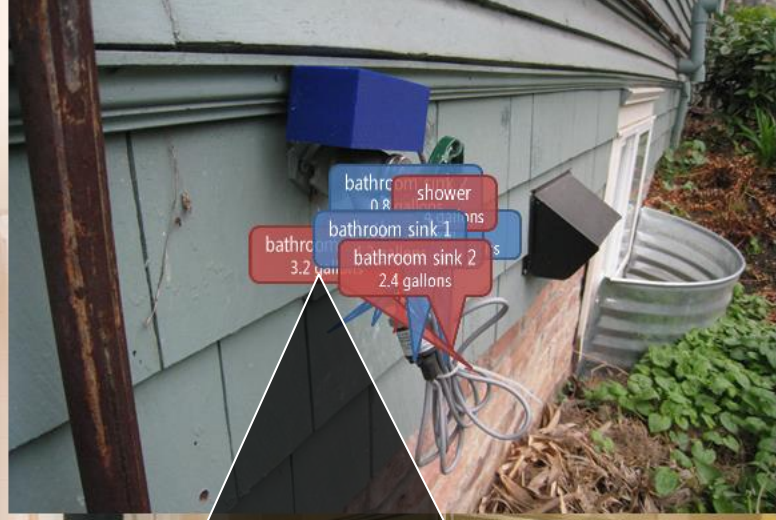
bathroom sink 1
4.2 gallons

bathroom sink 2
2.4 gallons

bathroom sink 2
0.8 gallons

[HydroSense, UbiComp 2009]

indirect sensing



HydroSense attempts to infer fixture-level usage for the entire home from a **single** point.

[HydroSense, UbiComp 2009]

This data presents new, rich opportunities for...

eco-feedback

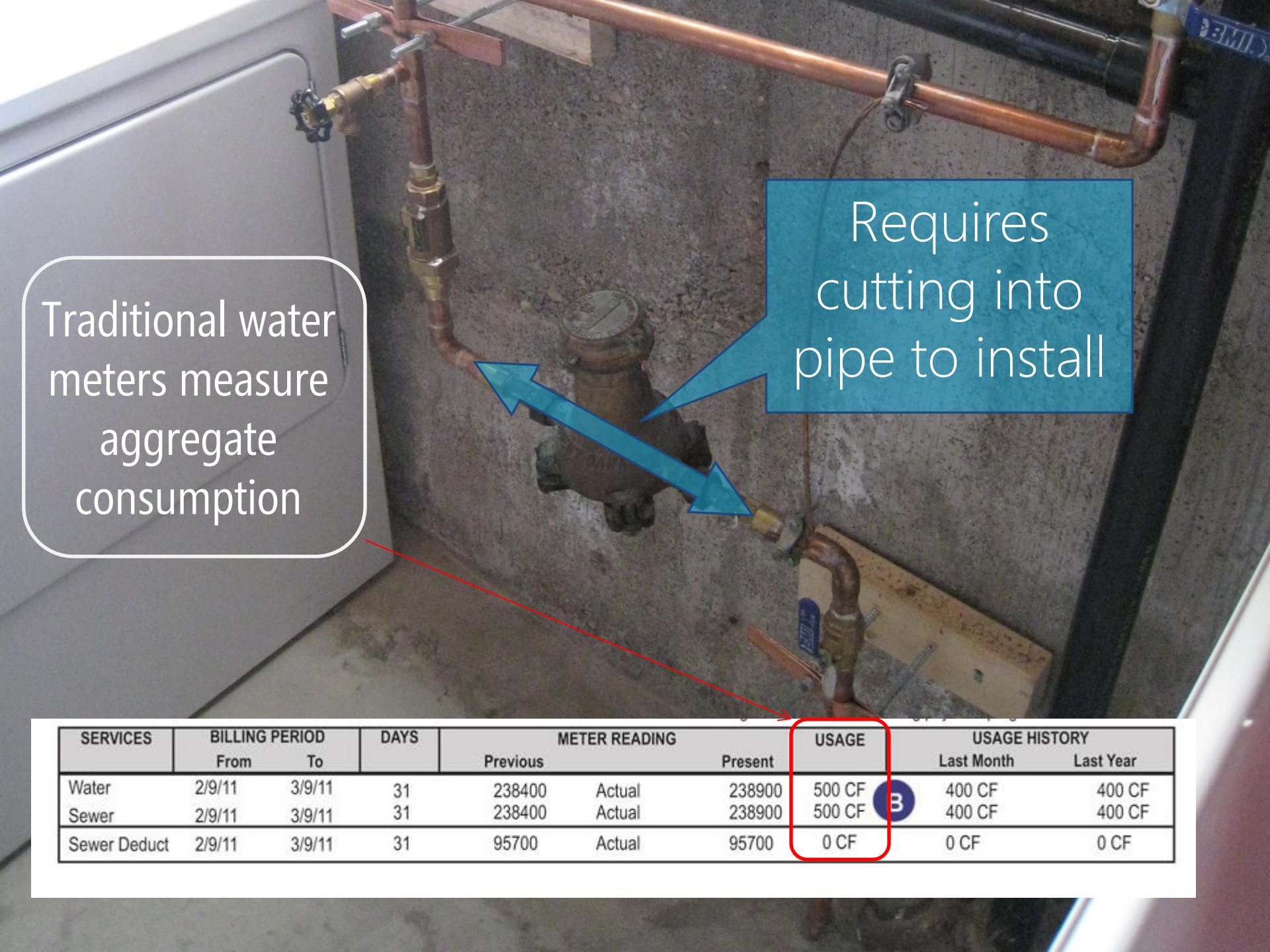
sensing and visualizing behavior to reduce environmental impact

What do we do with all this data?

How does HydroSense work?

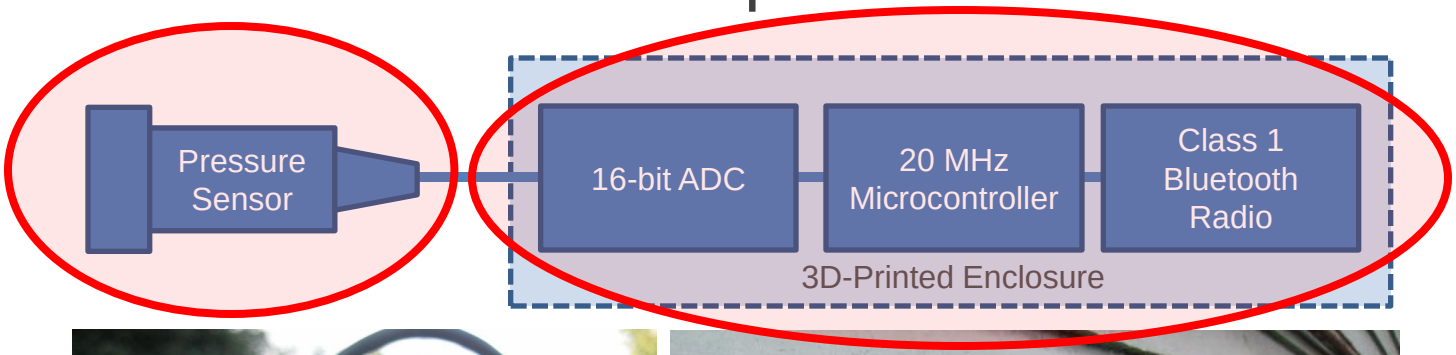
How did we evaluate it?

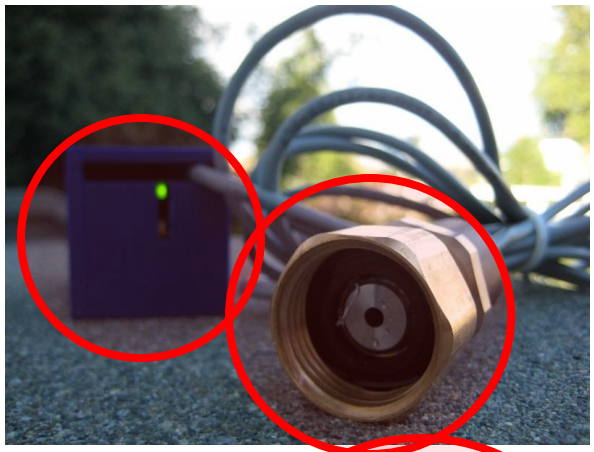

hydrosense
• single, screw-on sensor
• identifies fixture usage
• estimates flow
Froehlich et al., UbiComp2009; Larson et al., PMC2010

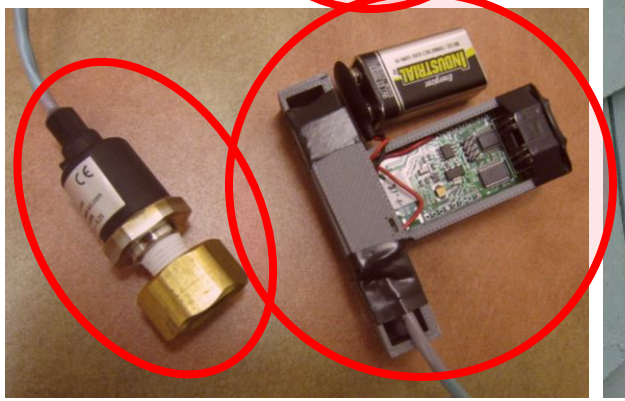


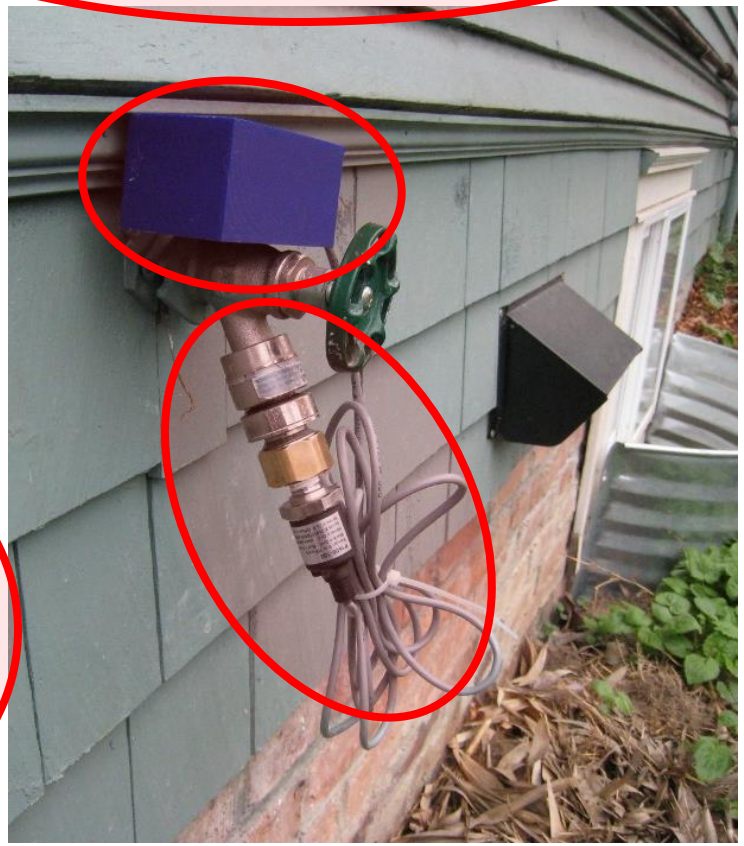
SERVICES	BILLING PERIOD From	To	DAYS	METER READING Previous		Present	USAGE	USAGE HISTORY Last Month	Last Year
Water	2/9/11	3/9/11	31	238400	Actual	238900	500 CF	400 CF	400 CF
Sewer	2/9/11	3/9/11	31	238400	Actual	238900	500 CF	400 CF	400 CF
Sewer Deduct	2/9/11	3/9/11	31	95700	Actual	95700	0 CF	0 CF	0 CF

hydrosense implementation





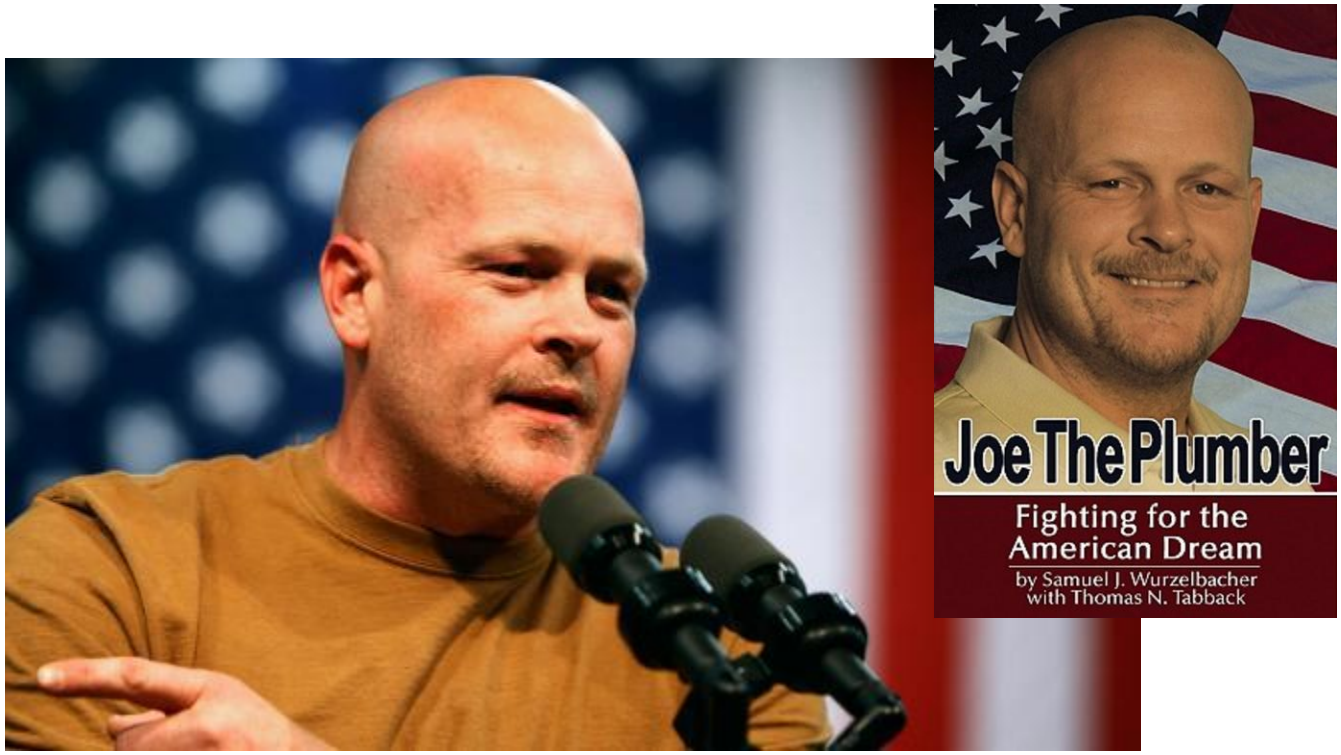




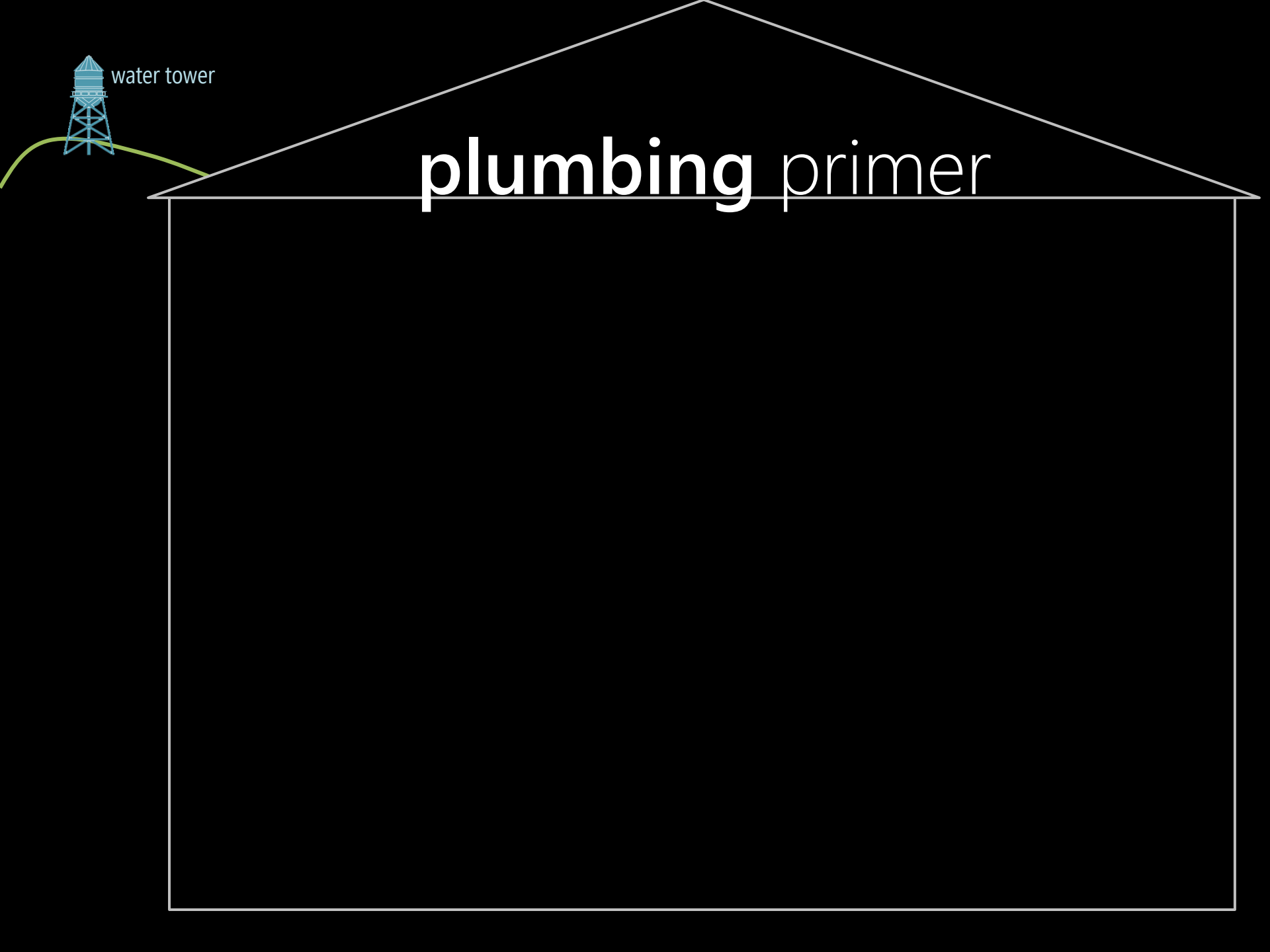
brief plumbing primer

brief plumbing primer

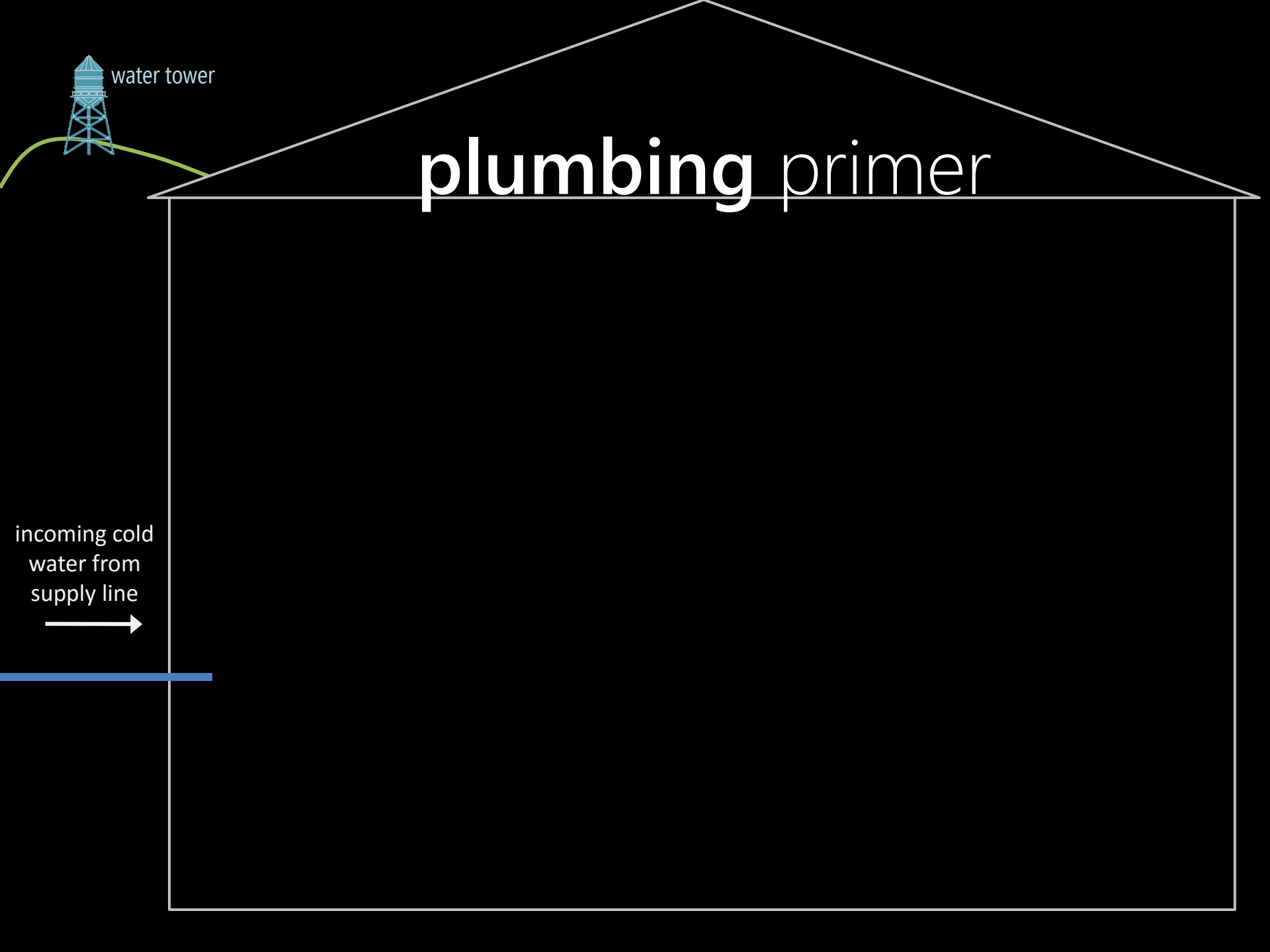
brief plumbing primer

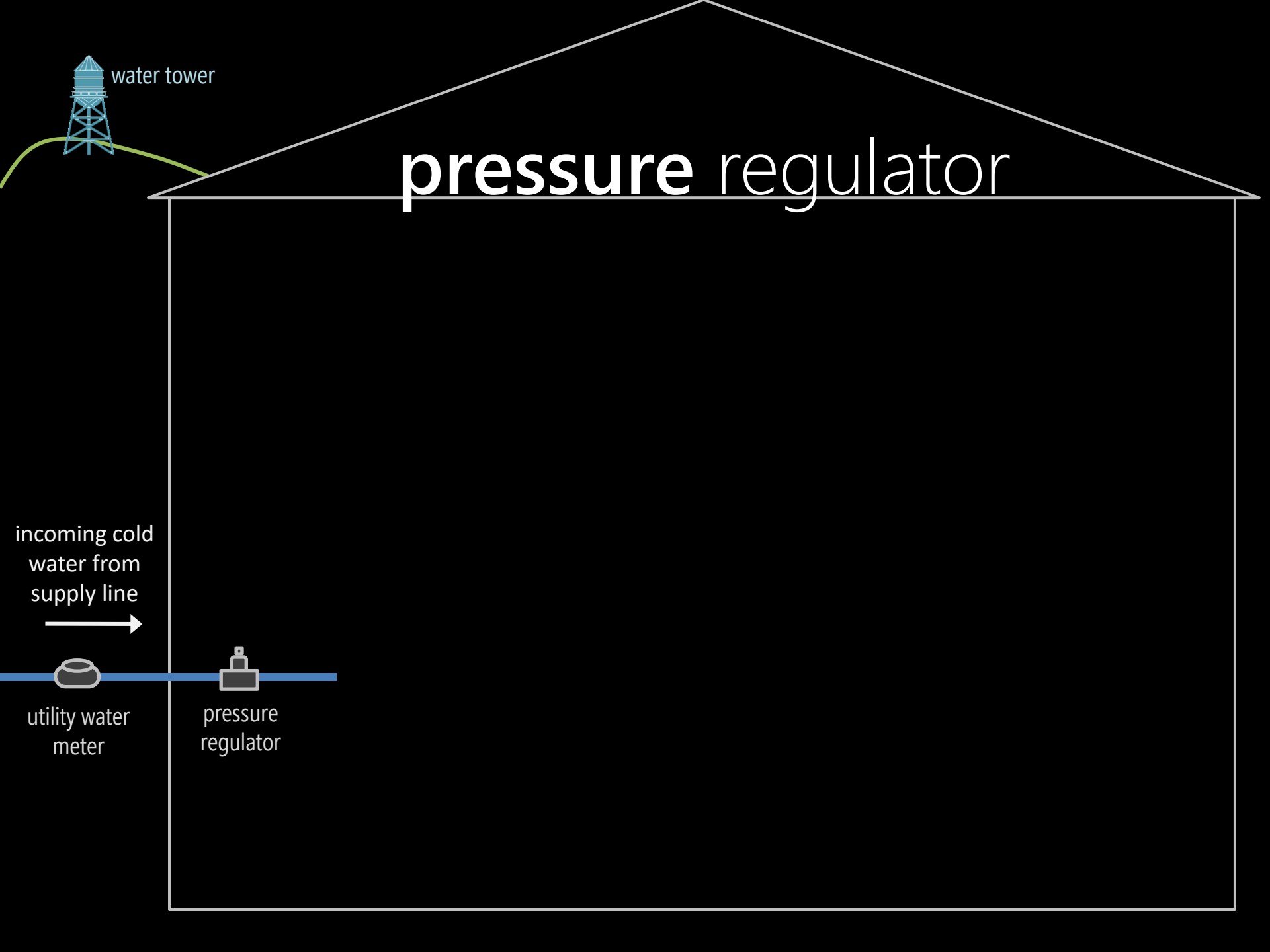


It's Samuel Joseph Wurzelbacher!



plumbing primer

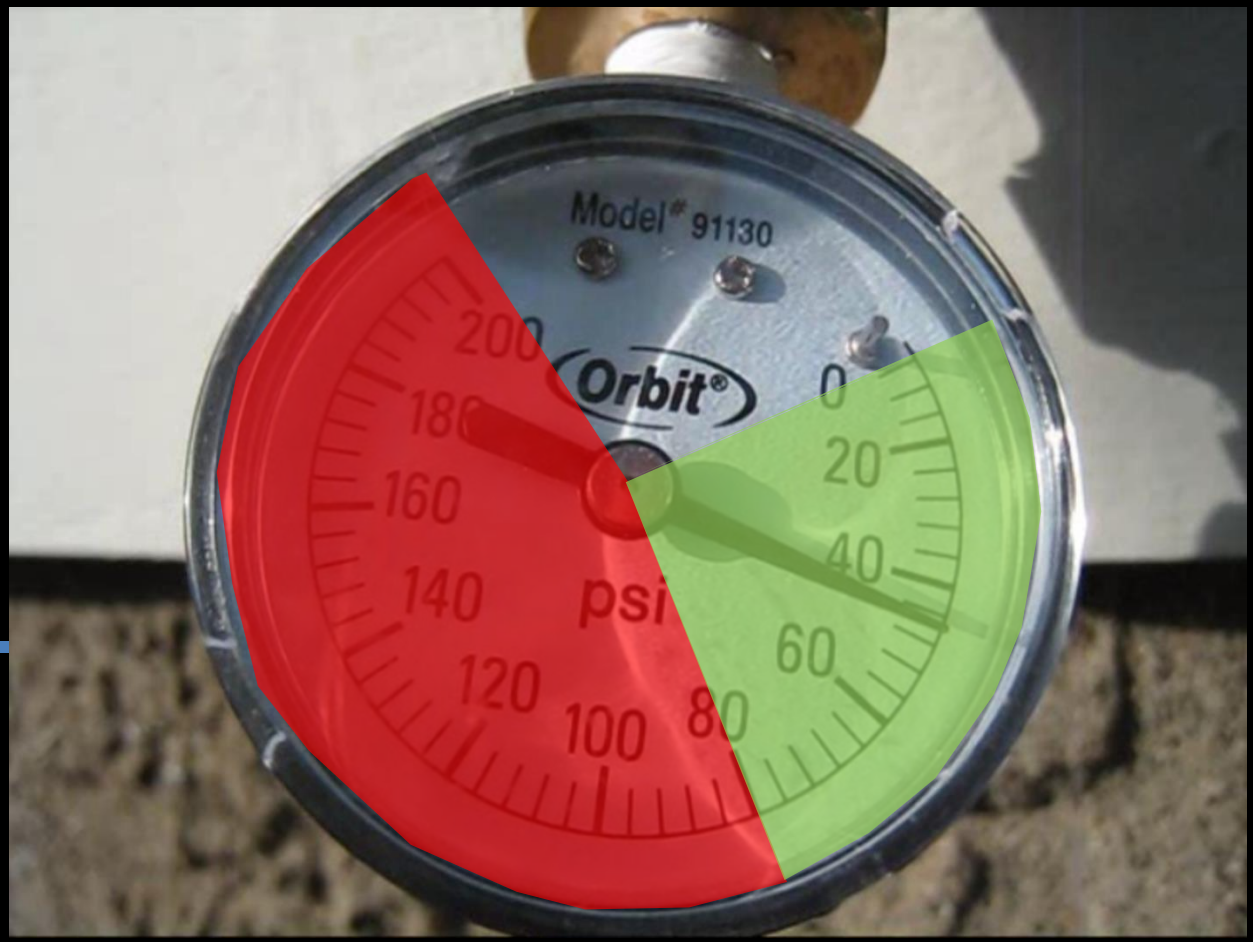

water tower
plumbing primer
incoming cold water from supply line


water tower
pressure regulator
incoming cold water from supply line
utility water meter
pressure regulator

water tower

pressure regulator

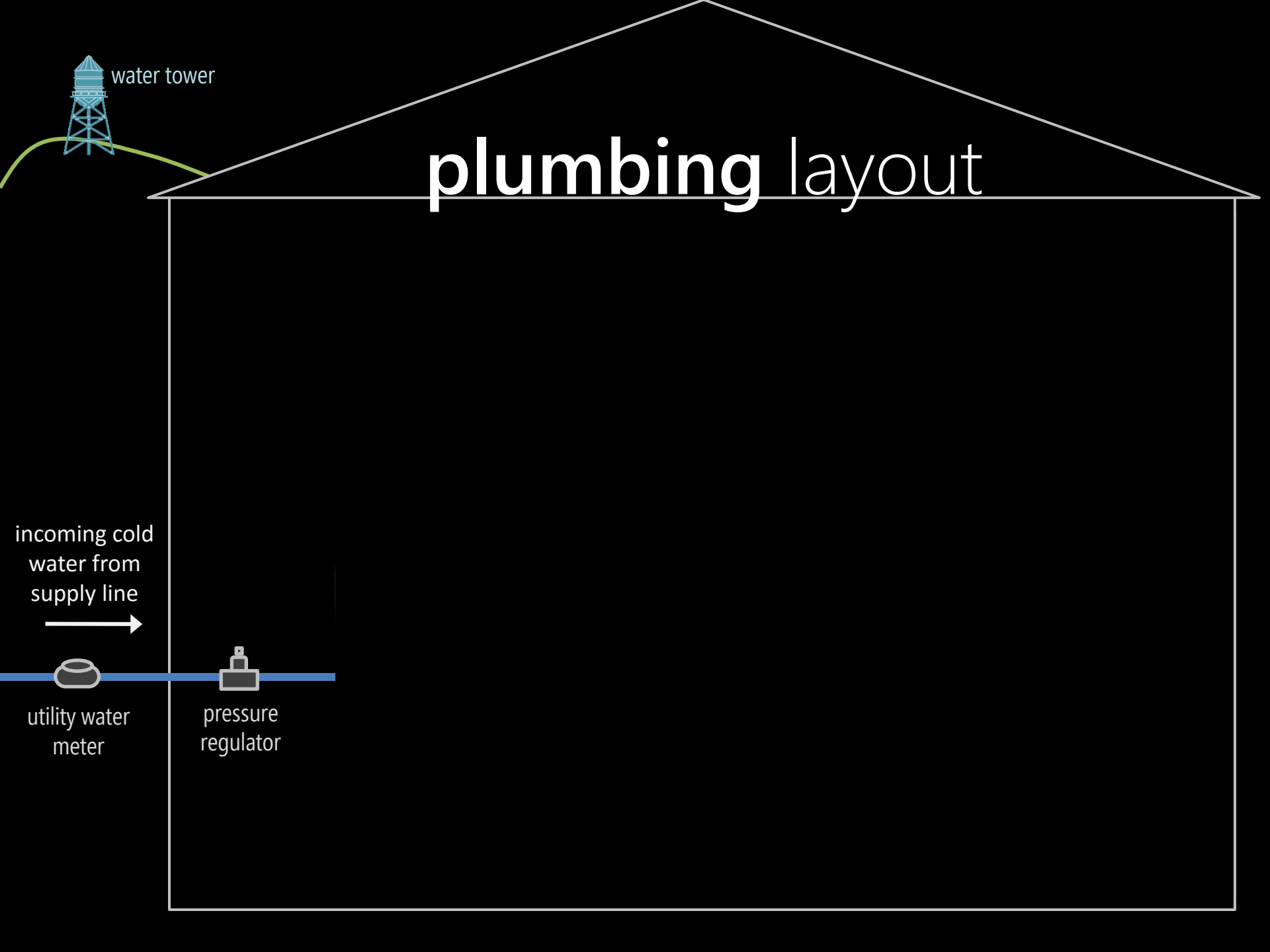
incoming cold water from supply line

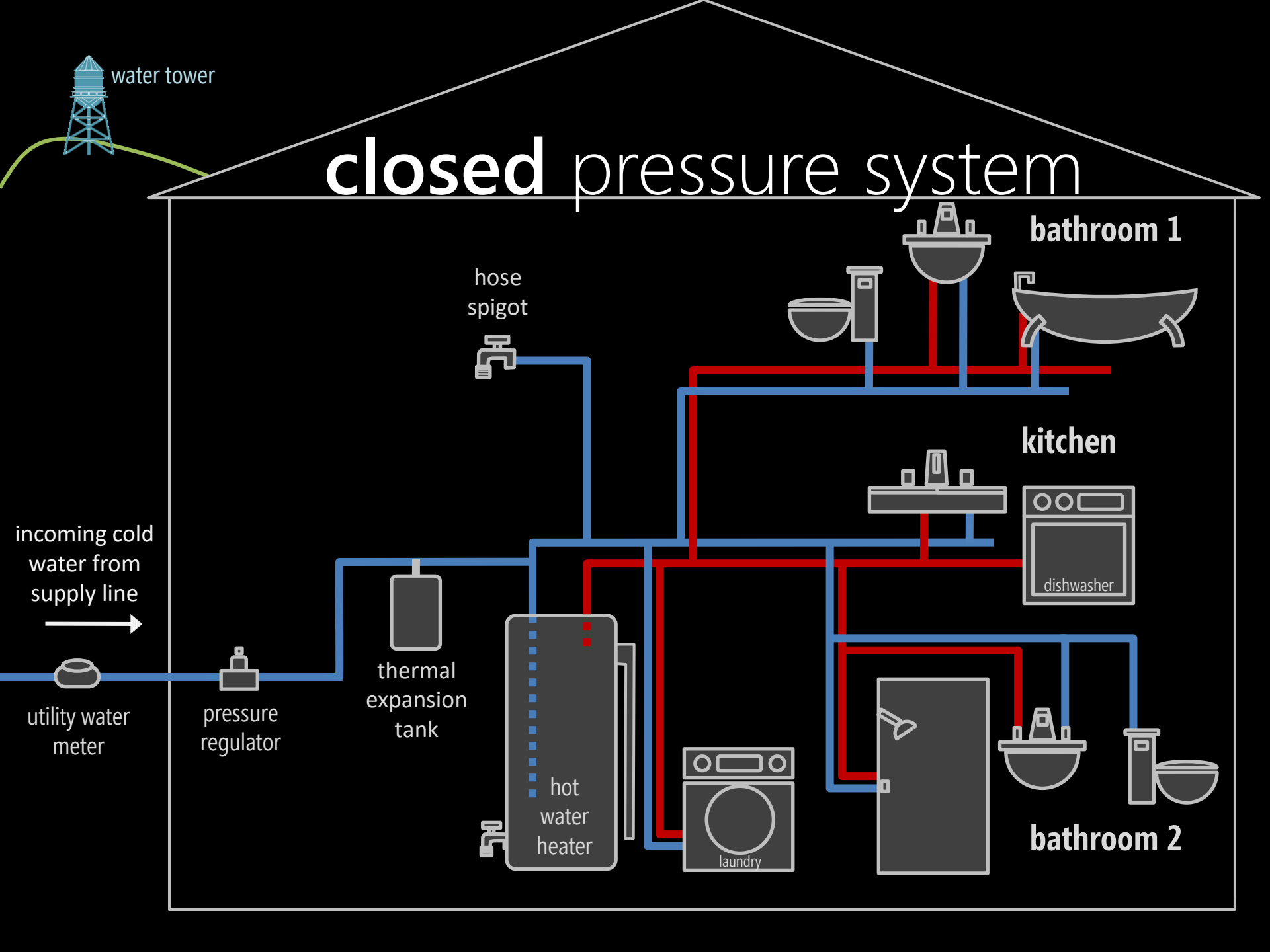


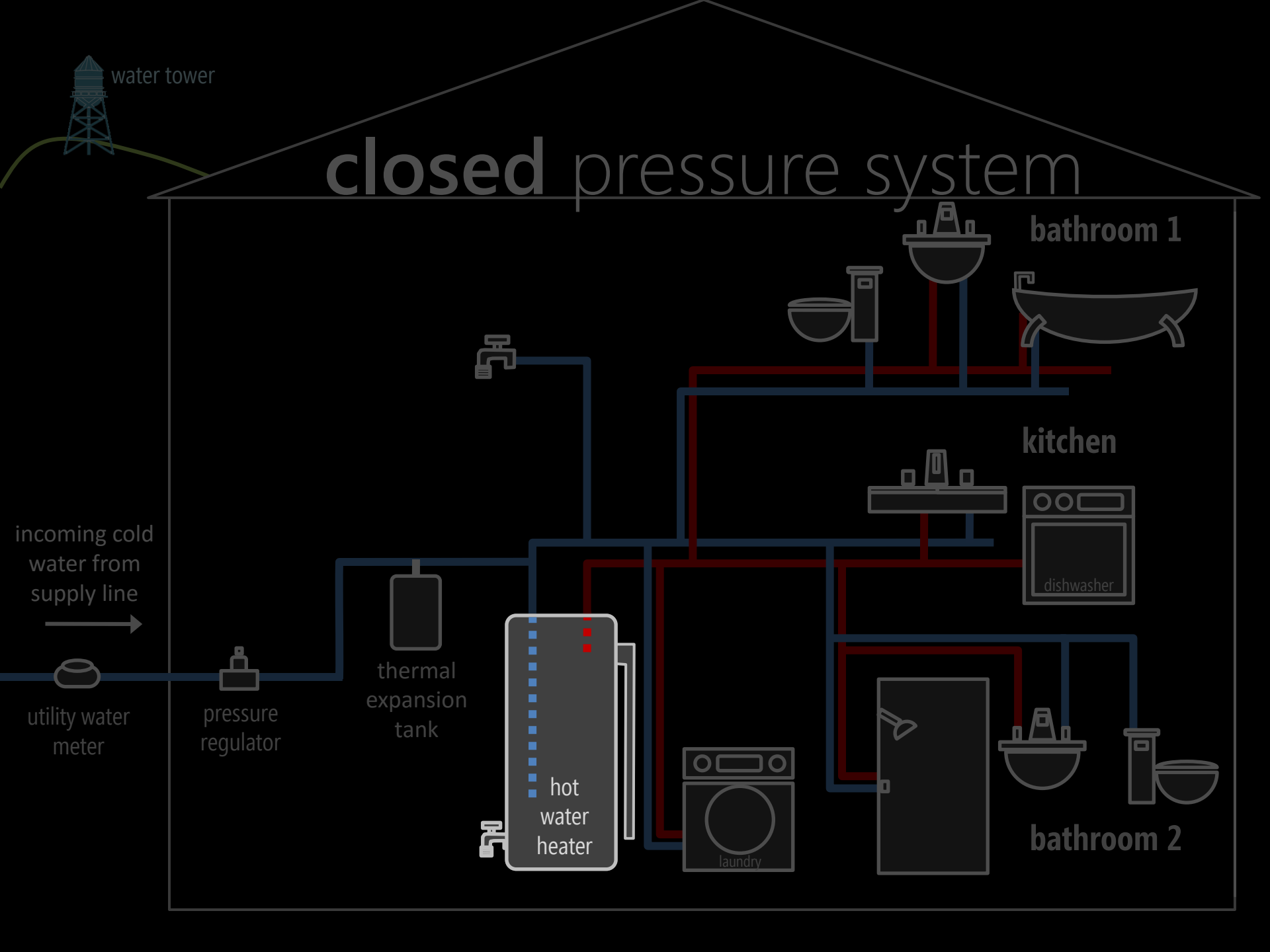
utility water meter

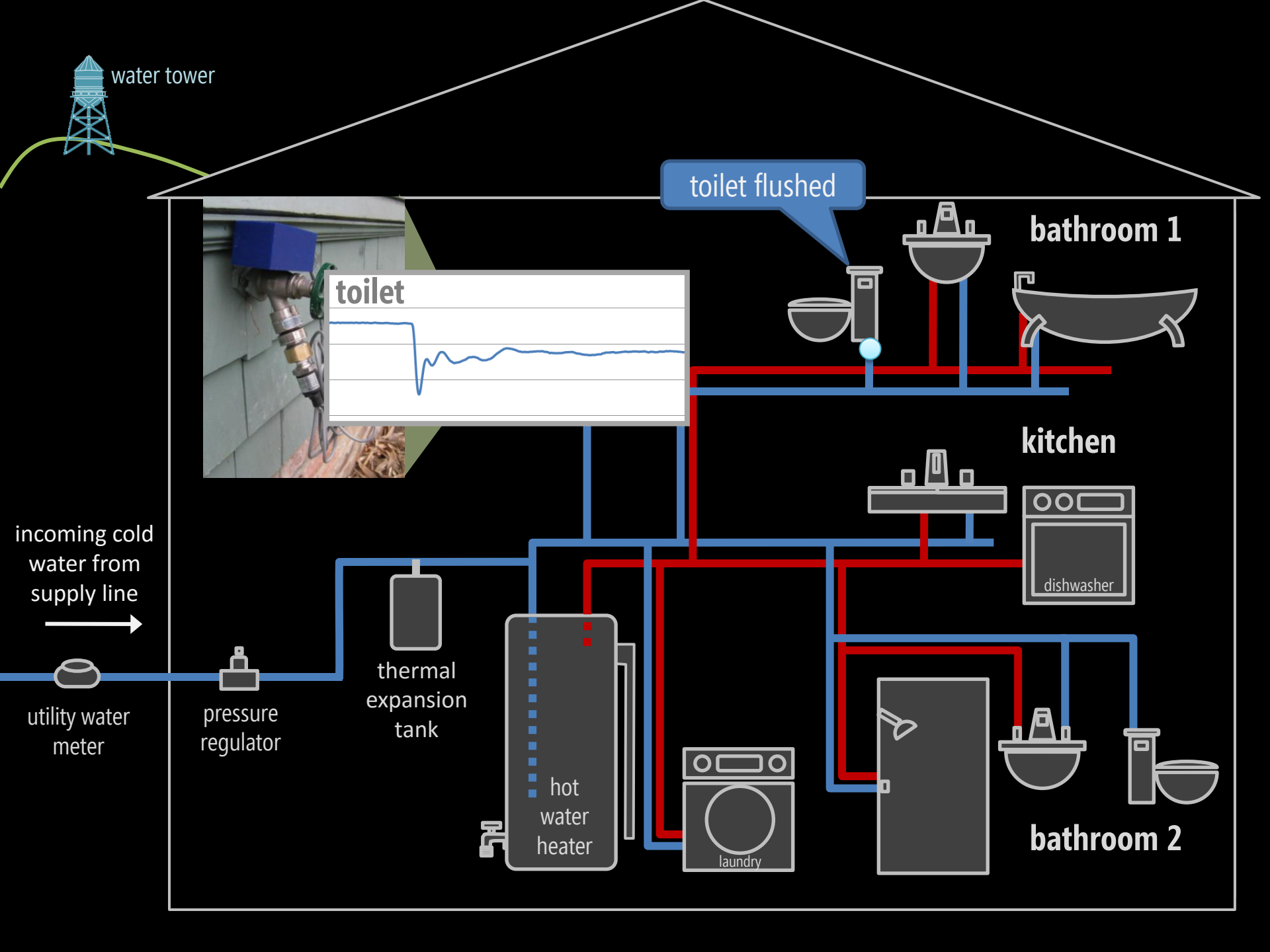
pressure regulator

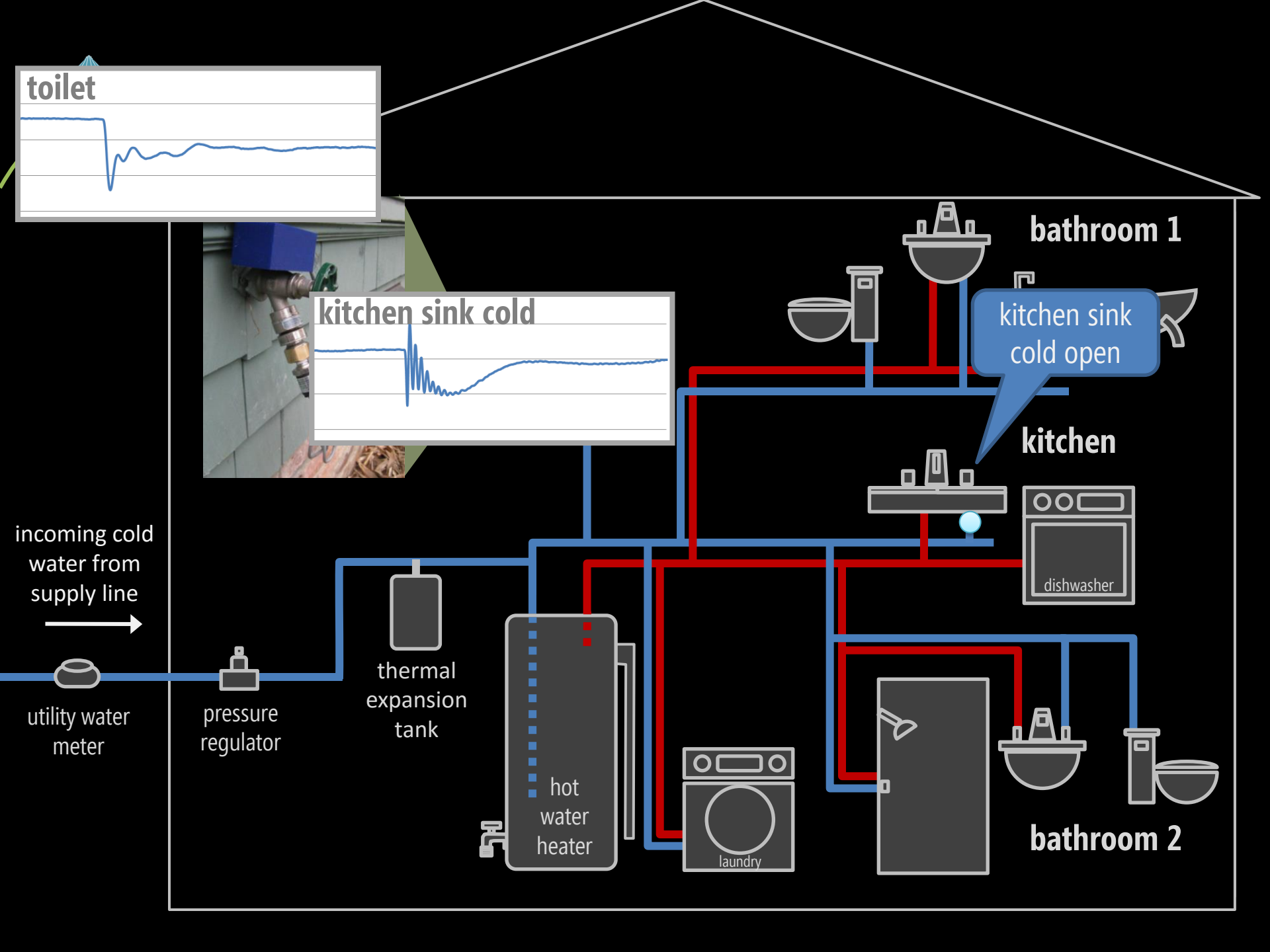
plumbing layout

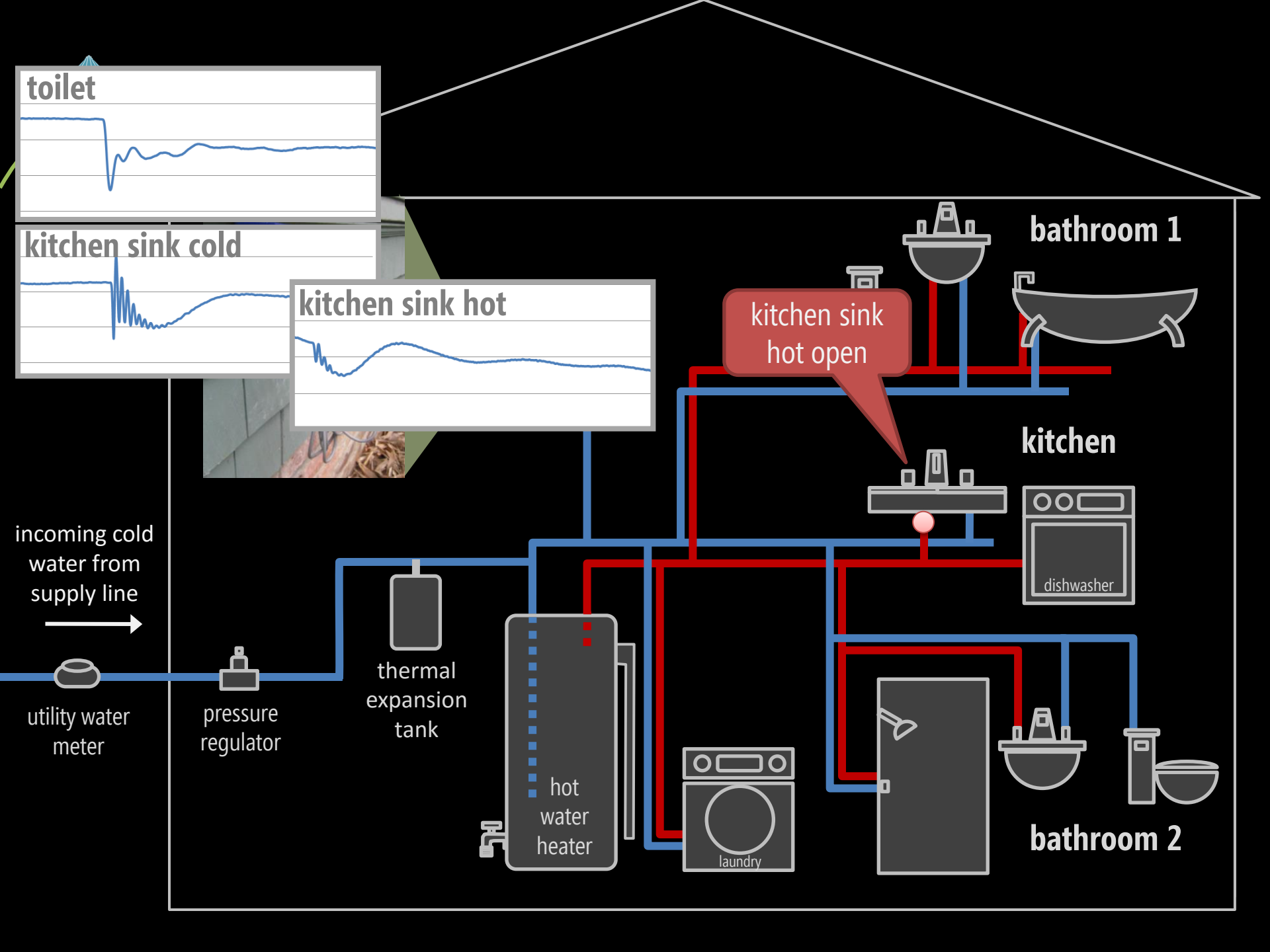


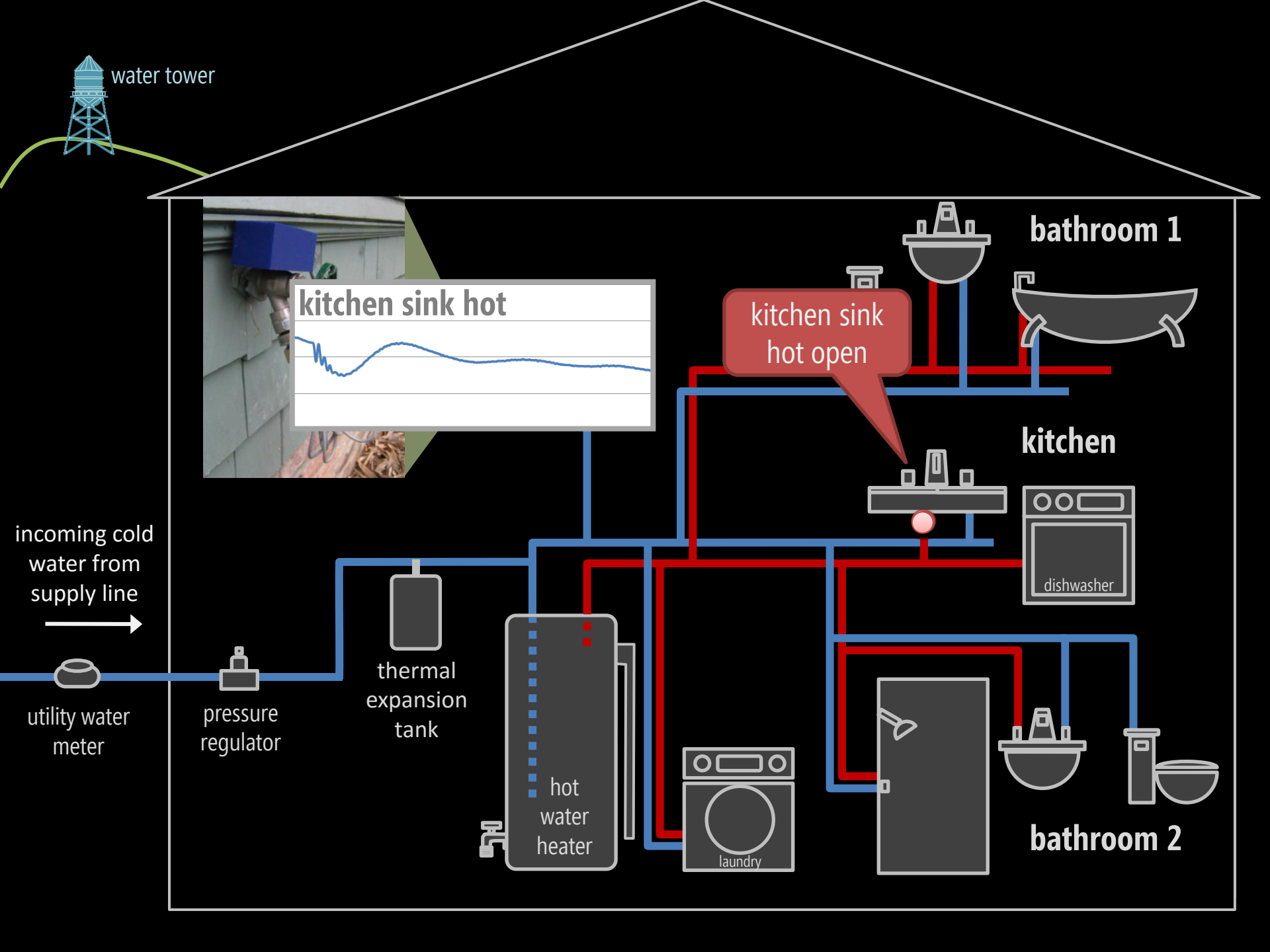

water tower
closed pressure system
bathroom 1
hose spigot
kitchen
dishwasher
incoming cold water from supply line
utility water meter
pressure regulator
thermal expansion tank
hot water heater
laundry
bathroom 2

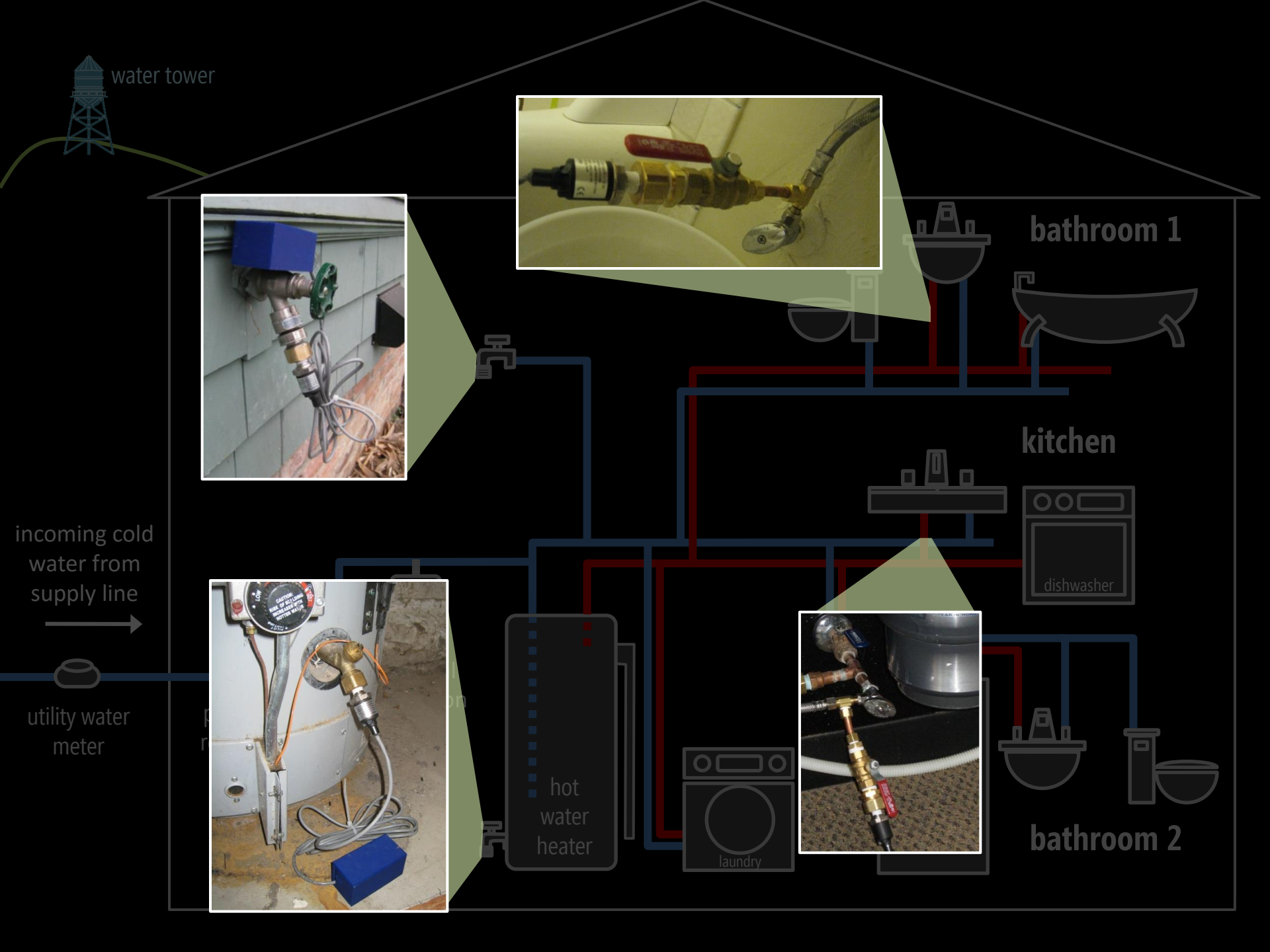

water tower
closed pressure system
bathroom 1
kitchen
dishwasher
incoming cold water from supply line
utility water meter
pressure regulator
thermal expansion tank
hot water heater
laundry
bathroom 2


water tower
toilet flushed
bathroom 1
toilet
kitchen
dishwasher
incoming cold water from supply line
utility water meter
pressure regulator
thermal expansion tank
hot water heater
laundry
bathroom 2

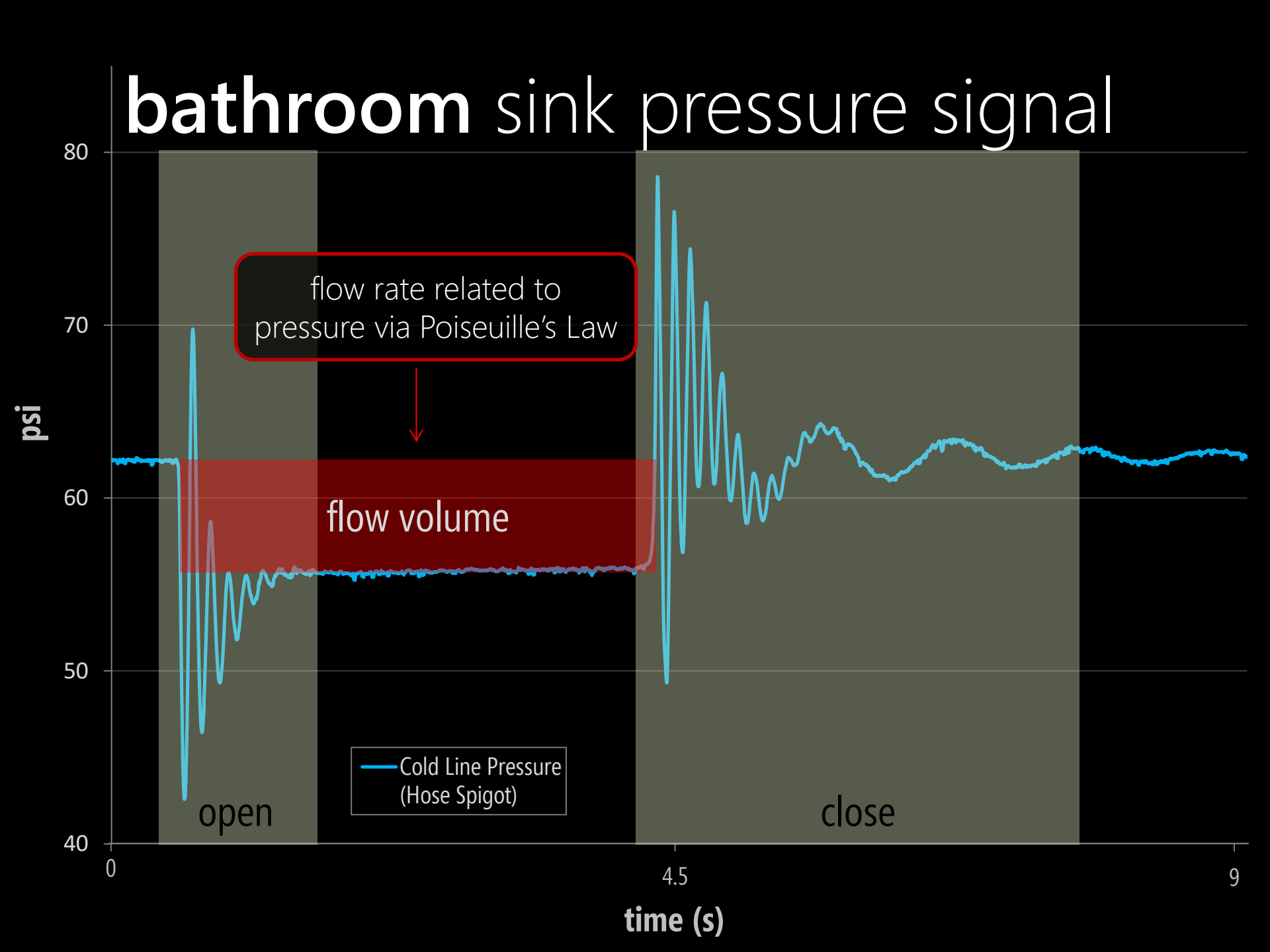

toilet
kitchen sink cold
bathroom 1
kitchen sink cold open
kitchen
dishwasher
incoming cold water from supply line
utility water meter
pressure regulator
thermal expansion tank
hot water heater
laundry
bathroom 2

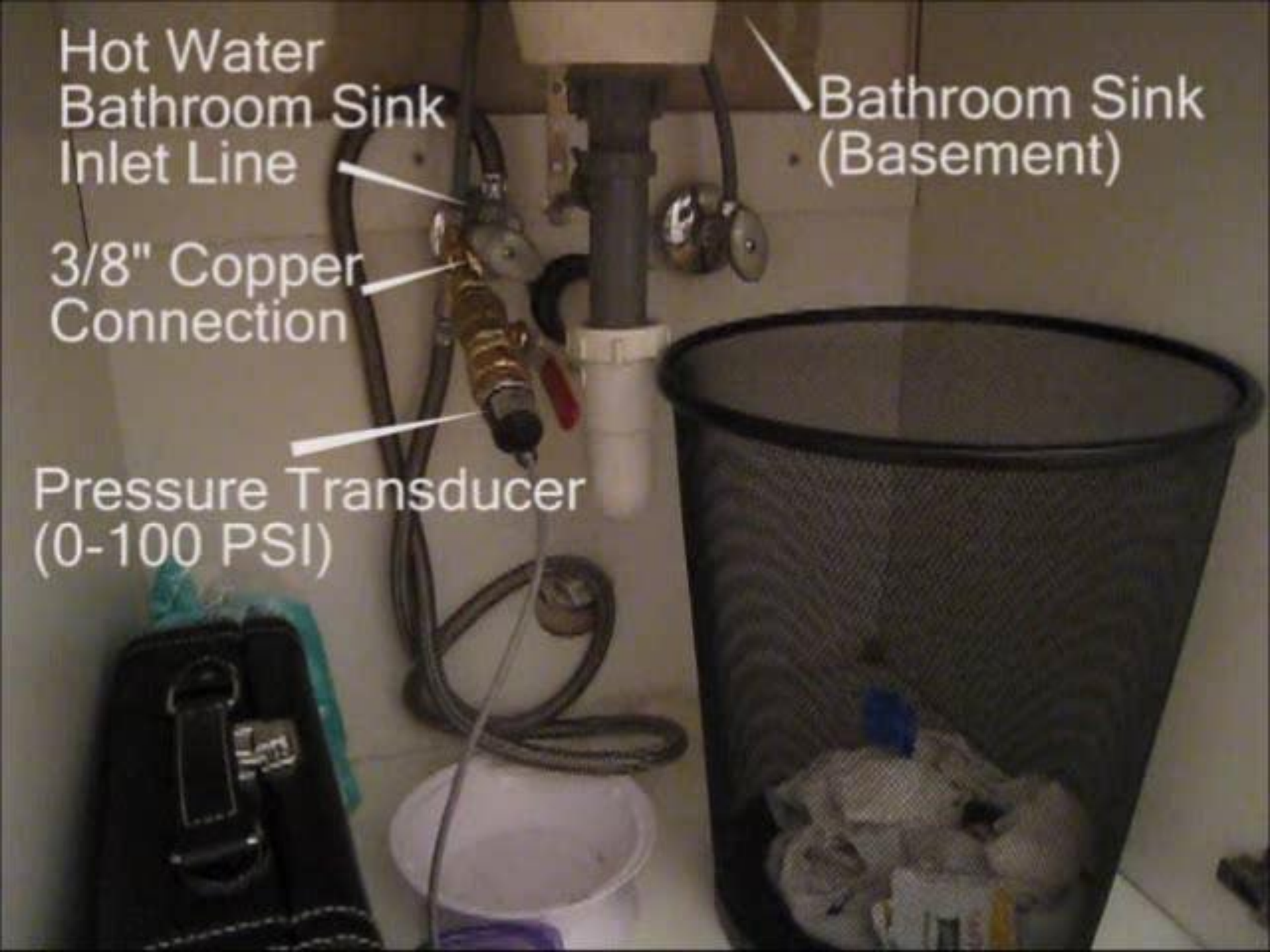

toilet
kitchen sink cold
kitchen sink hot
bathroom 1
kitchen sink hot open
kitchen
dishwasher
incoming cold water from supply line
utility water meter
pressure regulator
thermal expansion tank
hot water heater
laundry
bathroom 2


water tower
kitchen sink hot
kitchen sink hot open
bathroom 1
kitchen
dishwasher
incoming cold water from supply line
utility water meter
pressure regulator
thermal expansion tank
hot water heater
laundry
bathroom 2

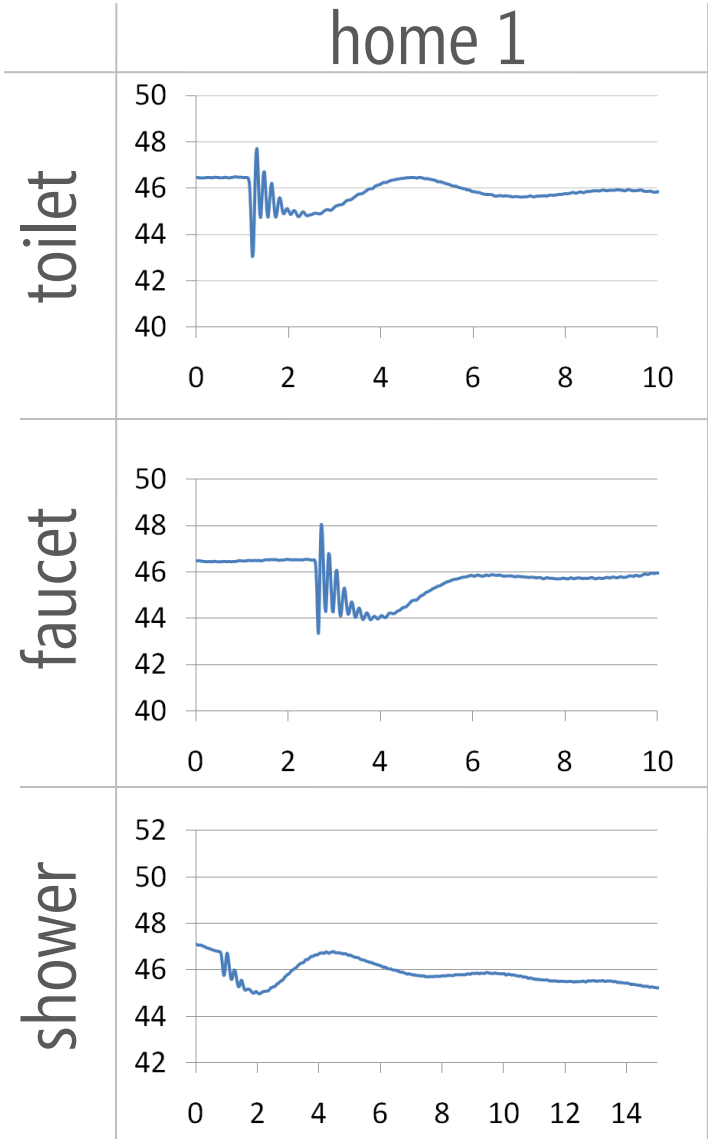

water tower
bathroom 1
kitchen
dishwasher
incoming cold water from supply line
utility water meter
hot water heater
laundry
bathroom 2


bathroom sink pressure signal
80
70
60
50
40
psi
0
4.5
9
time (s)


bathroom sink pressure signal
80
70
60
50
40
psi
flow rate related to
pressure via Poiseuille's Law
flow volume
Cold Line Pressure
(Hose Spigot)
open
close
0
4.5
9
time (s)

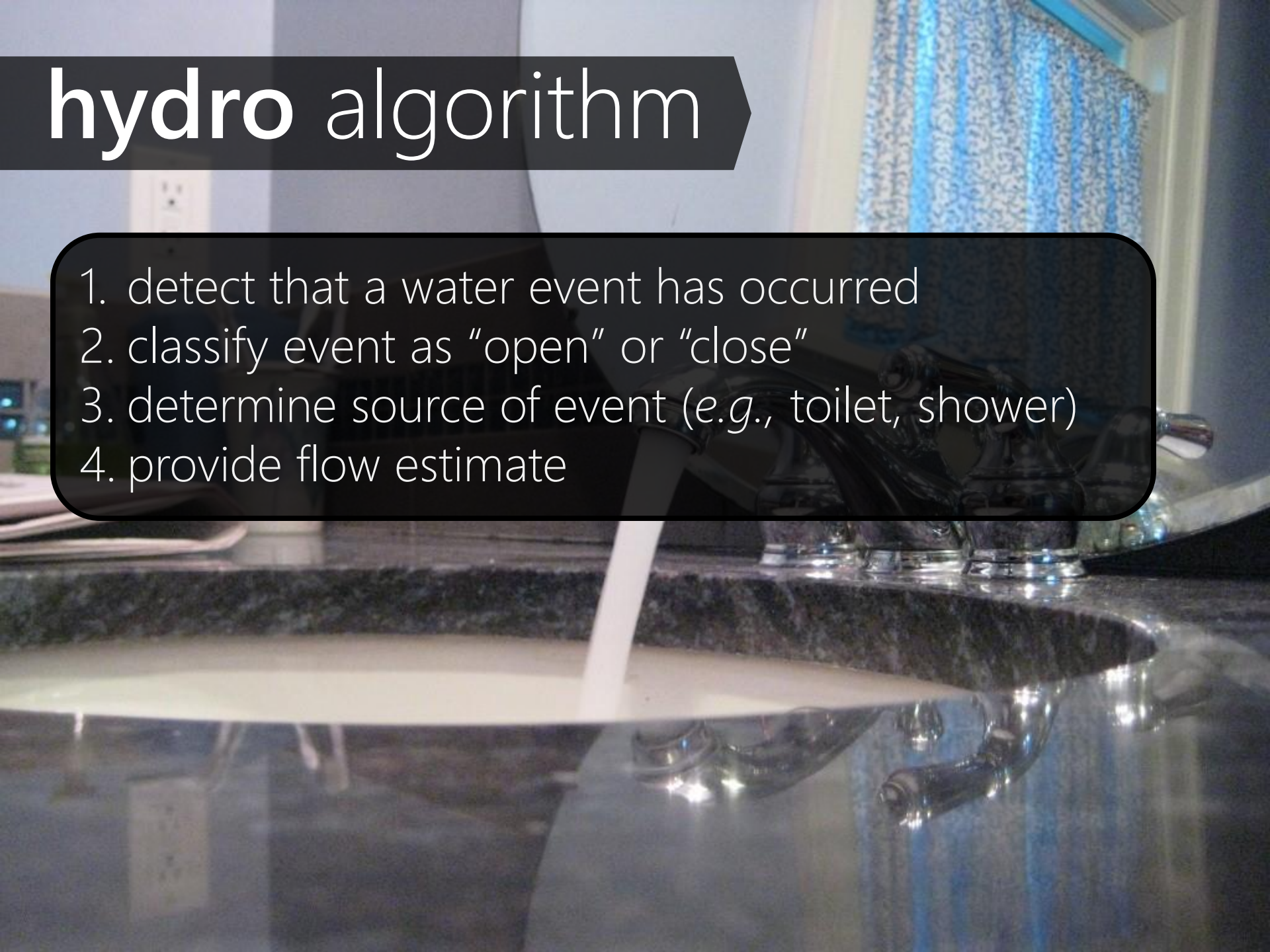

Hot Water
Bathroom Sink
Inlet Line
Bathroom Sink
(Basement)
3/8" Copper
Connection
Pressure Transducer
(0-100 PSI)

example open events



signature dependent on:

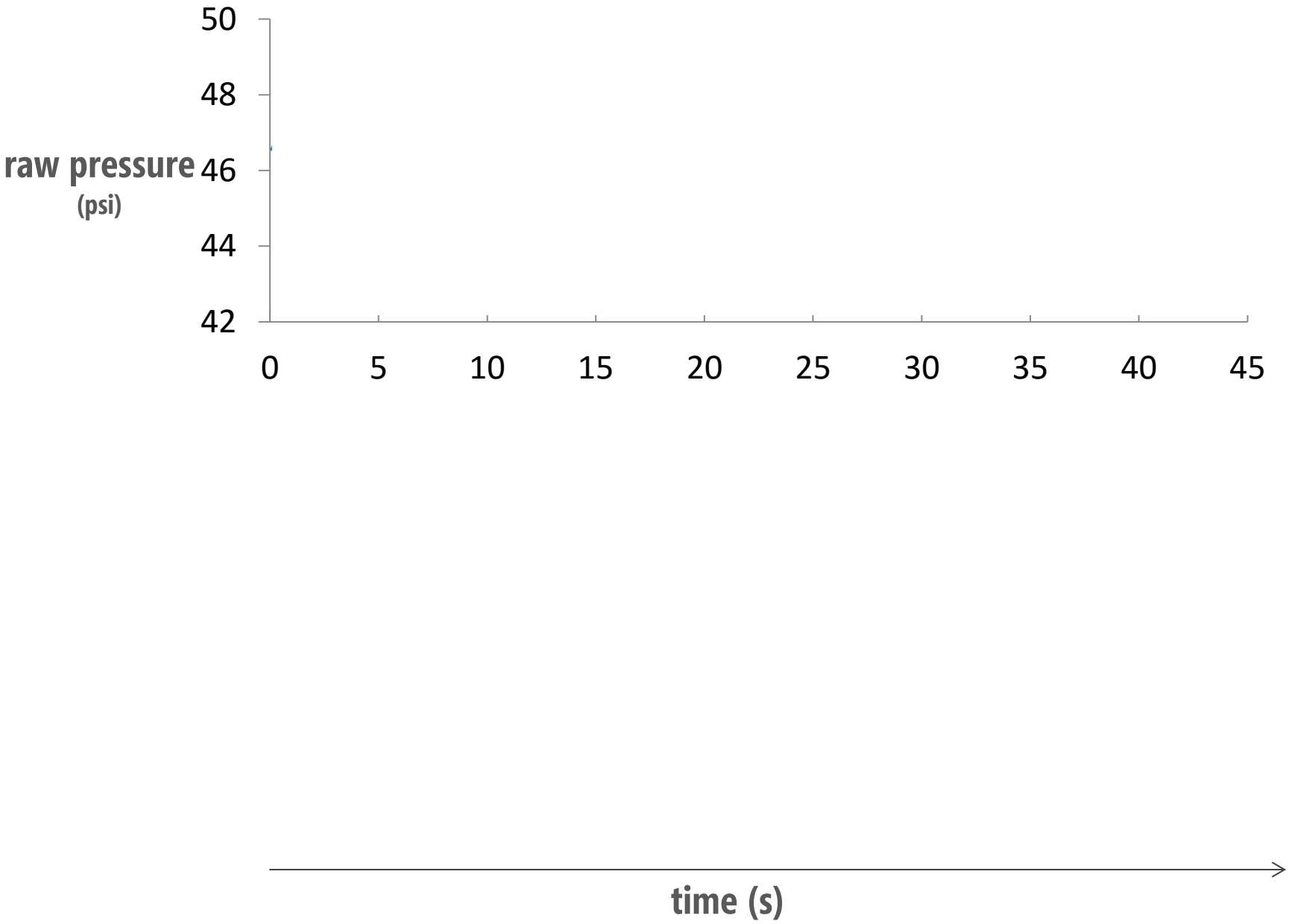
- fixture type
- valve type
- valve location in home



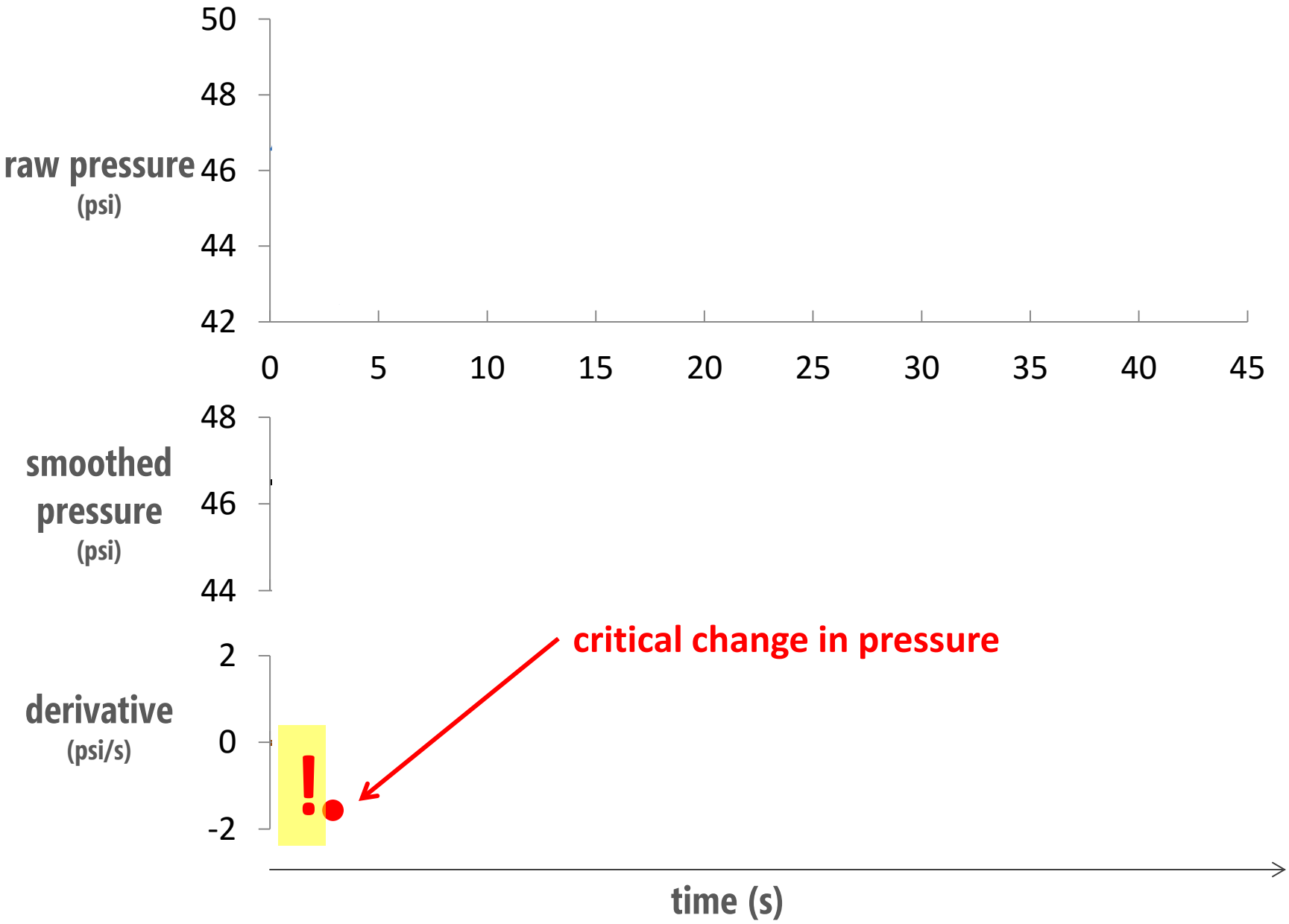
hydro algorithm

1. detect that a water event has occurred
2. classify event as “open” or “close”
3. determine source of event (*e.g.*, toilet, shower)
4. provide flow estimate

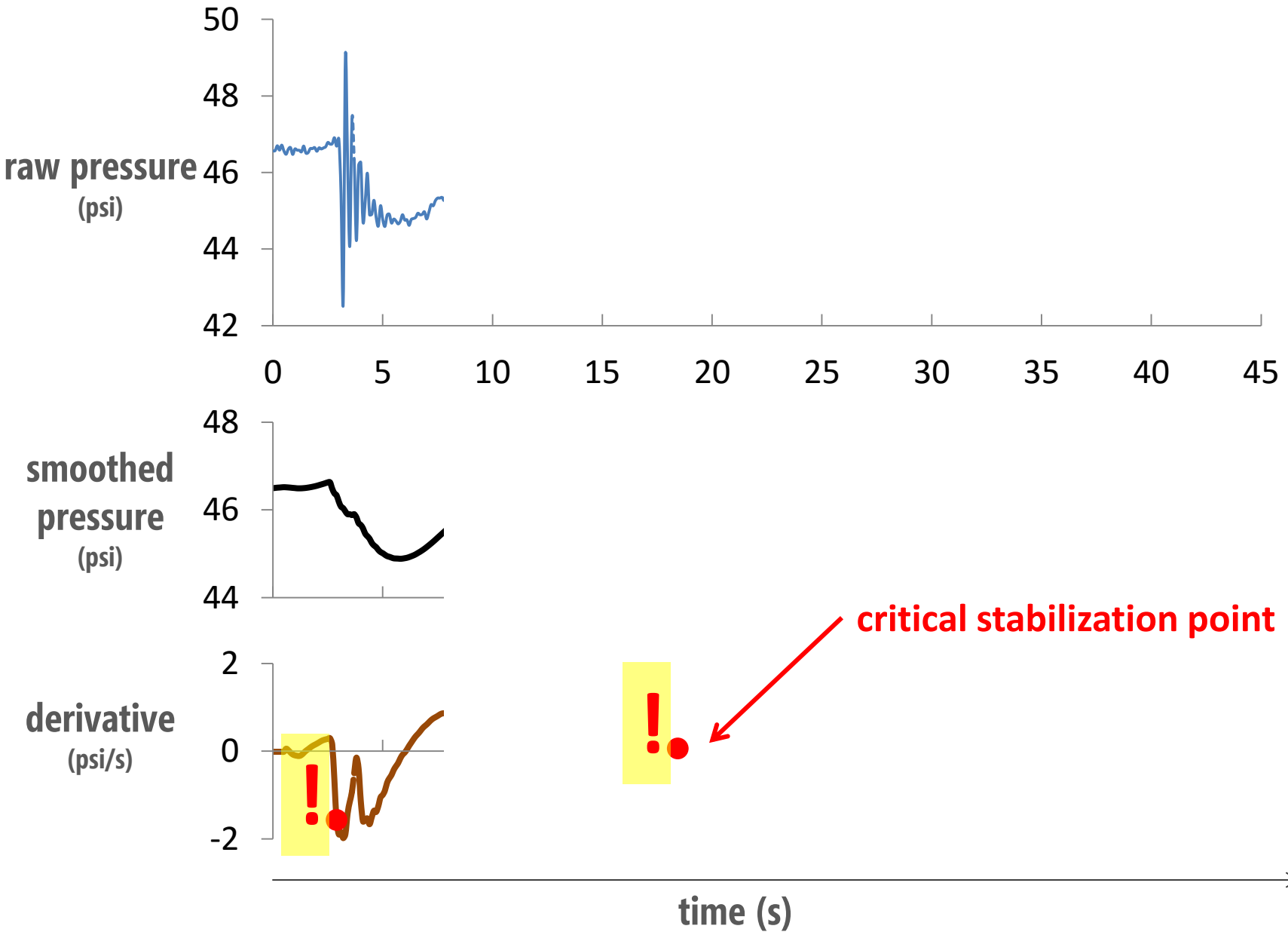
event detection/segmentation



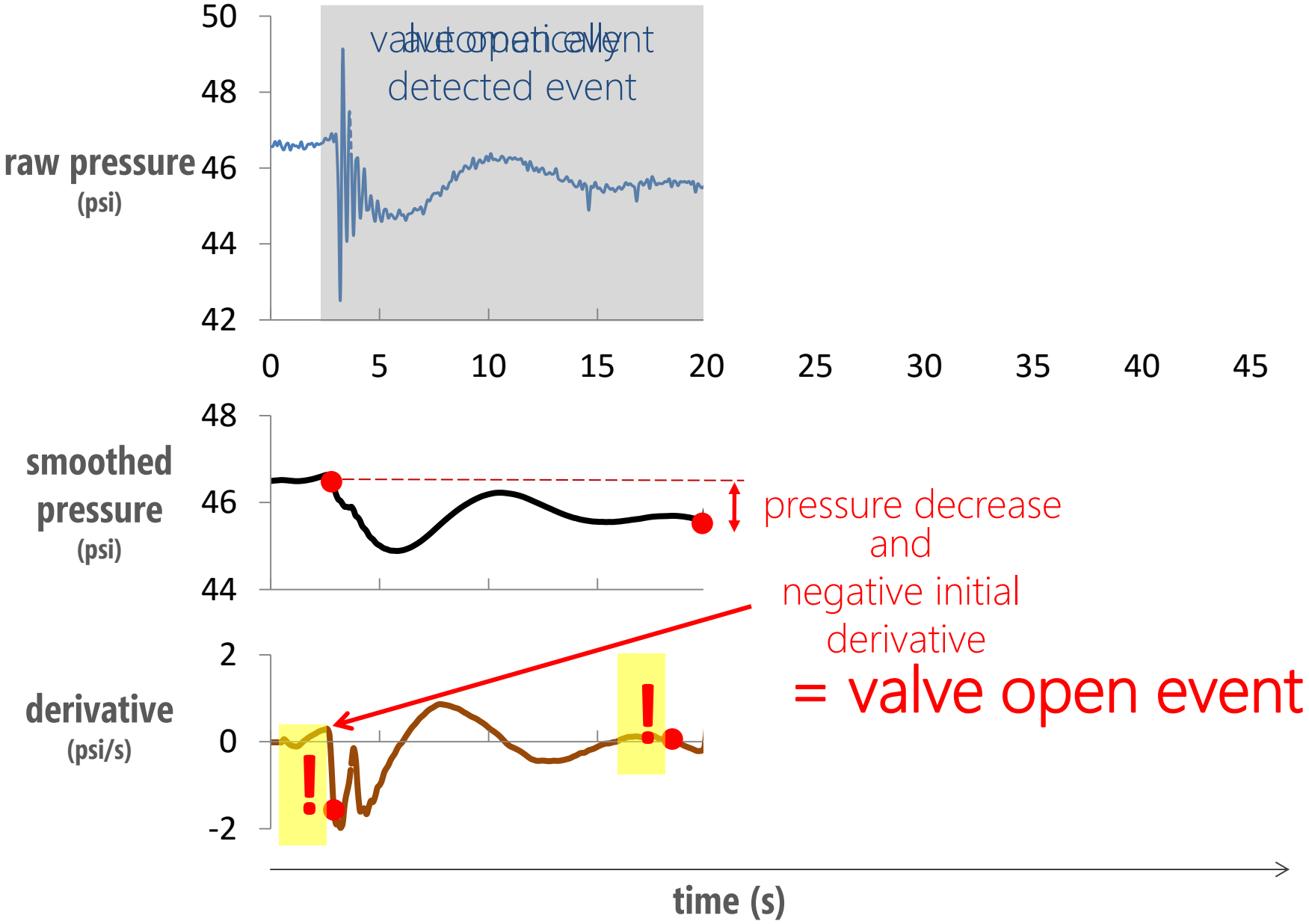
event detection/segmentation



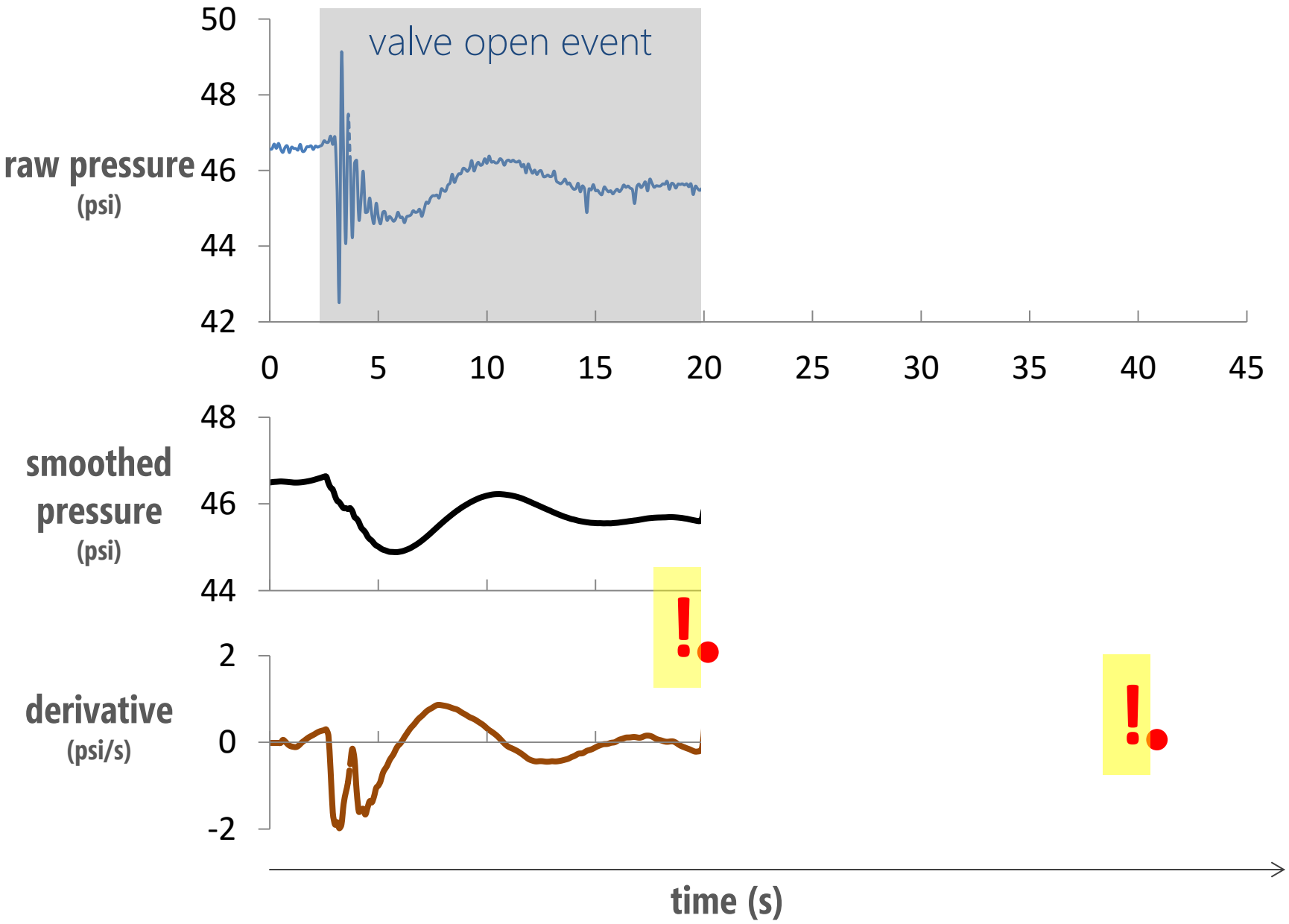
event detection/segmentation



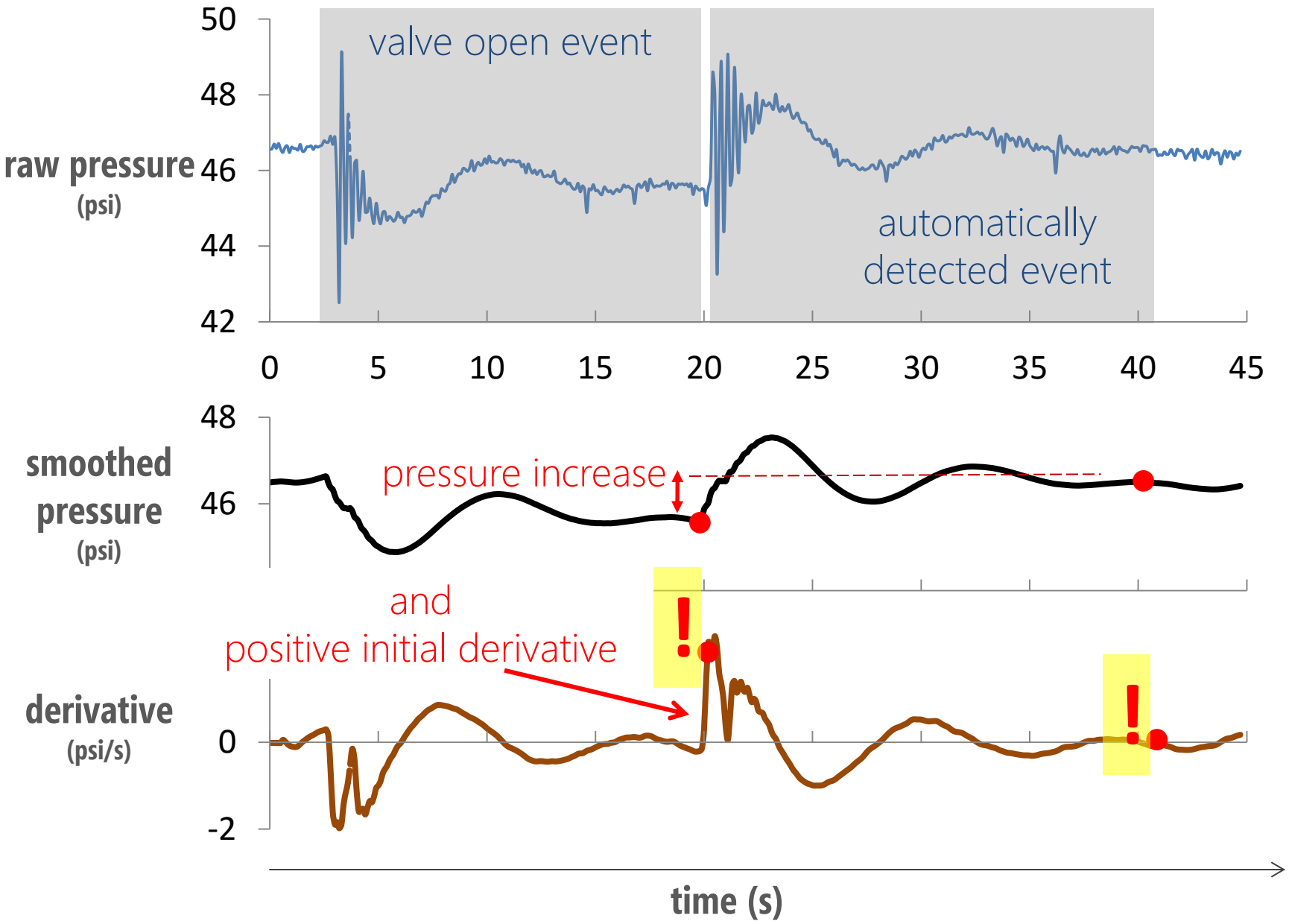
event detection/segmentation



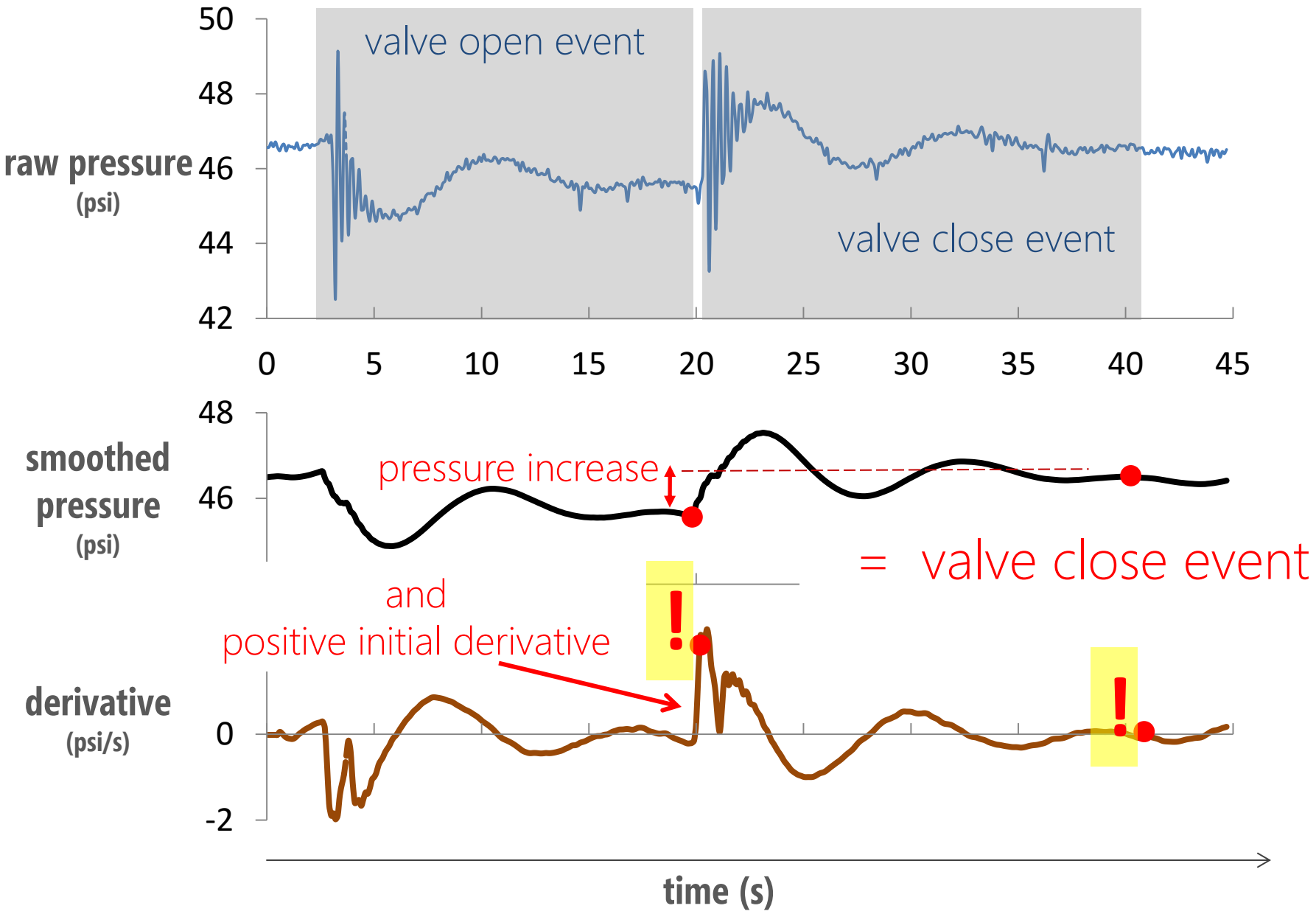
event detection/segmentation



event detection/segmentation

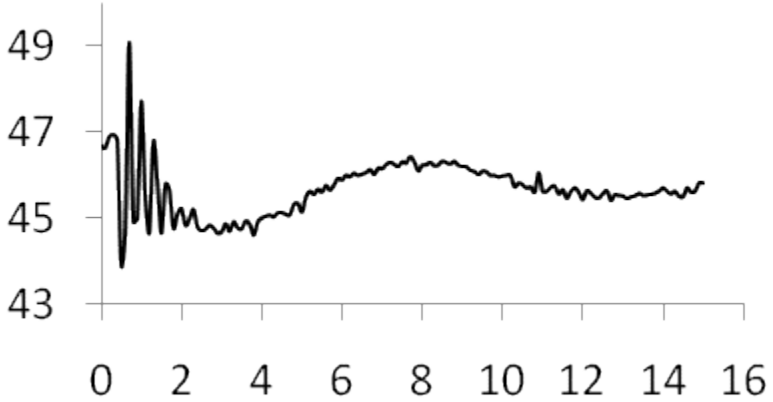


event detection/segmentation

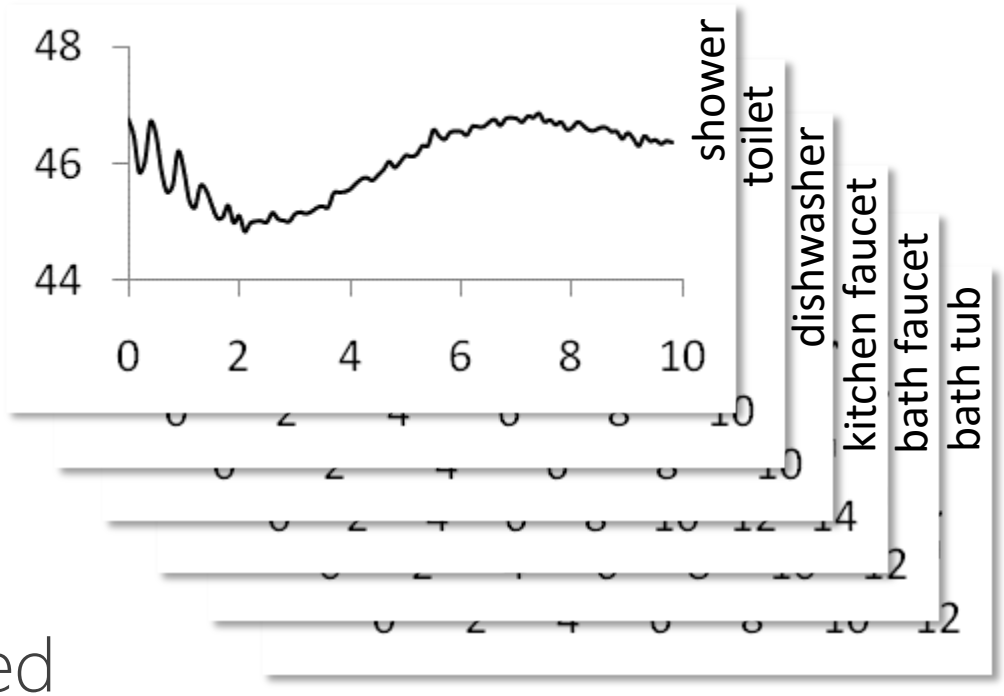


fixture classification

unclassified open event

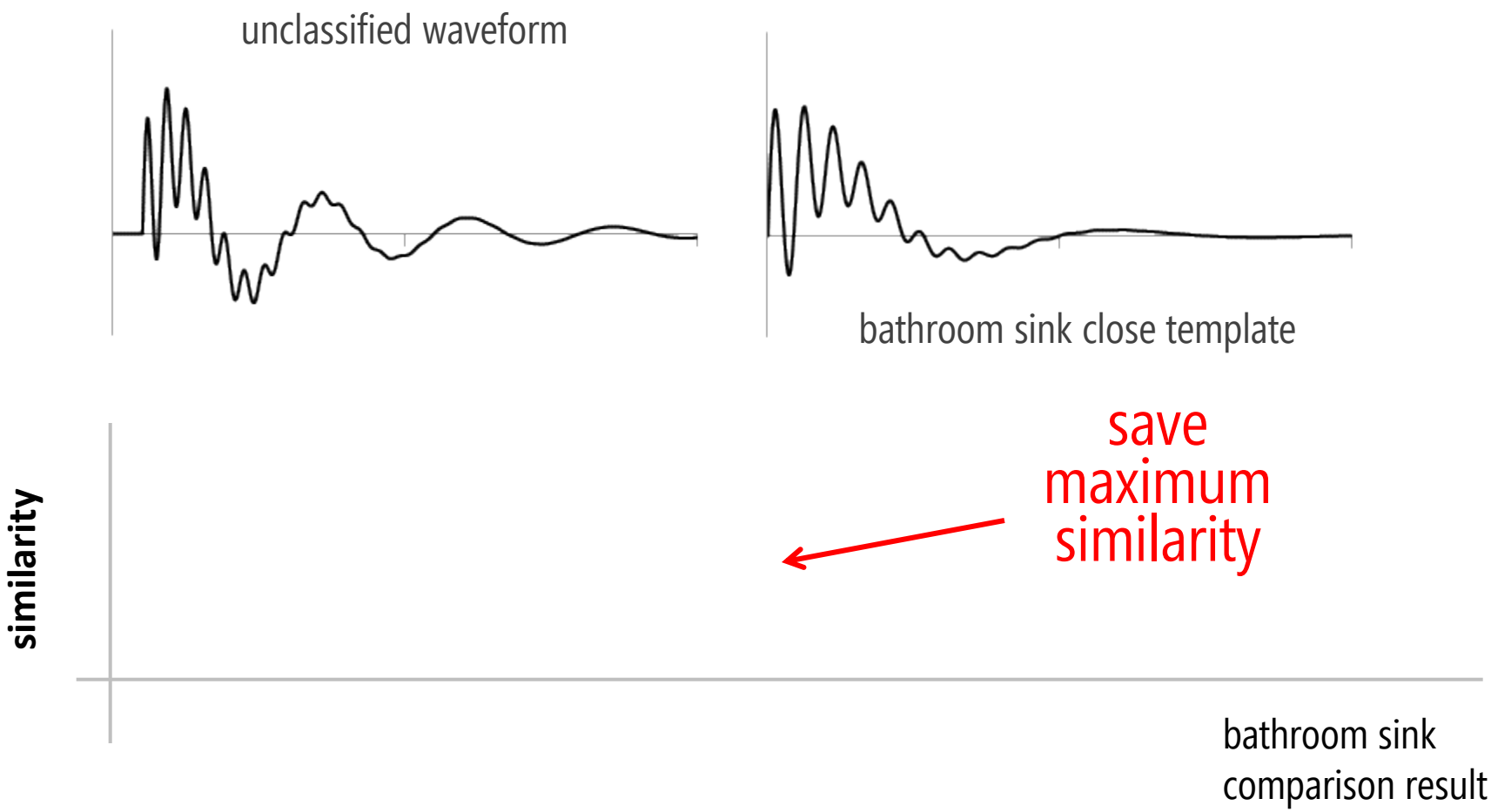


open event library

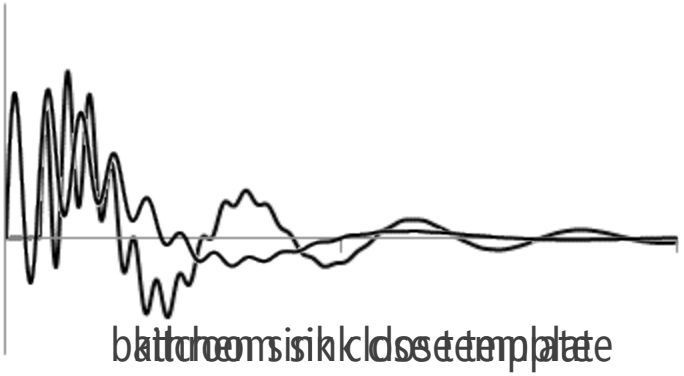


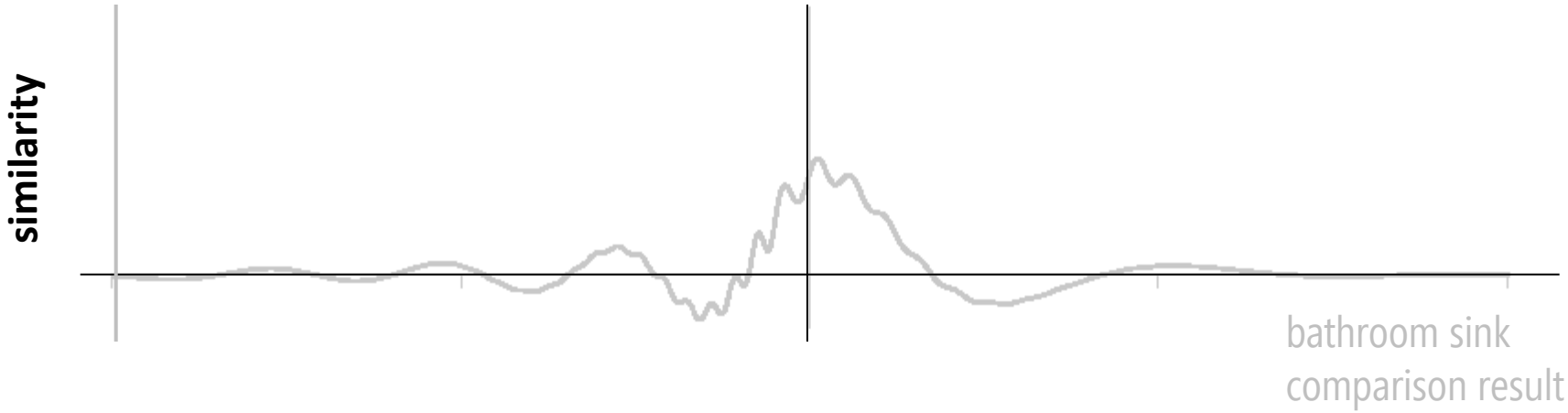
compare via matched filtering across multiple signal transformations

matched filtering

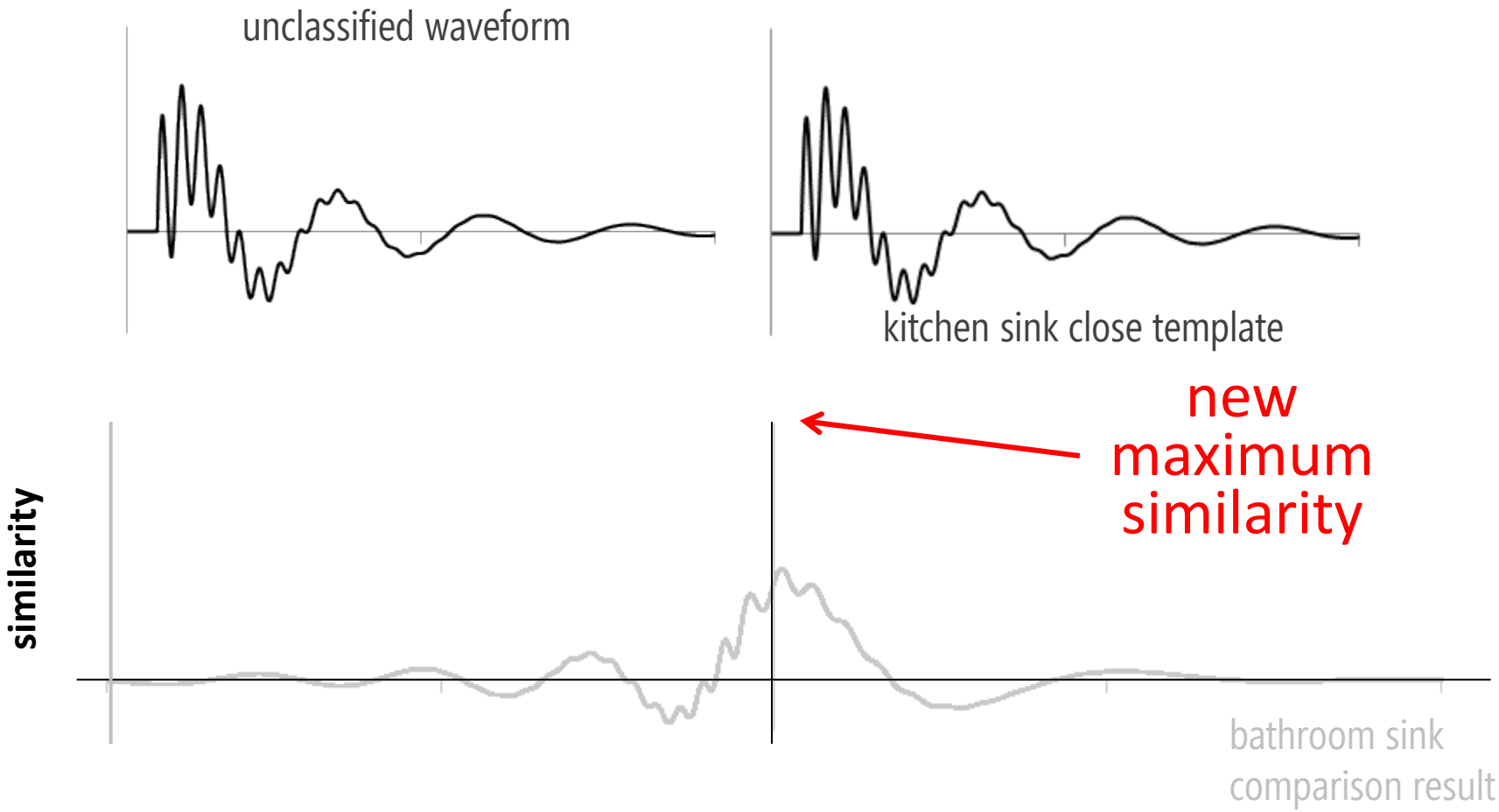


matched filtering

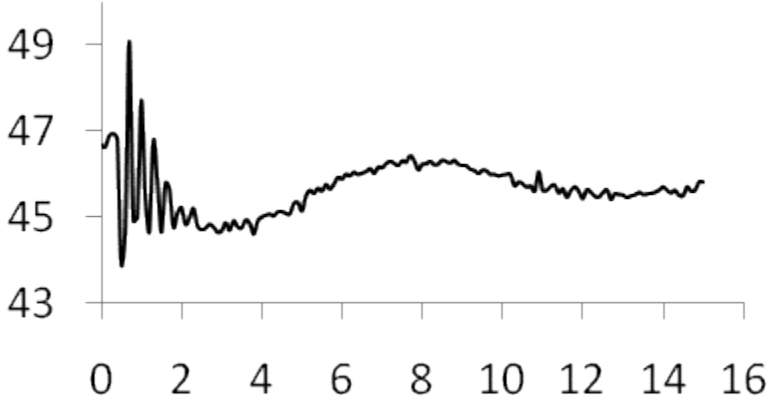




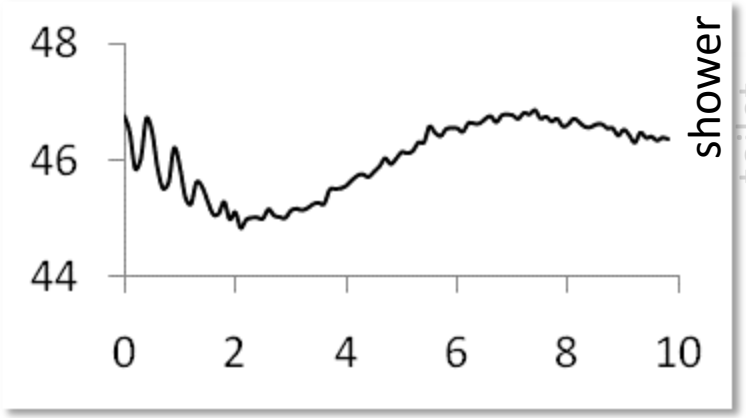
matched filtering



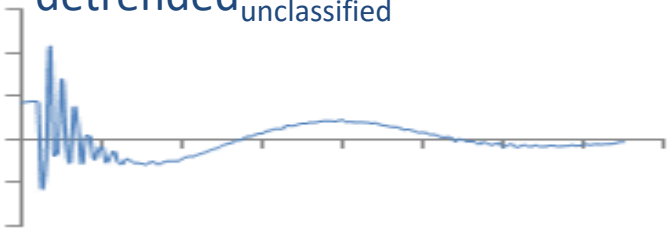
unclassified open event



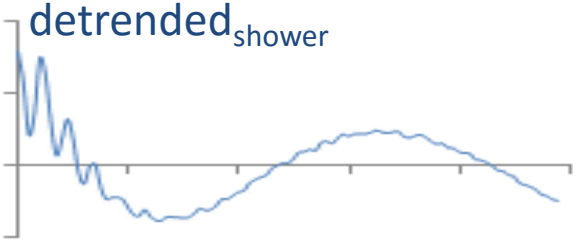
open event library



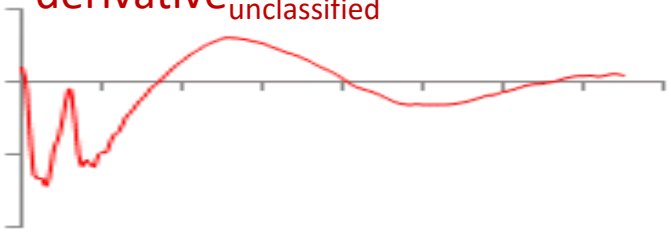
detrended$_{unclassified}$



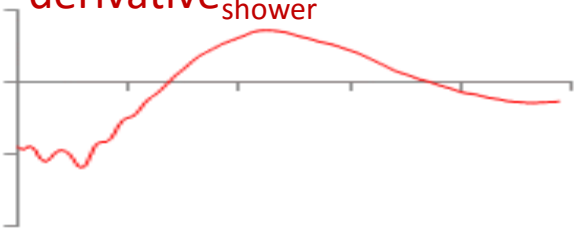
detrended$_{shower}$



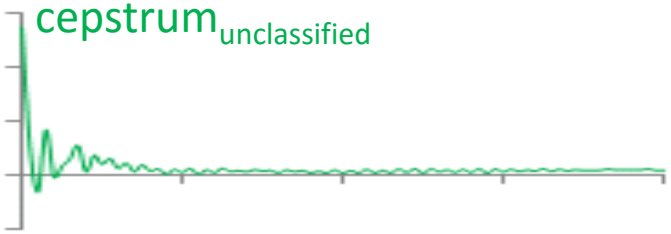
derivative$_{unclassified}$



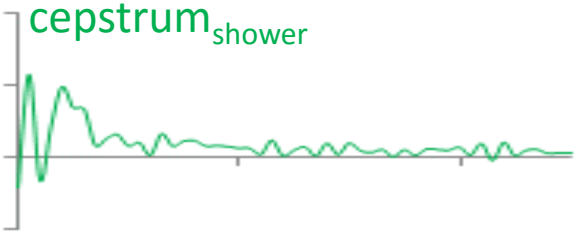
derivative$_{shower}$

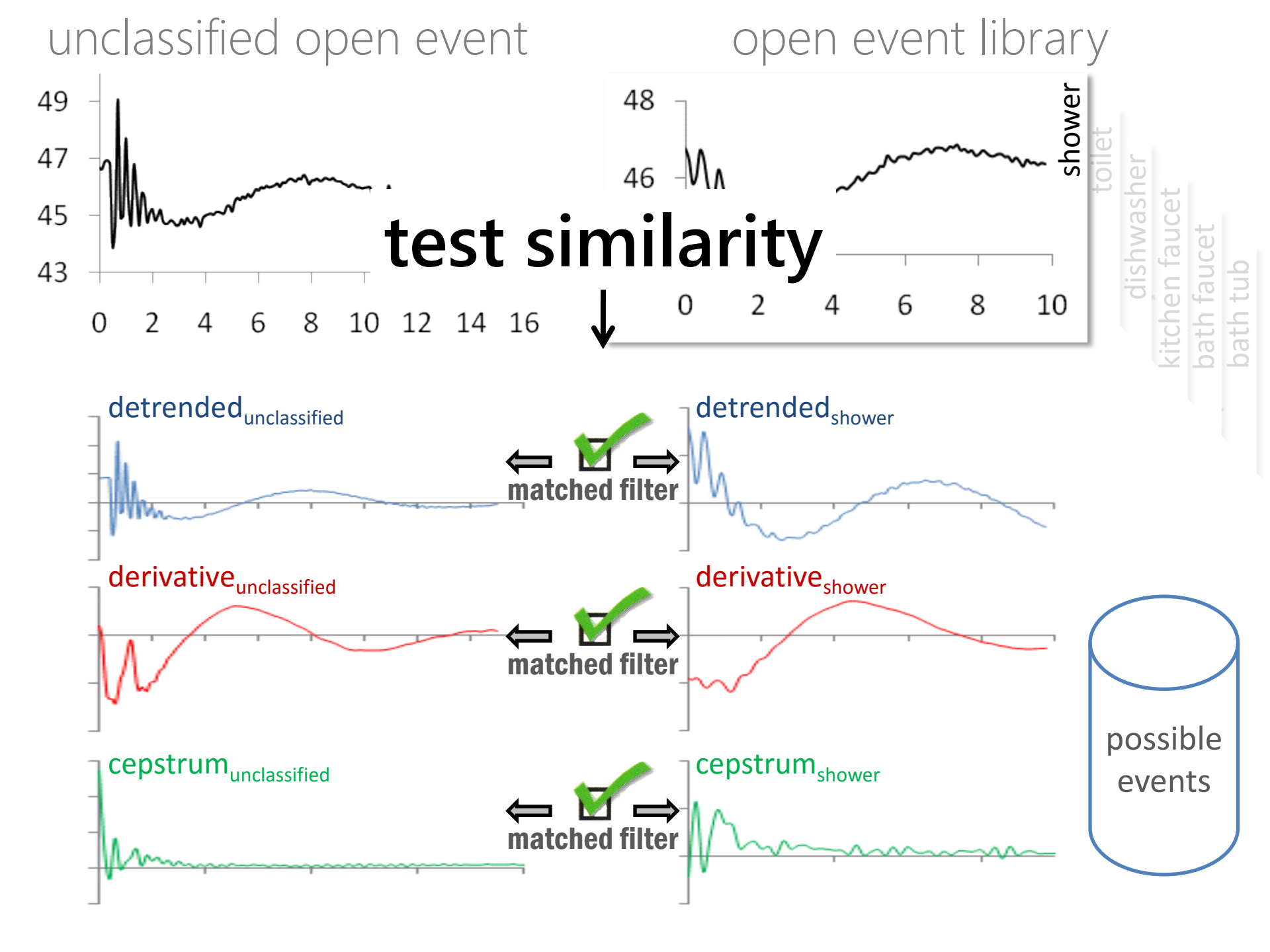


cepstrum$_{unclassified}$

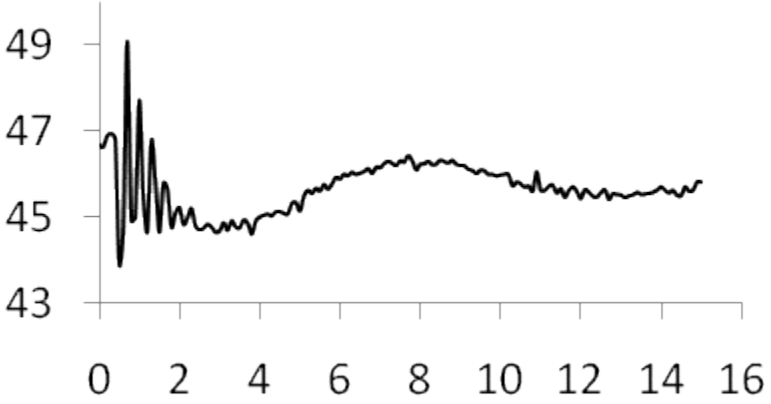


cepstrum$_{shower}$

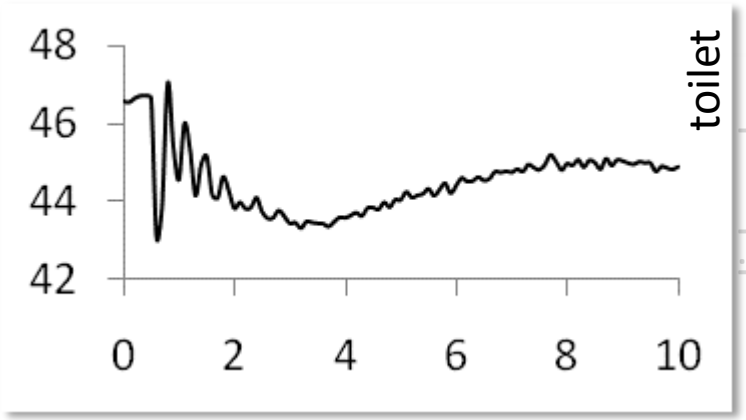


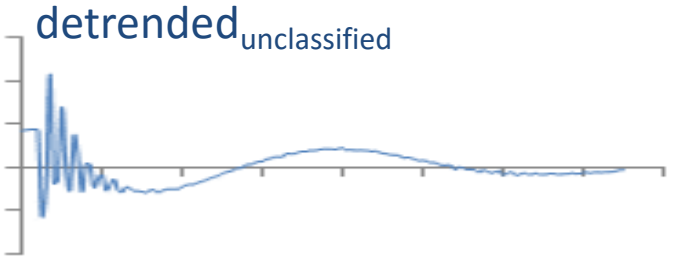

unclassified open event
open event library
49
47
45
43
0 2 4 6 8 10 12 14 16
48
46
shower
toilet
dishwasher
kitchen faucet
bath faucet
bath tub
0 2 4 6 8 10
test similarity
detrended unclassified
detrended shower
matched filter
derivative unclassified
derivative shower
matched filter
cepstrum unclassified
cepstrum shower
matched filter
possible events

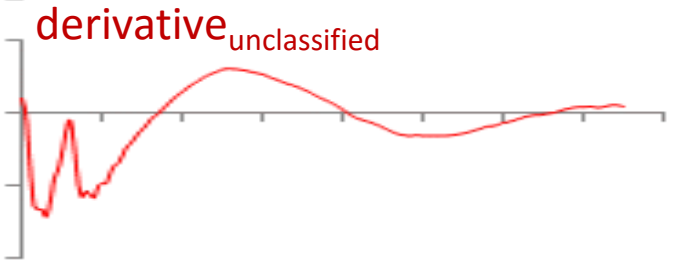
unclassified open event

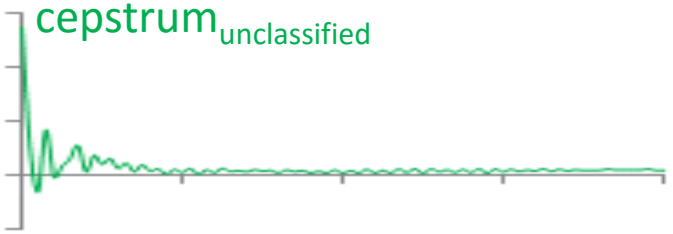


open event library

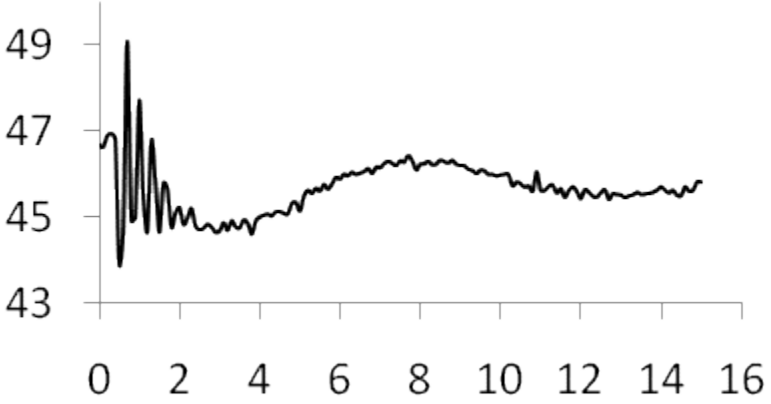




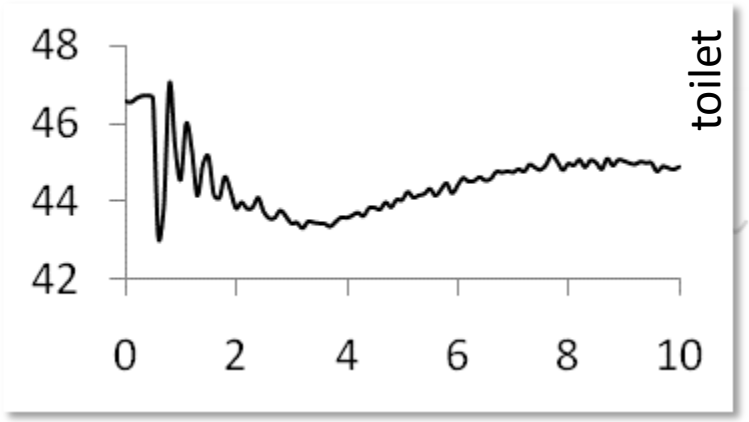




unclassified open event

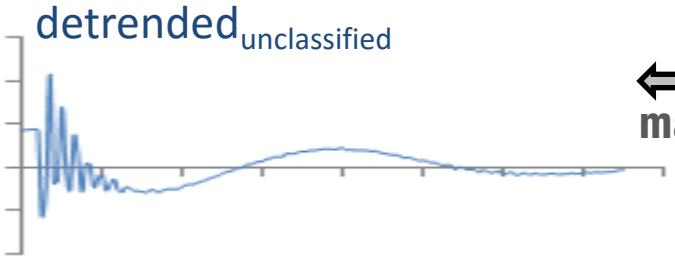


open event library



dishwasher
kitchen faucet
bath faucet
bath tub

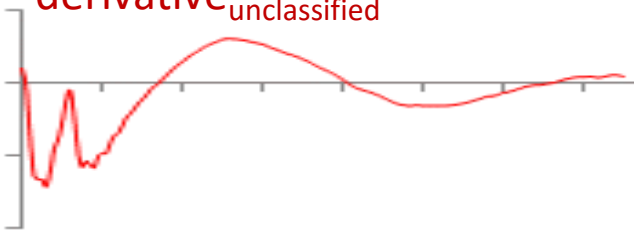
detrended$_{unclassified}$



matched filter

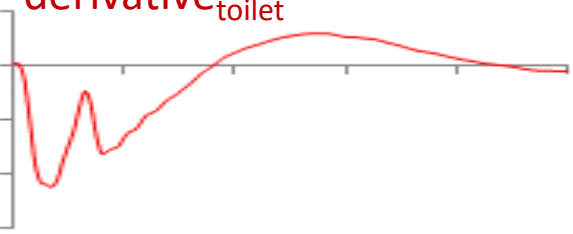
detrended$_{toilet}$

derivative$_{unclassified}$

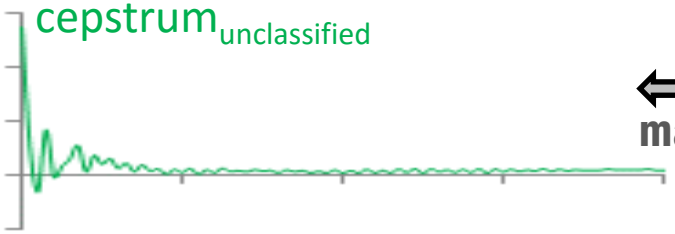


matched filter

derivative$_{toilet}$



cepstrum$_{unclassified}$

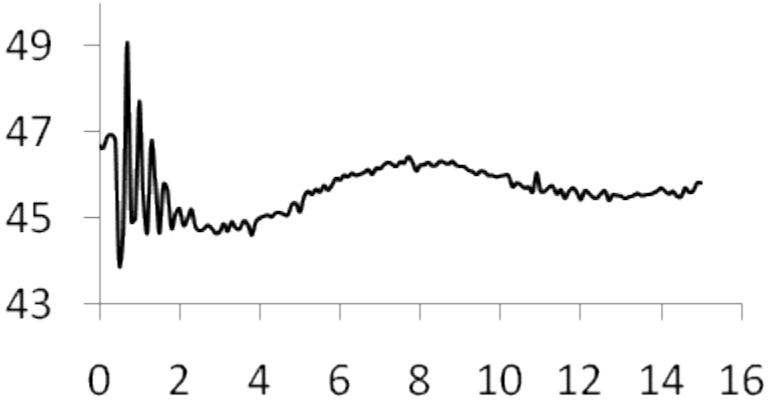


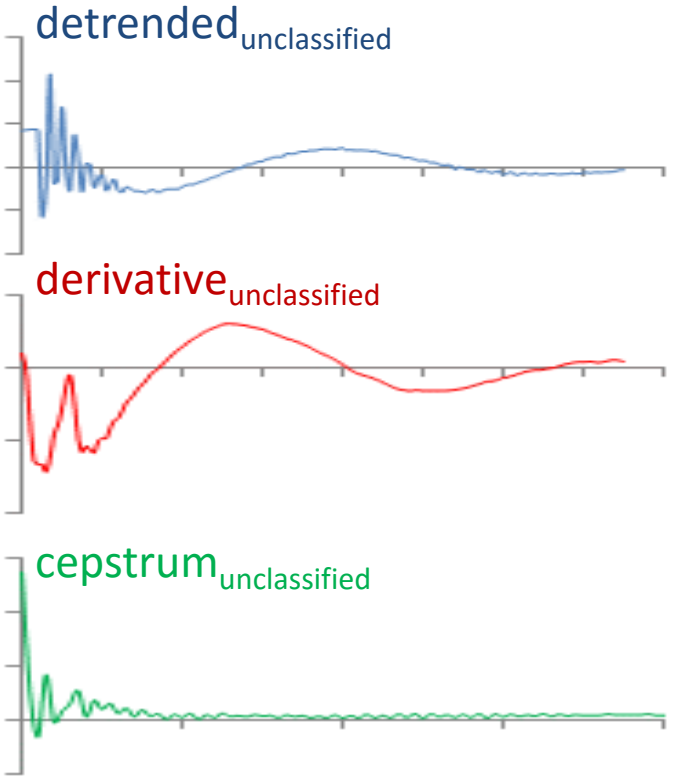
matched filter

cepstrum$_{toilet}$

possible events

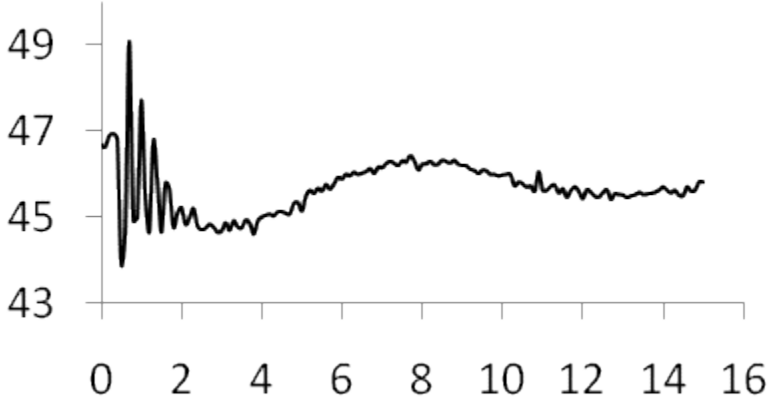
unclassified open event

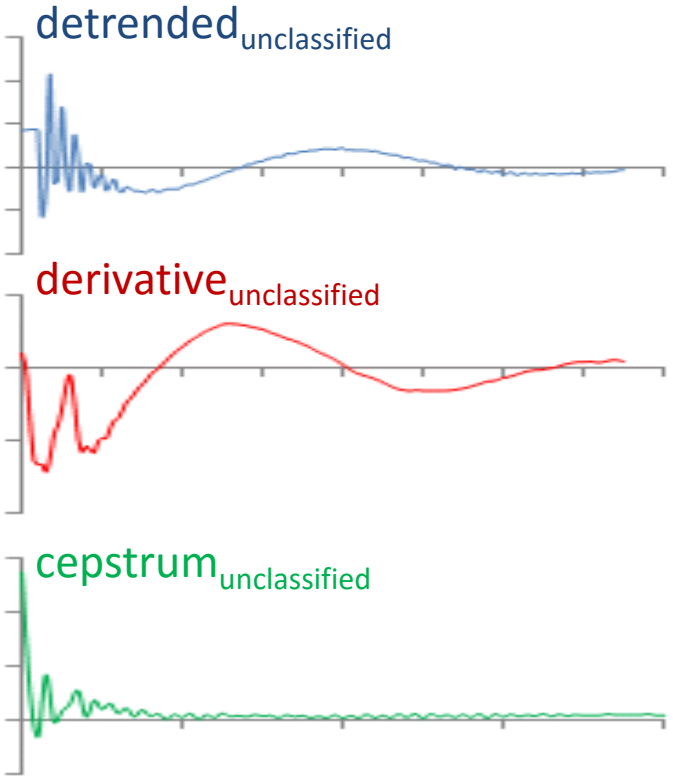




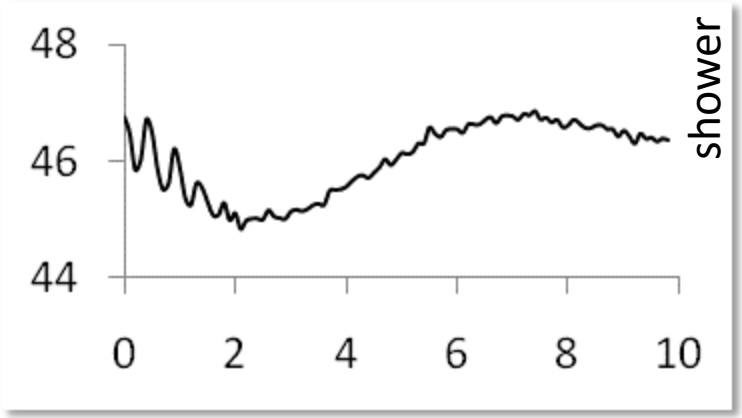
open event library

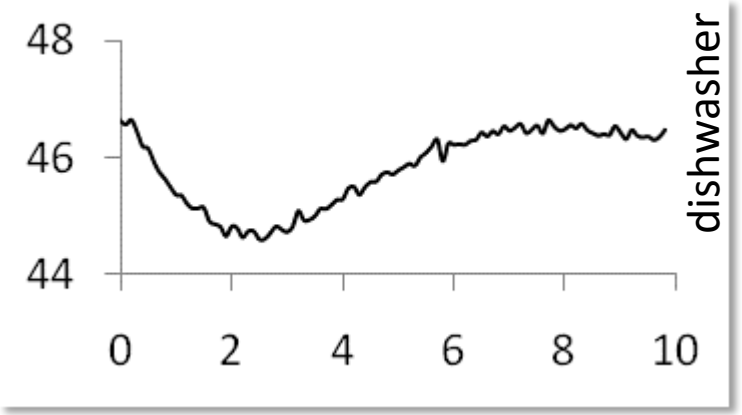
unclassified open event

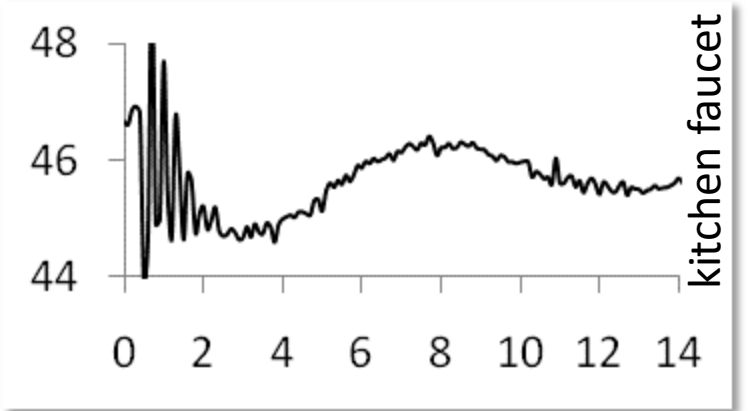




open event library

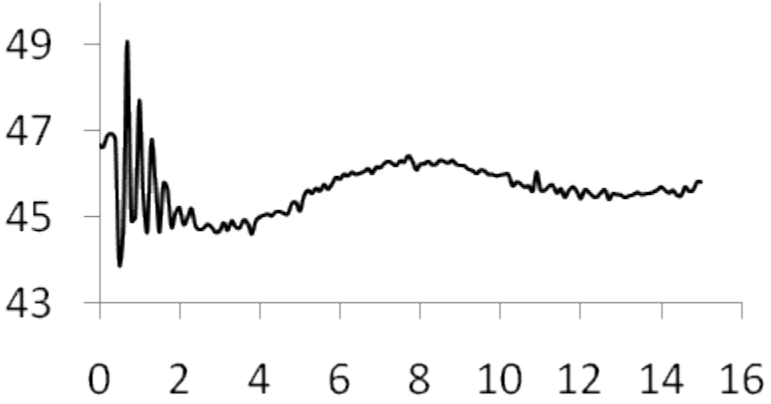


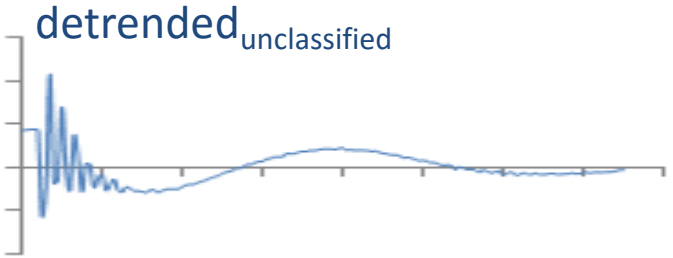


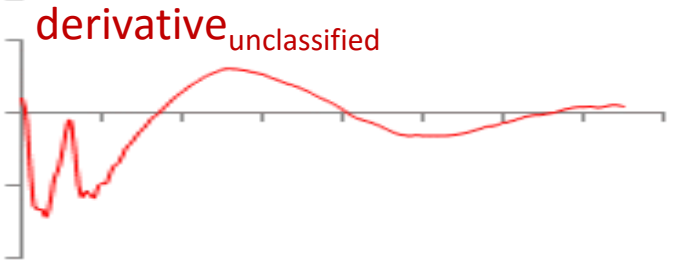


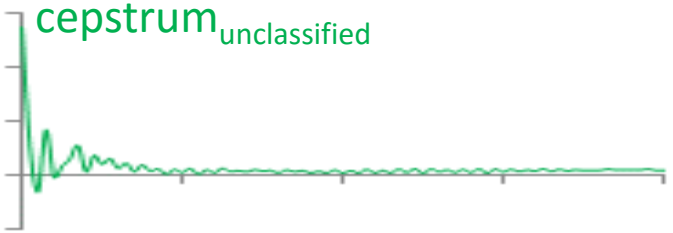
possible events

unclassified open event

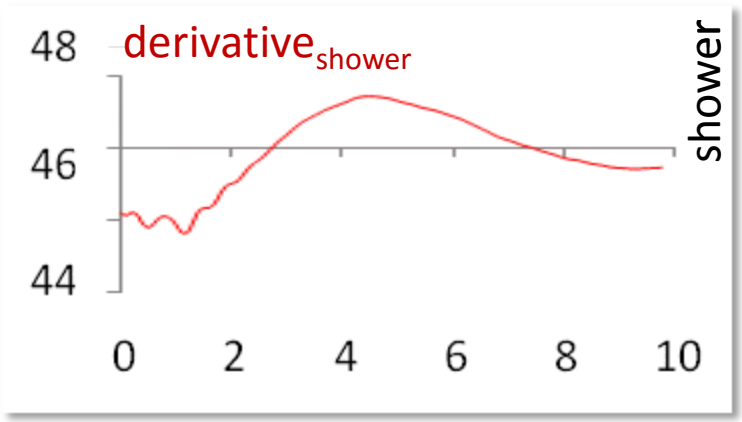


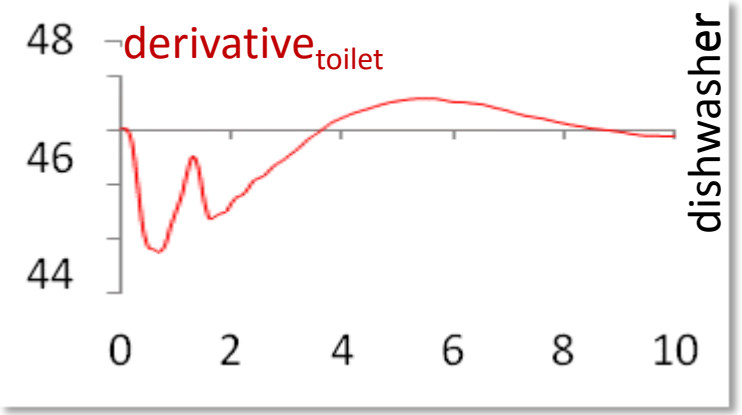


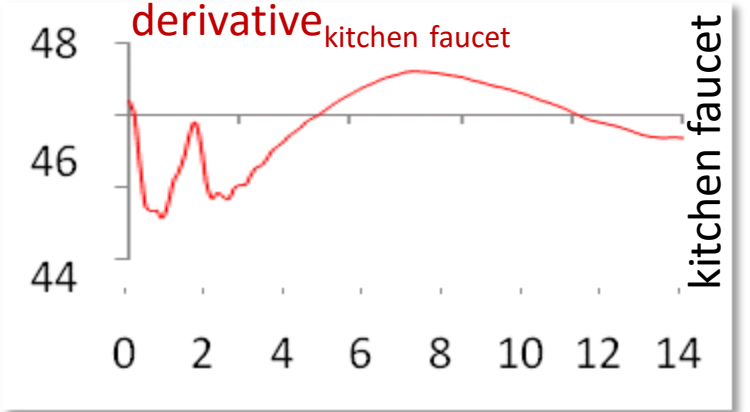




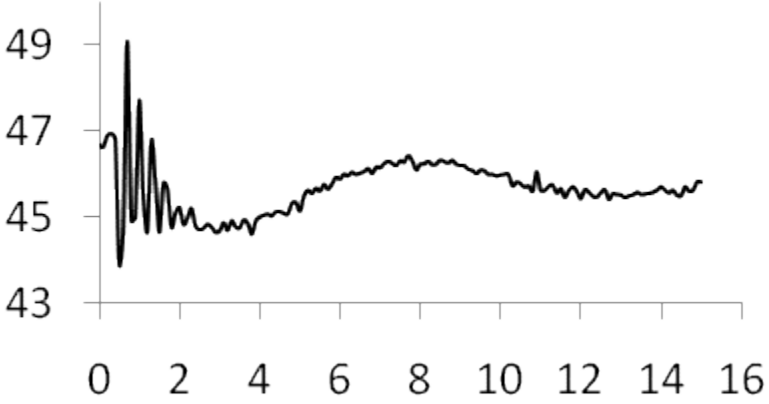
open event library



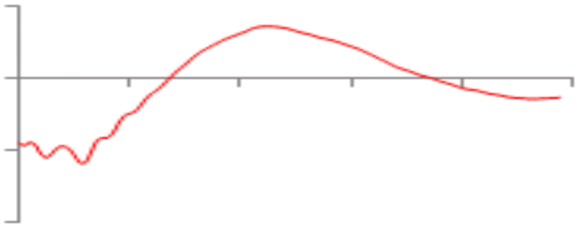




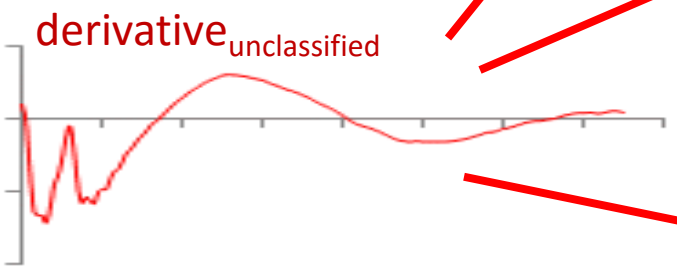
unclassified open event

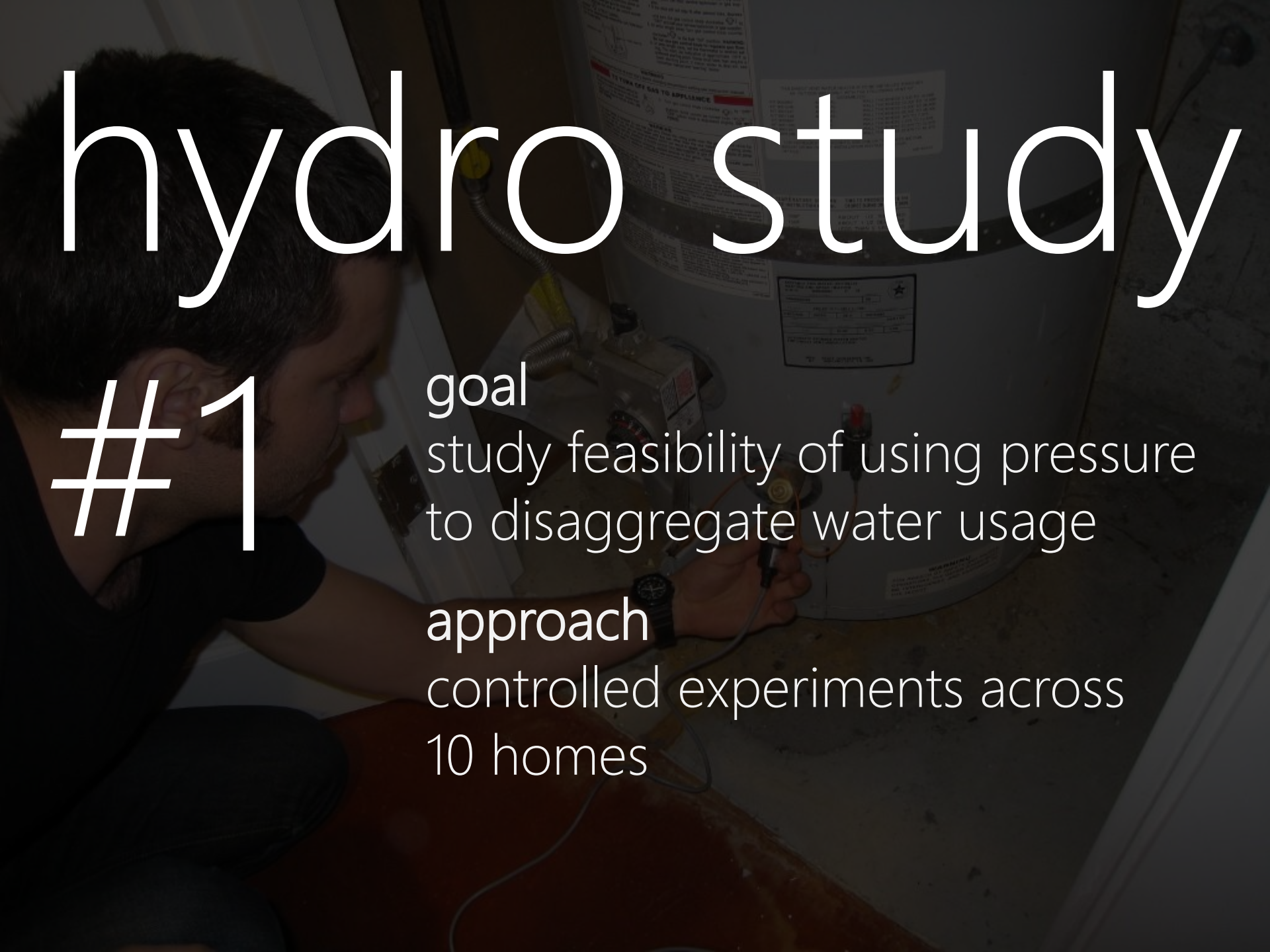


open event library



nearest neighbor match



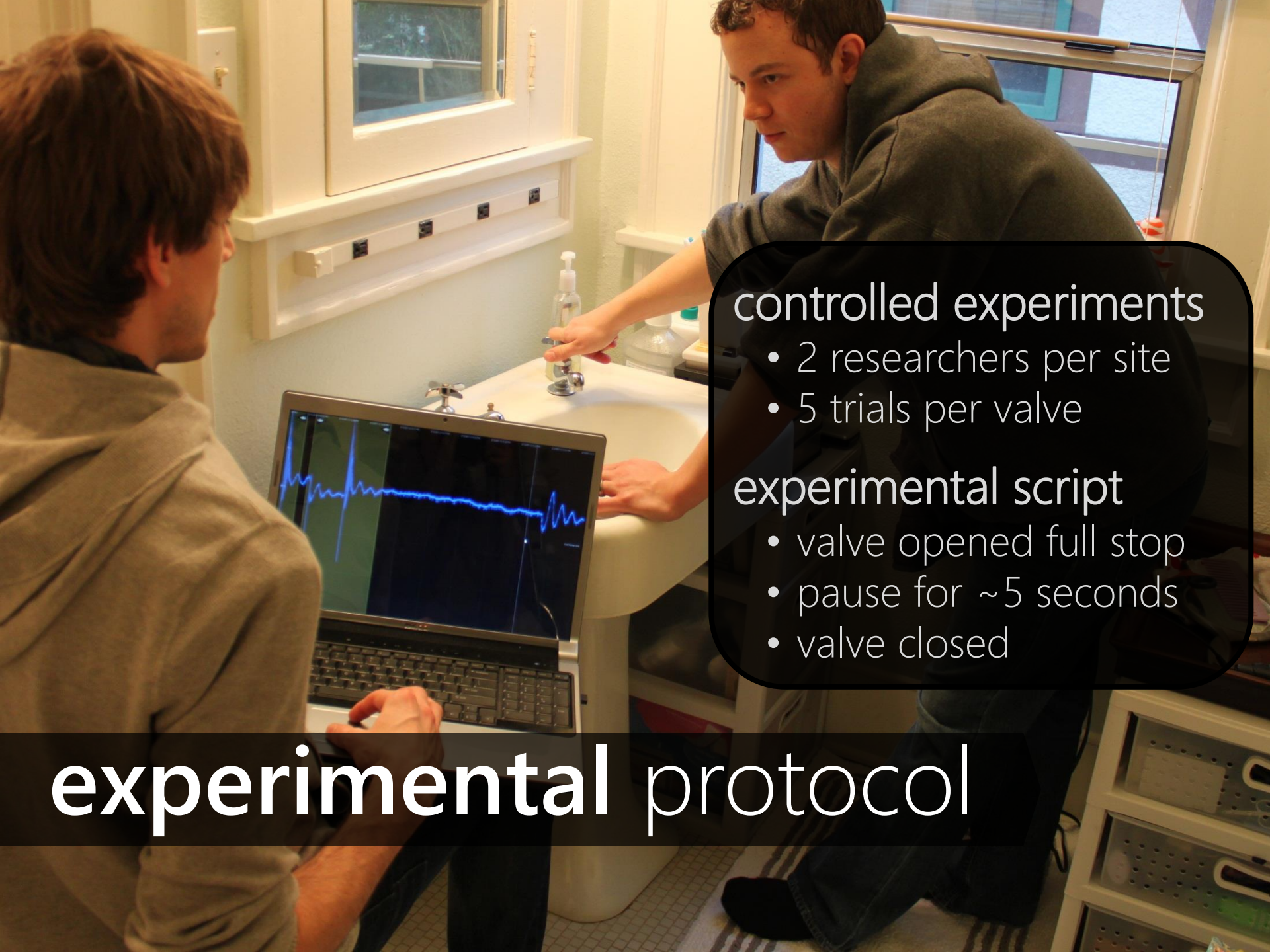


hydro study

#1

goal
study feasibility of using pressure to disaggregate water usage

approach
controlled experiments across 10 homes



controlled experiments

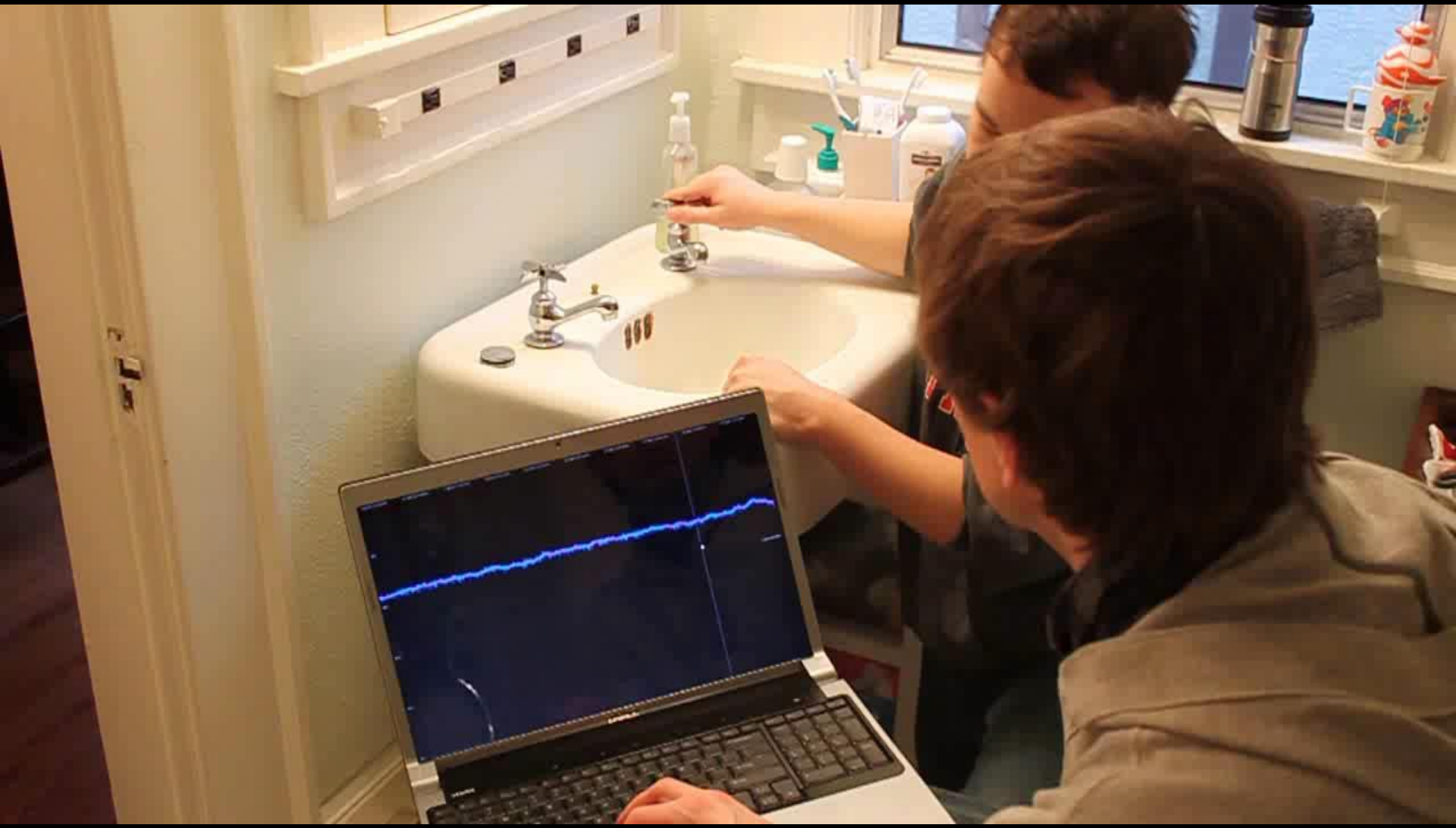
- 2 researchers per site
- 5 trials per valve

experimental script

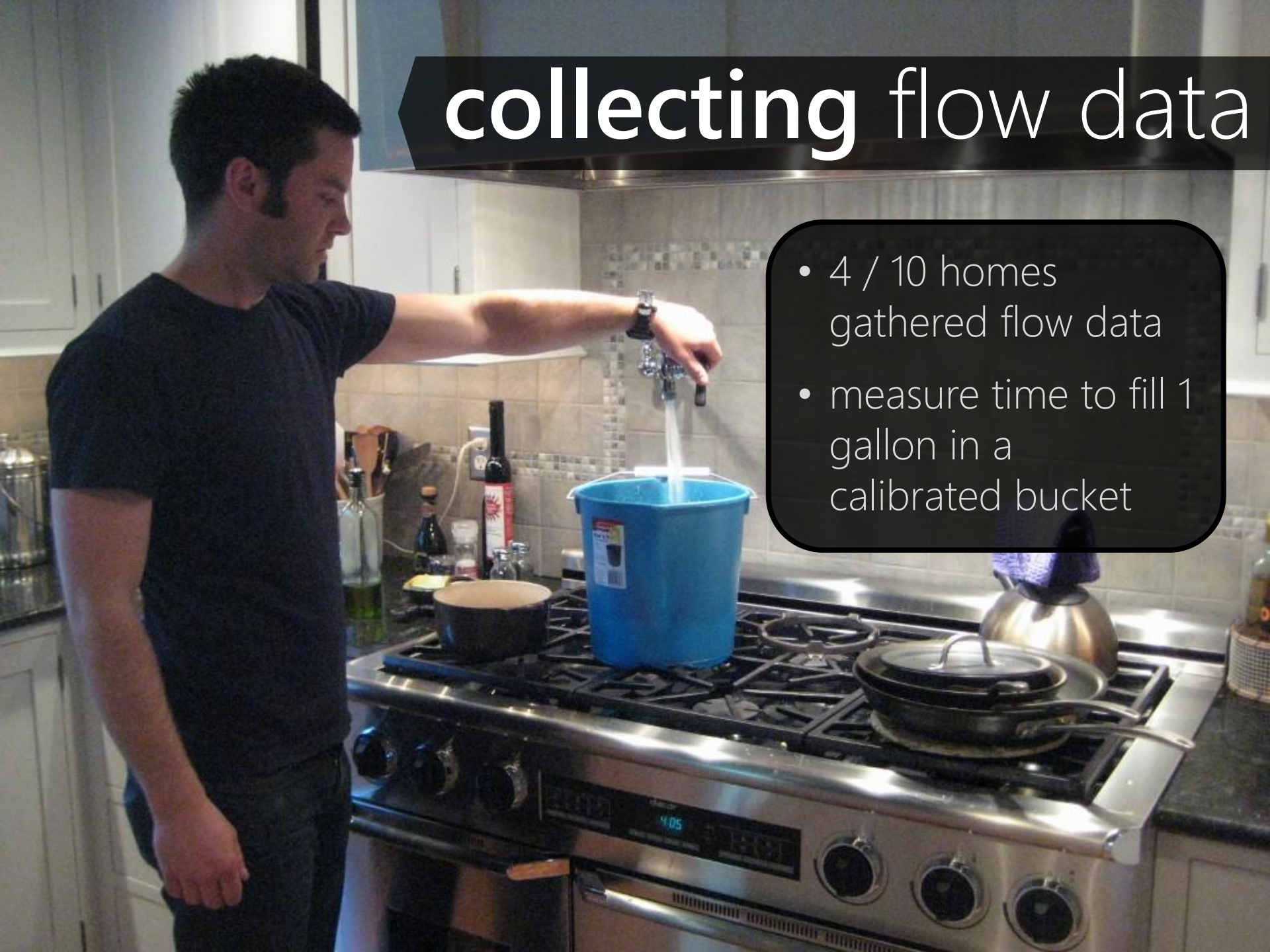
- valve opened full stop
- pause for ~5 seconds
- valve closed

experimental protocol

controlled data collection



collecting flow data



- 4 / 10 homes gathered flow data
- measure time to fill 1 gallon in a calibrated bucket

data collection stats

ten test sites

- 706 trials
- 155 flow trials
- 84 total fixtures tested

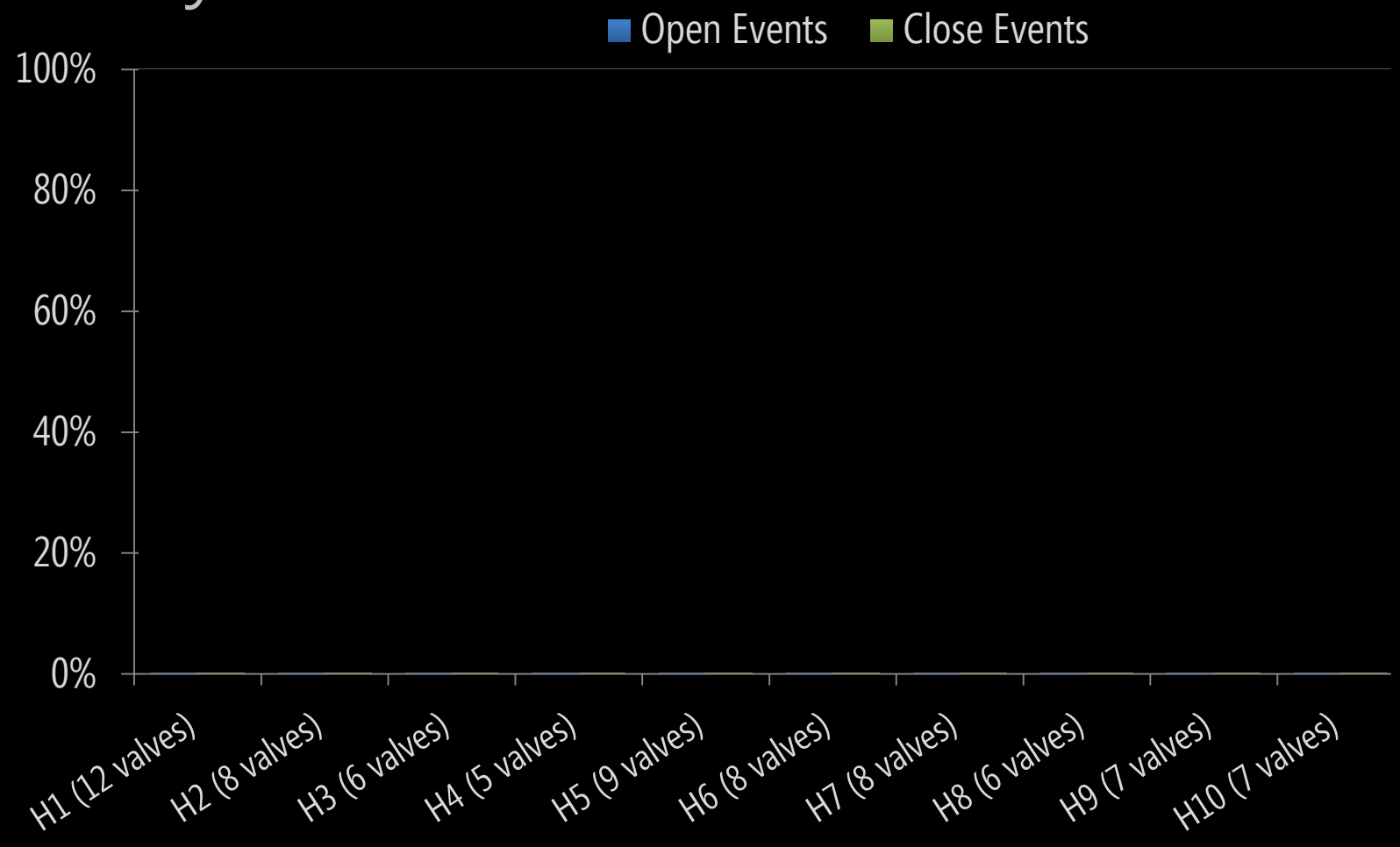
classification experiments

10-fold cross validation

1. break data into 10 sets of size n/10
2. train on 9 datasets and test on 1
3. repeat for each combination of datasets
4. take mean accuracy

fixture classification results

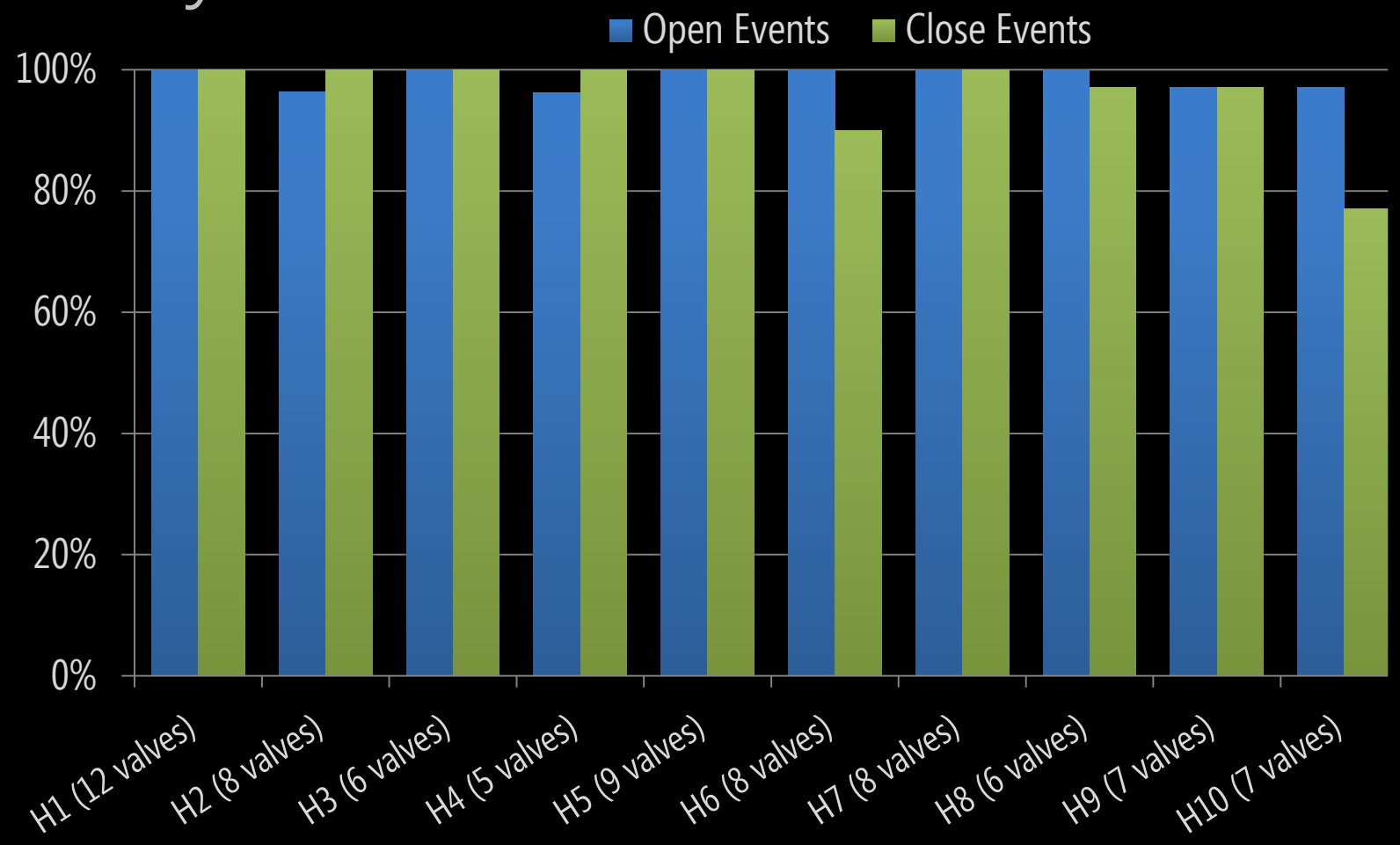
by home



10-fold cross validation

fixture classification results

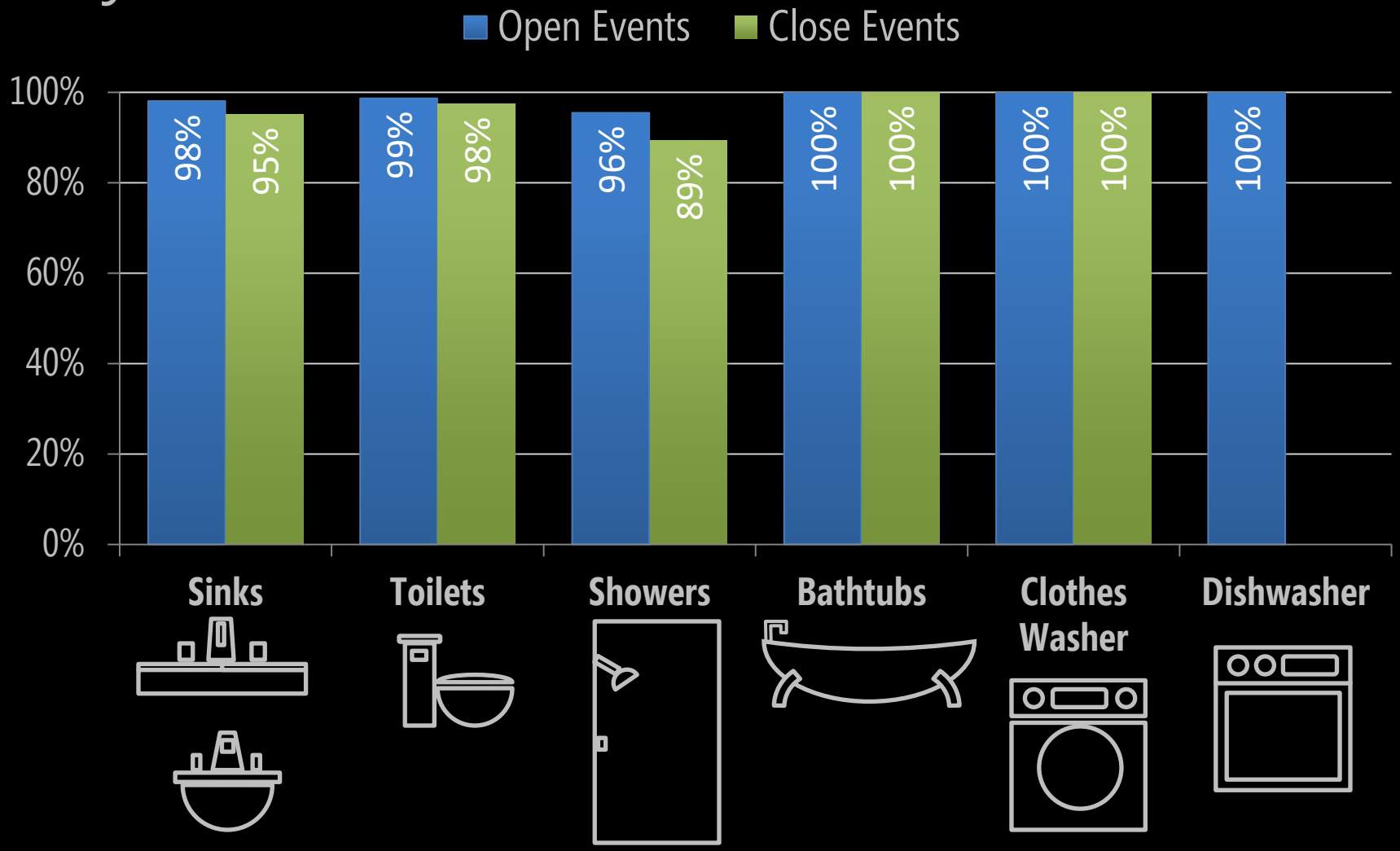
by home



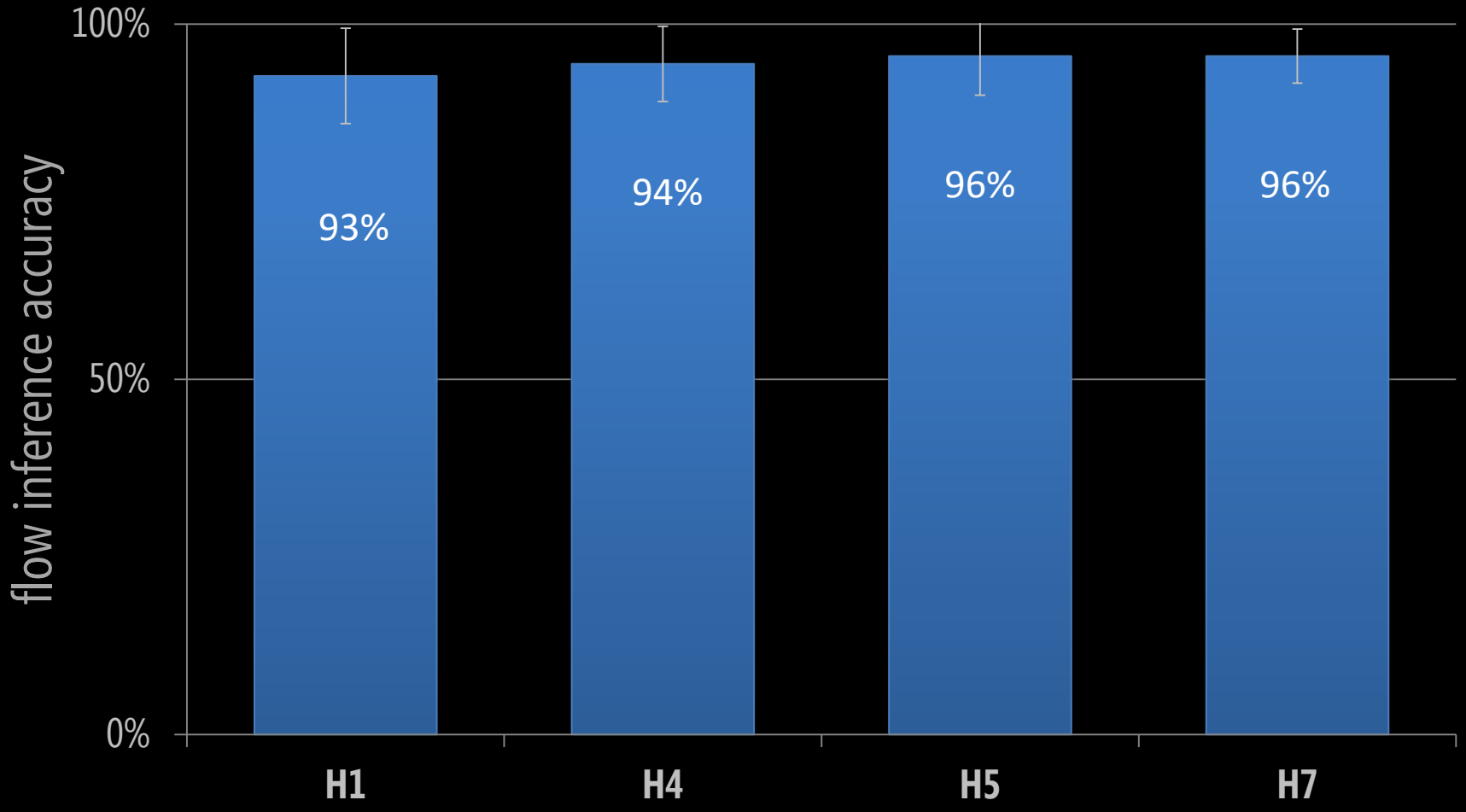
10-fold cross validation

fixture classification results

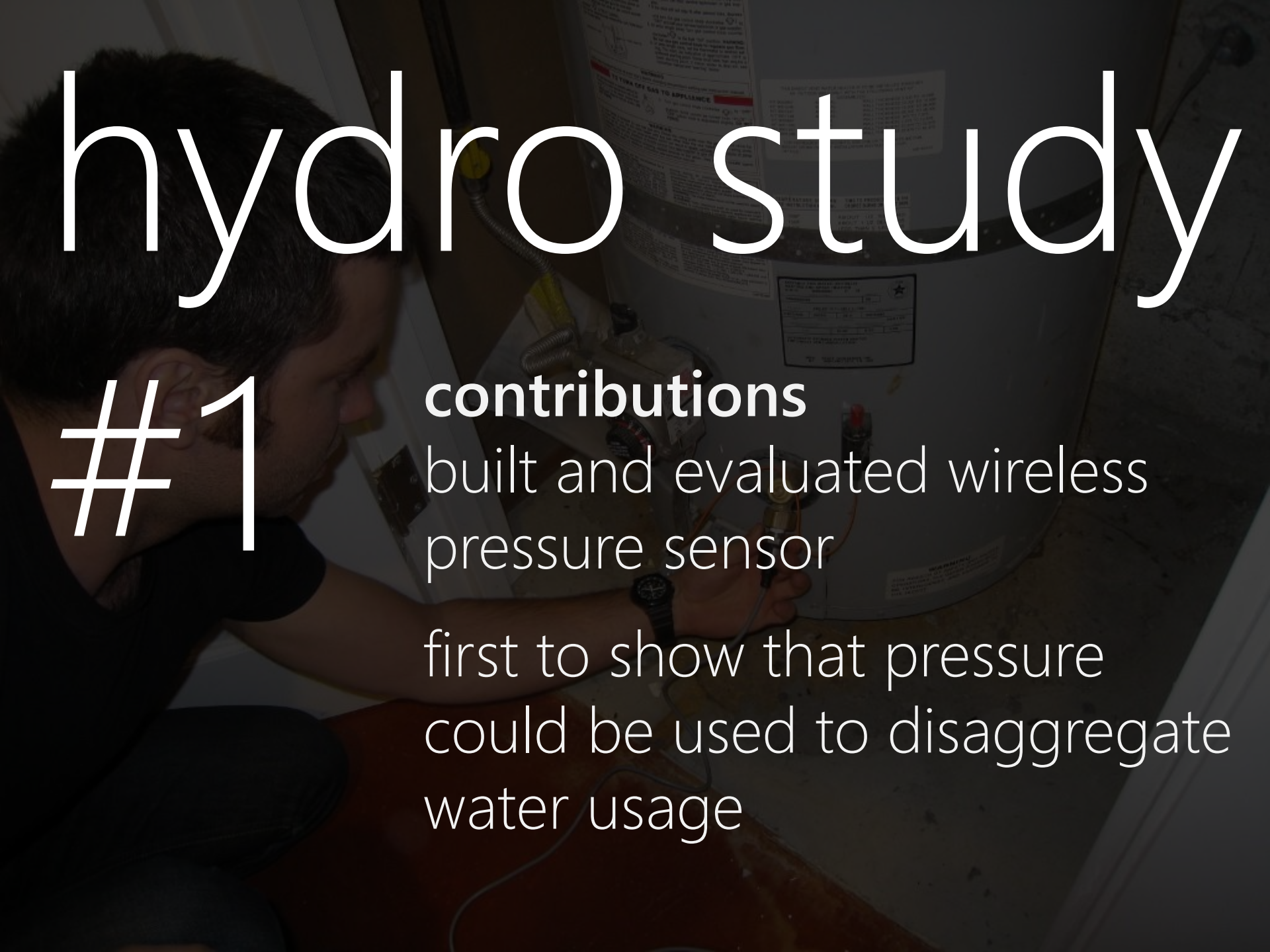
by fixture



flow inference results
by home



Within tolerances of domestic water meter accuracy; see [Arregui, 2003]



hydro study

#1

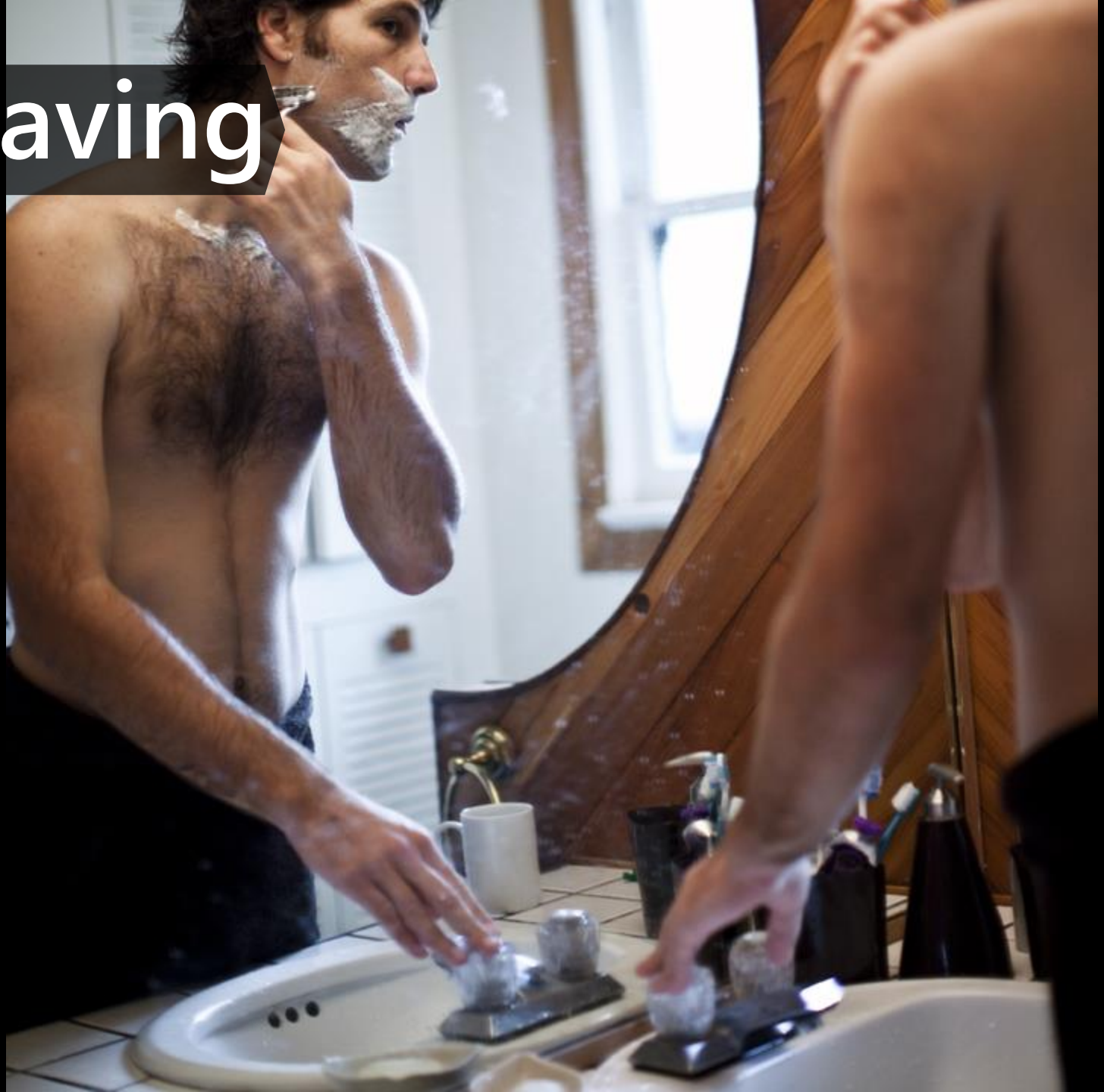
contributions

built and evaluated wireless pressure sensor

first to show that pressure could be used to disaggregate water usage

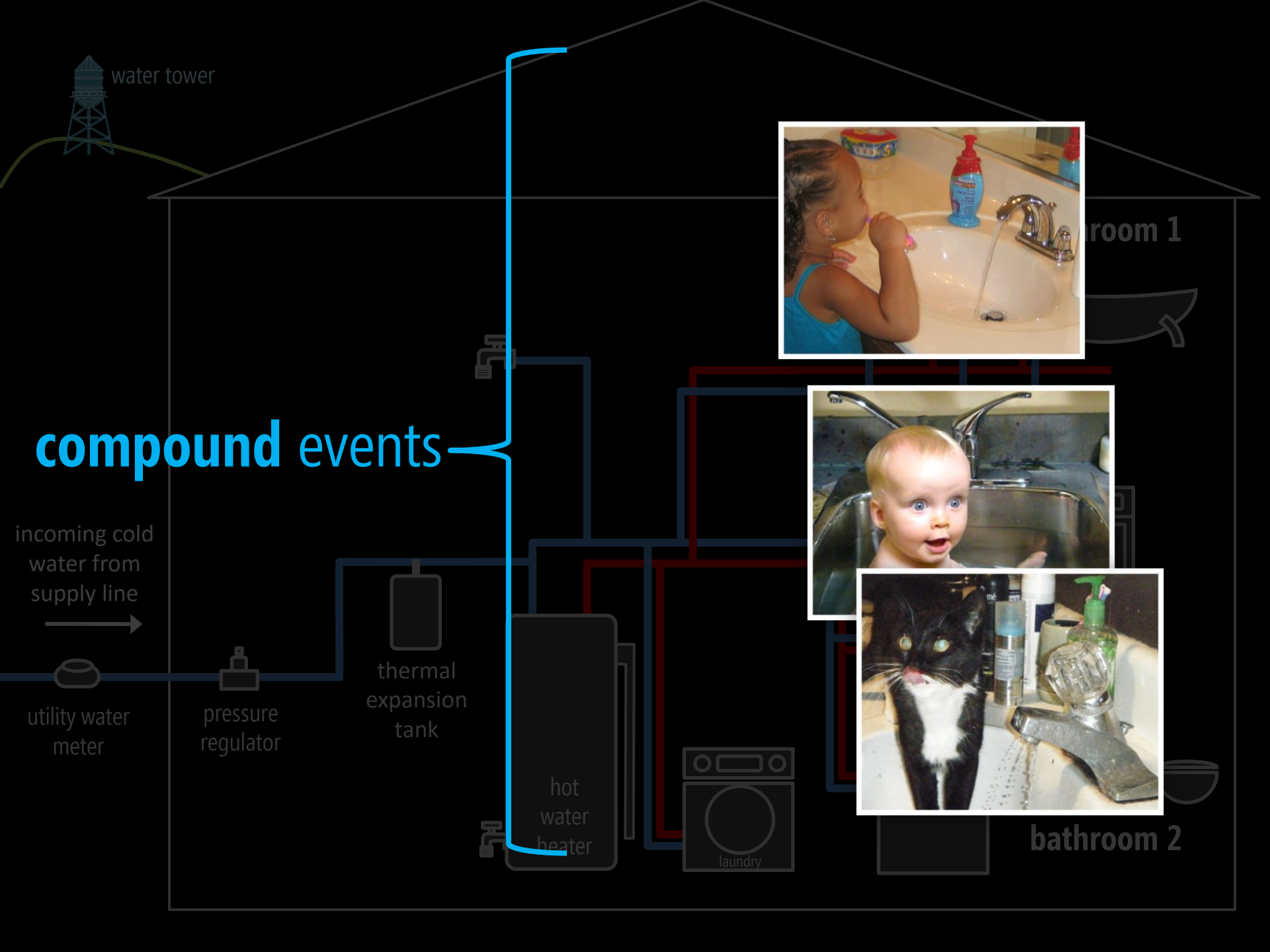

brushing teeth
Huggies
Clean & Fresh
hand soap
savon à mains

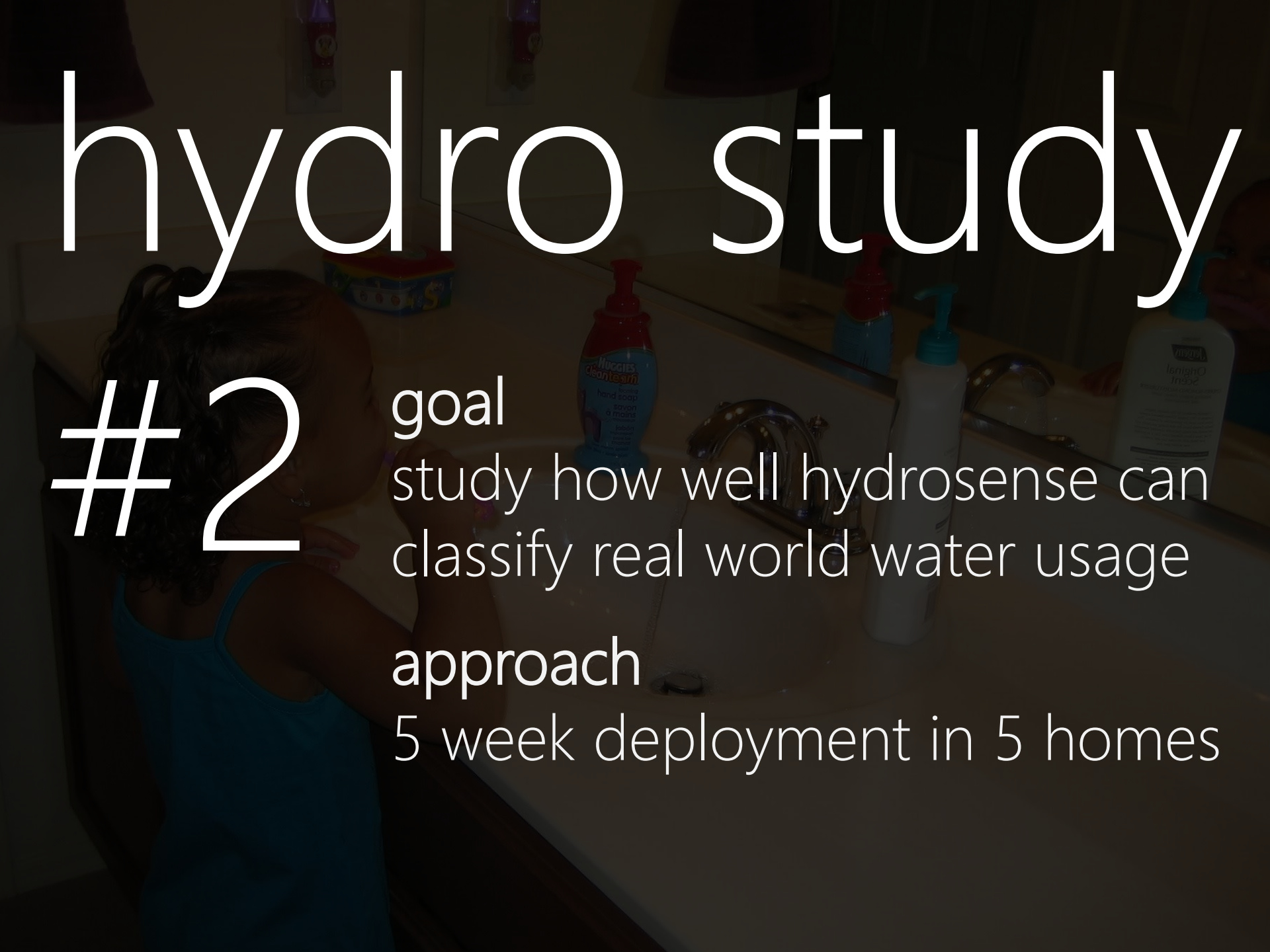
shaving




bathing

paw washing


water tower
compound events
incoming cold water from supply line
utility water meter
pressure regulator
thermal expansion tank
hot water heater
laundry
bathroom 2



hydro study

#2

goal

study how well hydrosense can classify real world water usage

approach

5 week deployment in 5 homes


in the first study, pressure waves were **manually** annotated with "ground truth labels" describing:
• the fixture used
• the water temperature

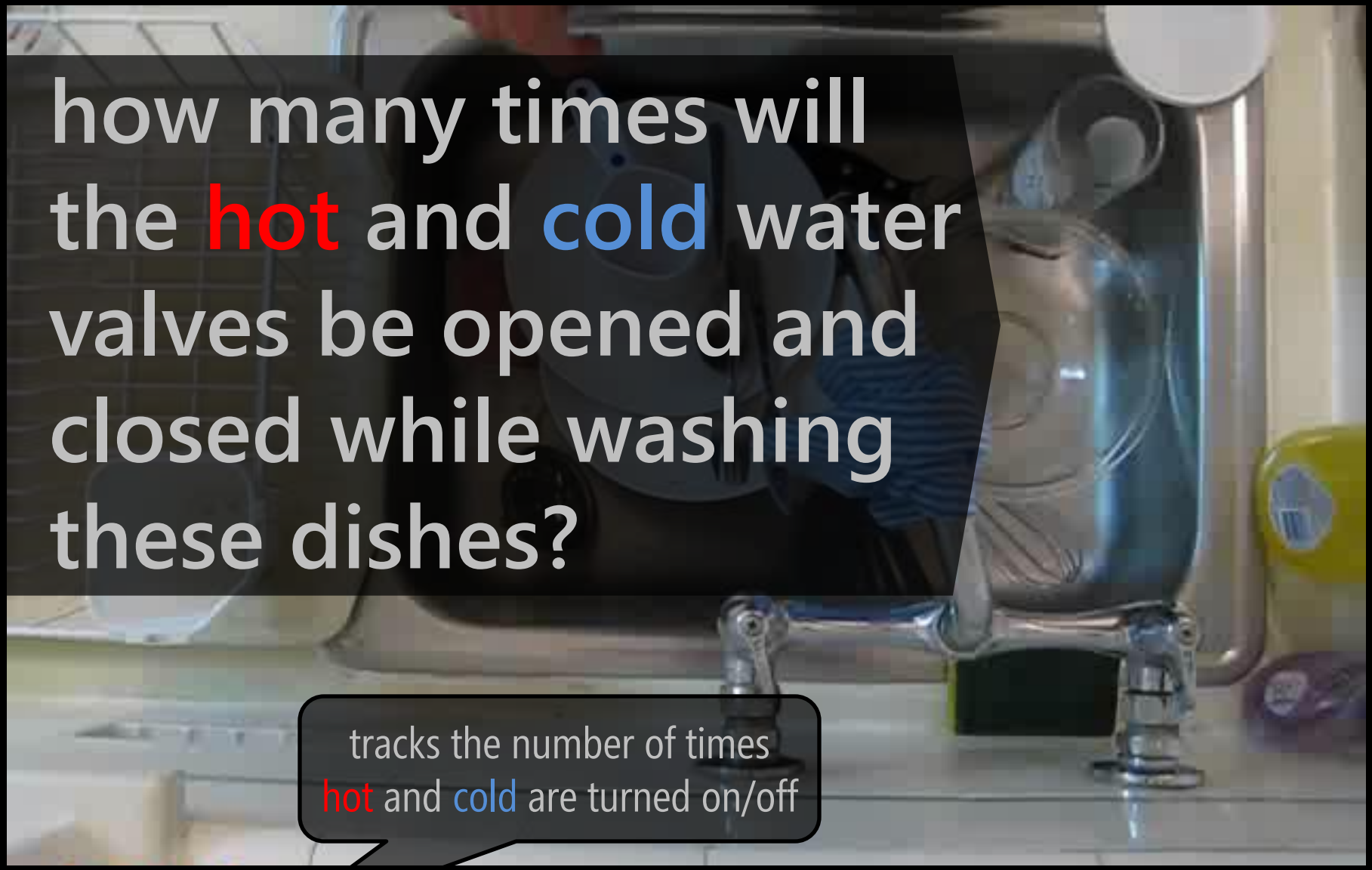

I’m about to flush the toilet!
Awesome! Marked it. Thanks Mr. Johnson

how

collect ground truth labels of

can we record **real-world** water usage?

wireless buttons


how many times will the hot and cold water valves be opened and closed while washing these dishes?
tracks the number of times hot and cold are turned on/off


hot: 0
cold: 0

wireless buttons

other failed solutions

intel labs shake sensors

thermistors

FAIL #3

nike+ piezo sensor

Firefox

Can the Nike+iPod Detect Water Facuet ...

www.youtube.com/watch?v=TKhlFs0EBTQ

Google

YouTube

Browse | Movies | Upload | Create Account | Sign In

Can the Nike+iPod Detect Water Facuet Handle Movement

jonfroehlich | Subscribe | 6 videos

Like | Share | Download

4,244

0 likes, 16 dislikes

Uploaded by jonfroehlich on Aug 7, 2009

The HydroSense team conducted a set of short, simple experiments investigating whether the Nike+iPod piezoelectric sensor could be used to detect faucet open/close handle movements.

Show more

Top Comments

our solution…


custom
direct
sensors

automated ground truth labeling method

design goals

hardware capabilities

1. wireless communication
2. low-power
3. water resistant

sensing capabilities

1. work across fixtures/appliances
2. detect opens/closes
3. discriminate hot/cold/mixed

function across fixtures

kitchen sink

bathroom sink

bath

shower

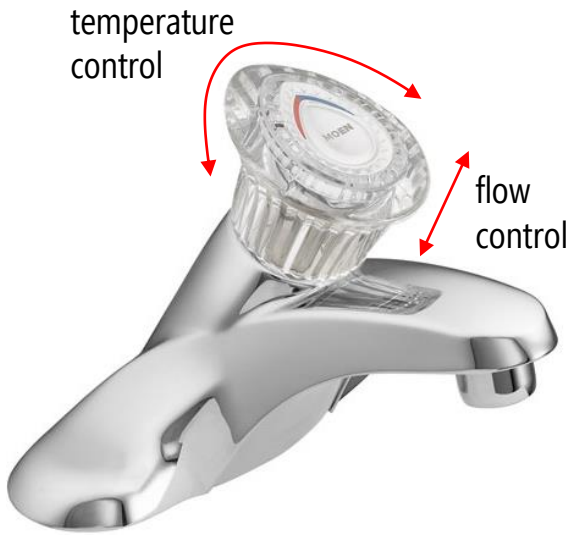
toilet

laundry basin

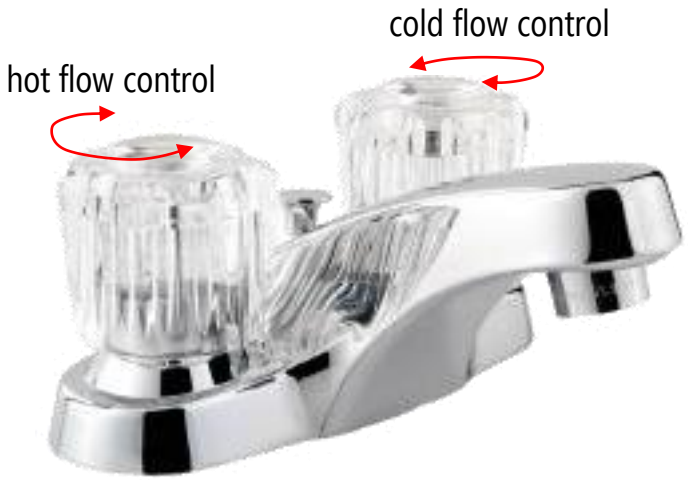
washing machine

dishwasher

challenge: fixture diversity



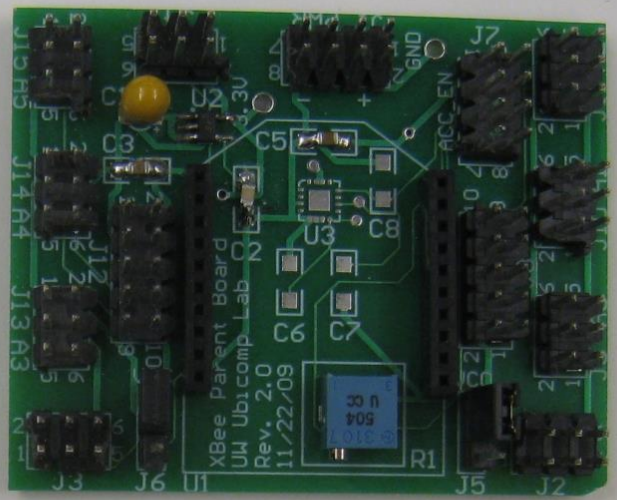
single handle faucet



dual handle faucet

custom ground truth data collection system

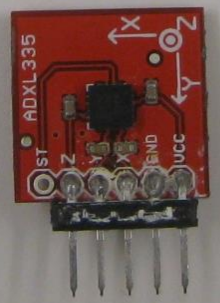
xbee wireless modem



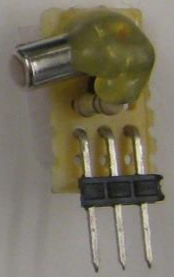
fixture usage sensor board

hall effect

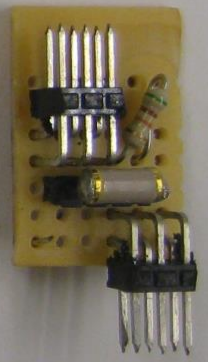
reed switch



3-axis accelerometer



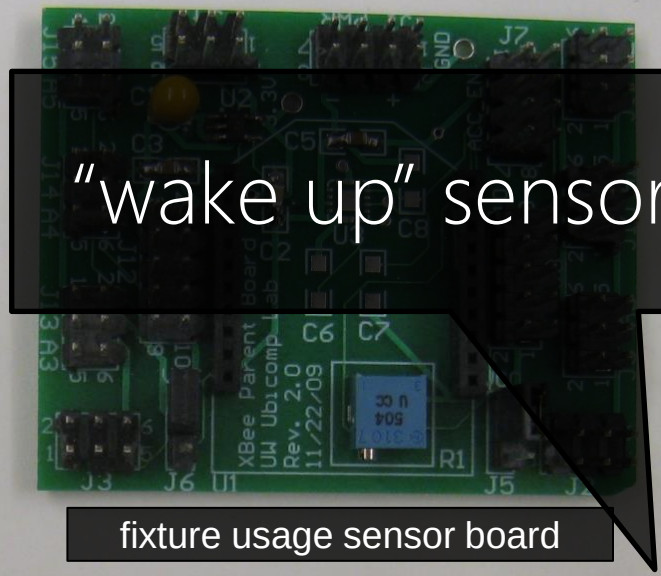
unidirectional ball switch



omnidirectional ball switch

custom ground truth data collection system

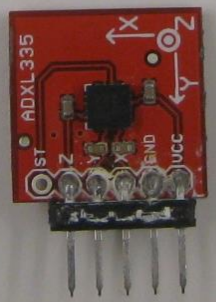
xbee wireless modem



fixture usage sensor board

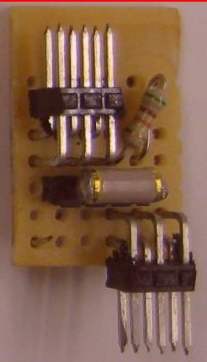
hall effect

reed switch



3-axis accelerometer

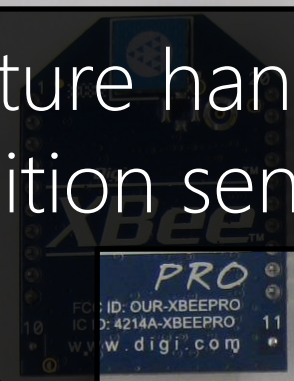
unidirectional ball switch



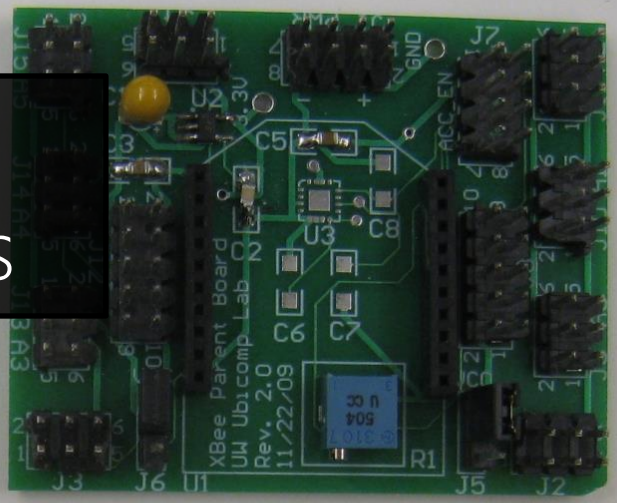
omnidirectional ball switch

custom ground truth data collection system

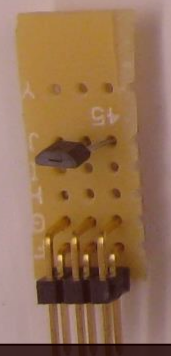
fixture handle position sensors



xbee wireless modem

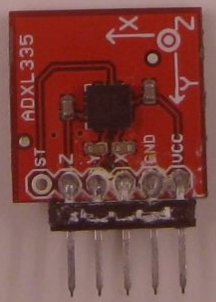


fixture usage sensor board



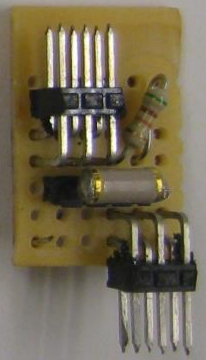
hall effect

reed switch



3-axis accelerometer

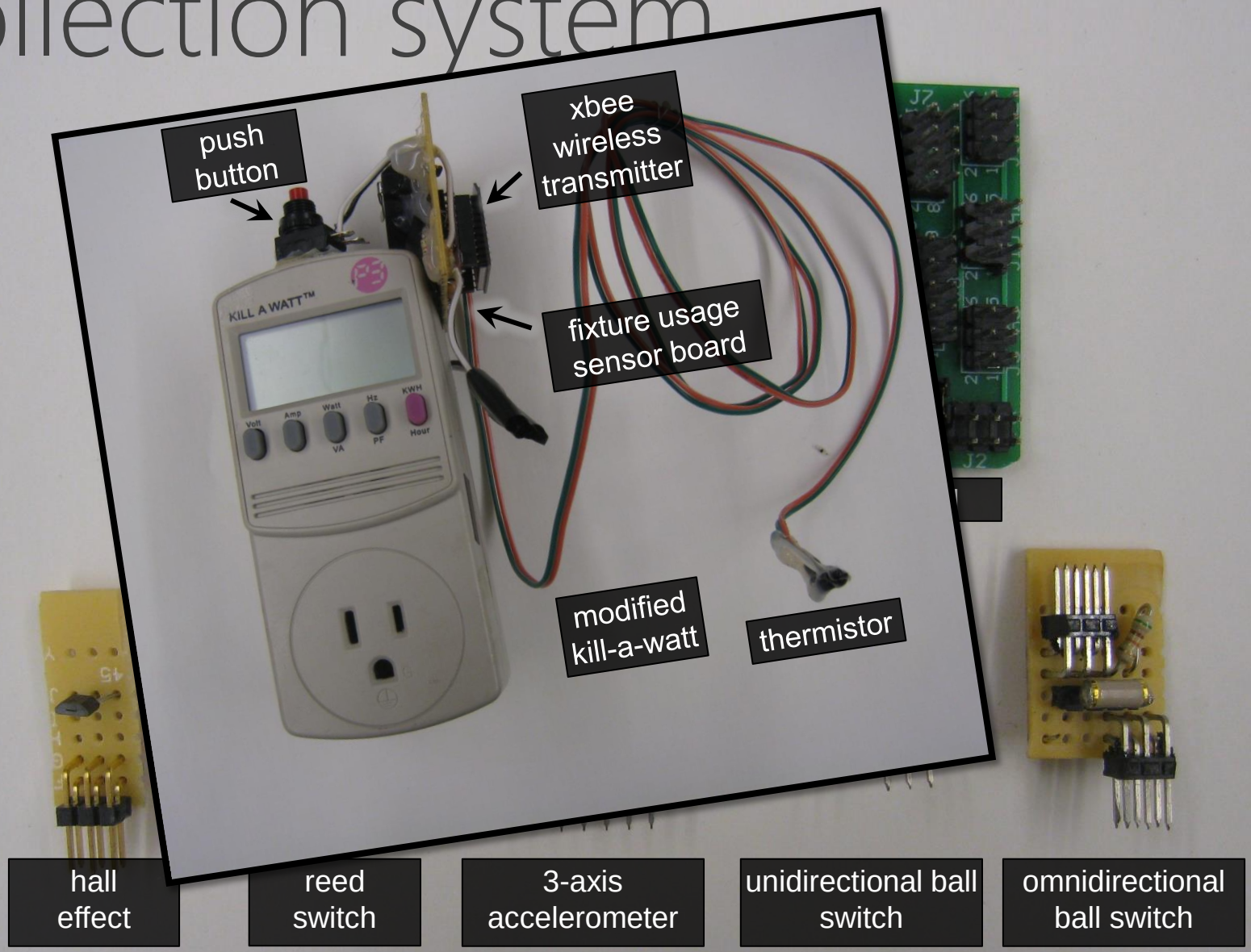
unidirectional ball switch



omnidirectional ball switch


accelerometer
Accelerometer
& Ball Switch
Taped on

custom ground truth data collection system

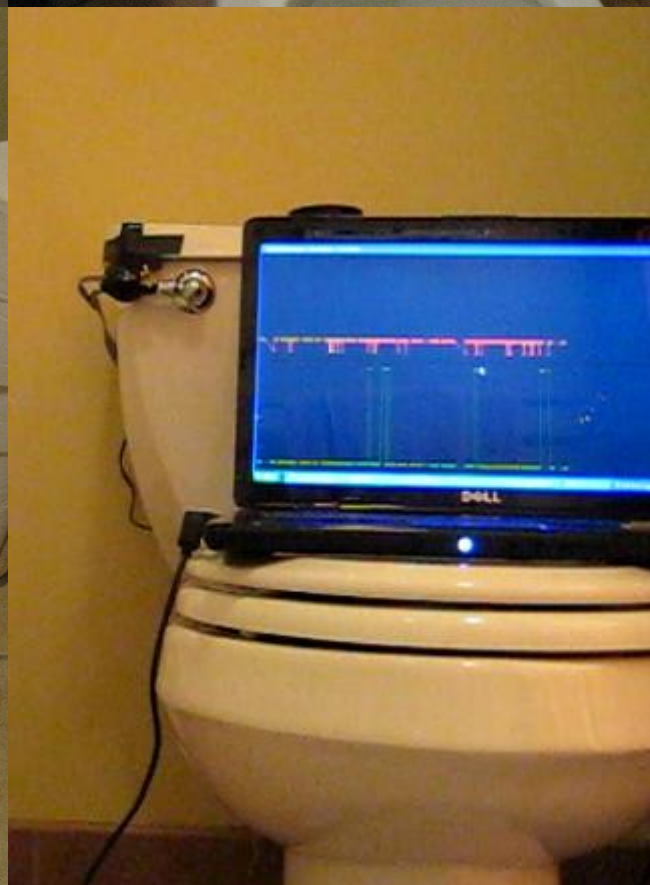


deployment sites

					
residents	2	2	4	2	2
size	3000 sqft	750 sqft	1200 sqft	700 sqft	750 sqft
floors	3	2	2	3rd flr	6th flr
fixtures	17	8	13	8	8
valves	28	13	21	13	13



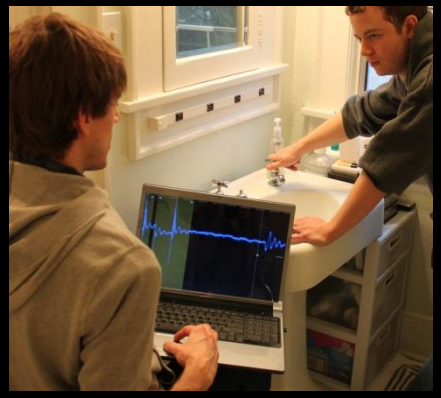




DELL


HOT
COLD

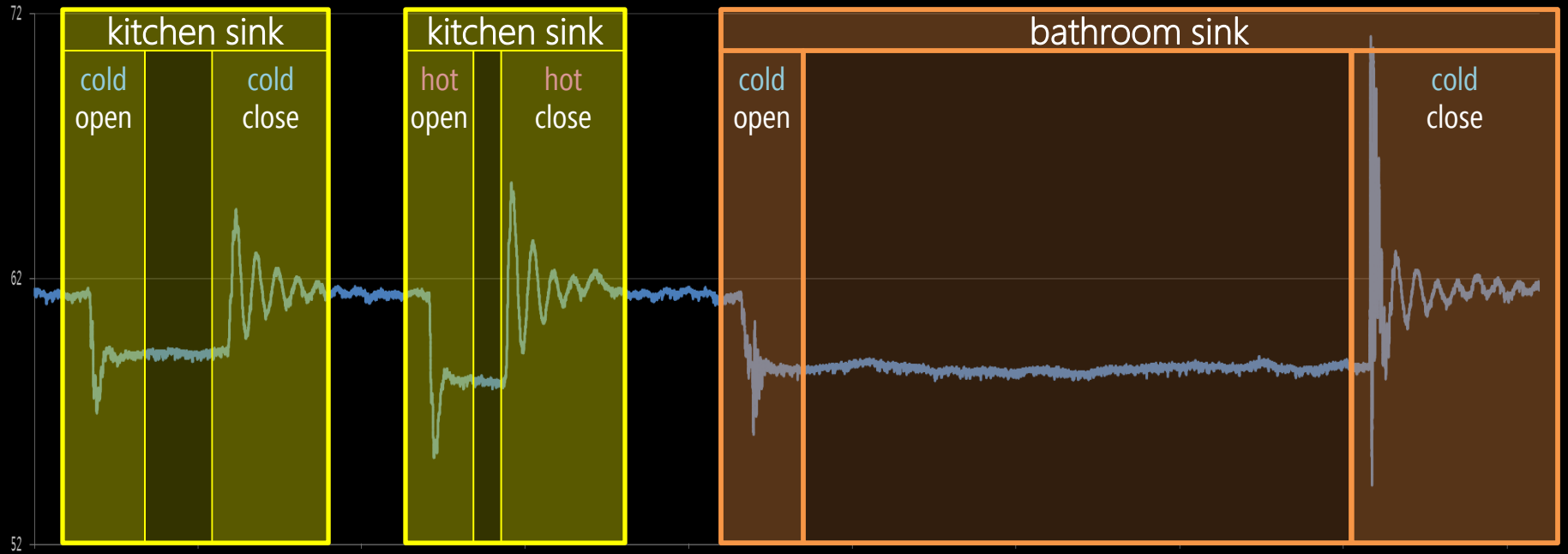

PB32
XBee
PULL KNOB TO START-PUSH TO STOP
XTRA RINSE
SET
COTTONS REGULAR
PERMANENT PRESS KNITS
PERMANENT PRESS
DELICATES
LIGHT SOIL
MEDIUM
HEAVY
POWER WASH
30 MIN AUTO SOAK
vy Duty Super Capacity
= RINSE
= EXTRA RINSE
= SPIN

ground truth labels

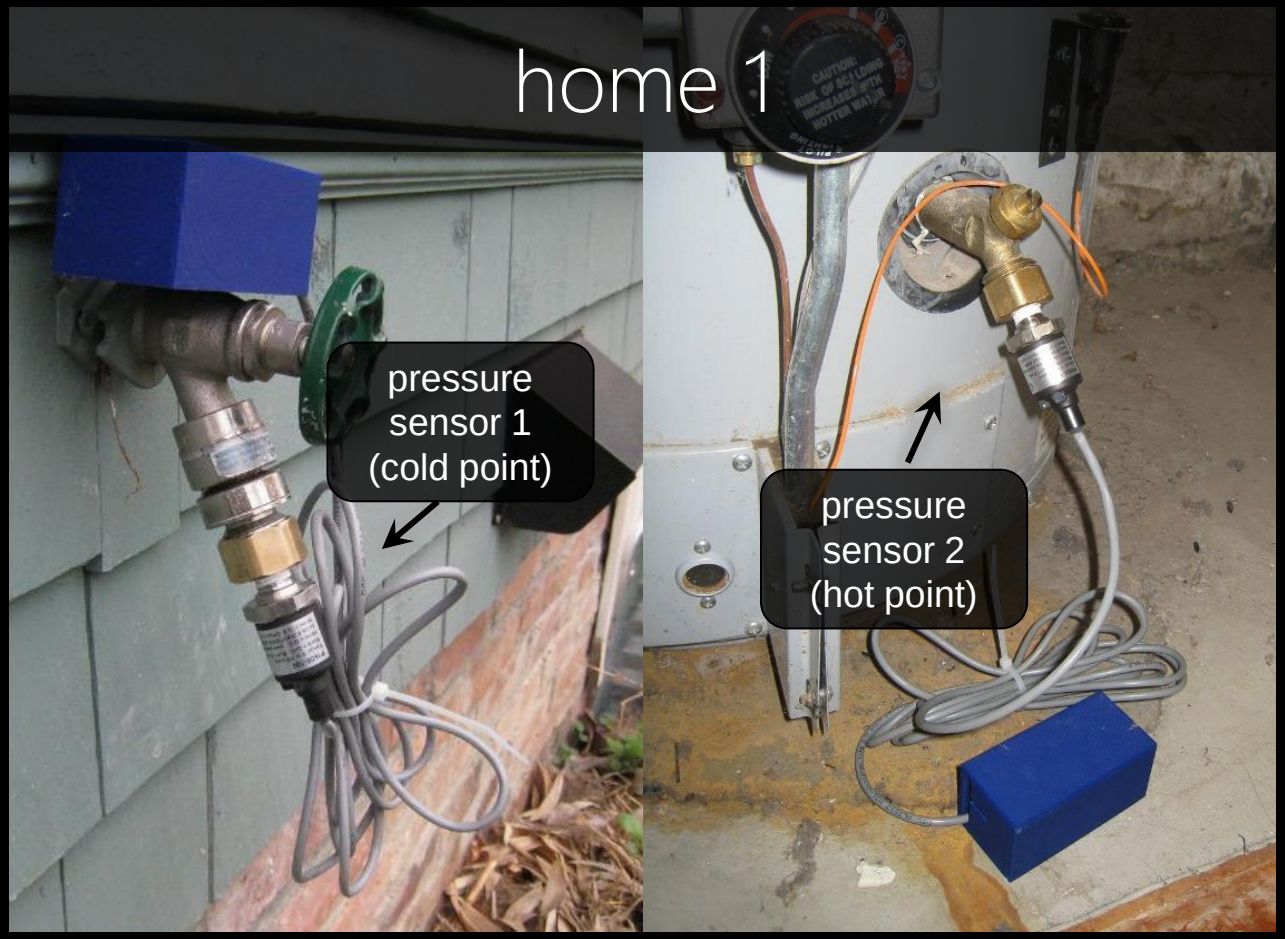


manual

automatic

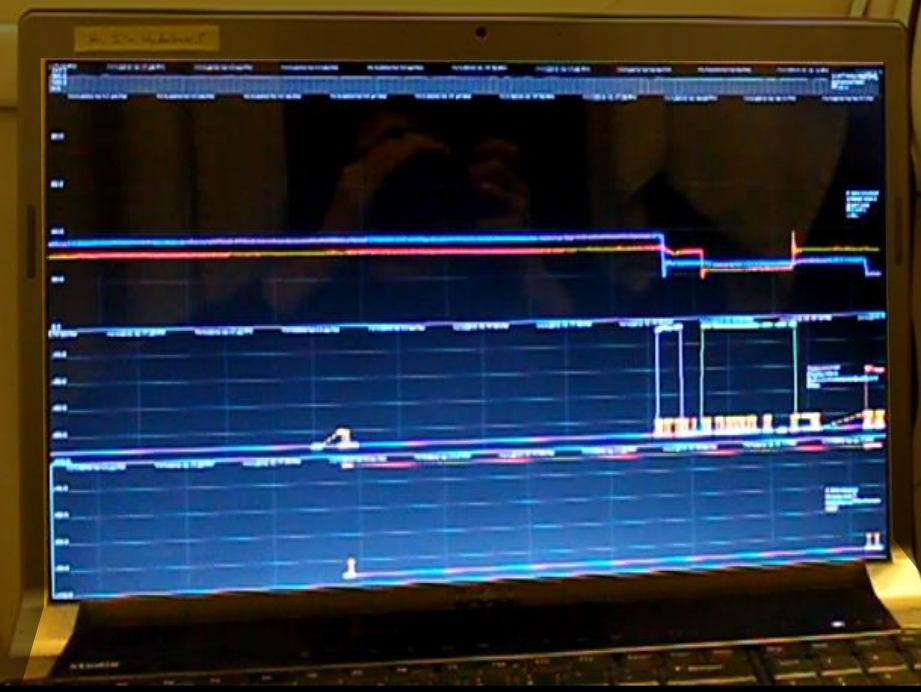


two pressure sensors per home



hydrosense data logger

records ground truth sensor data plus
two pressure streams for each home

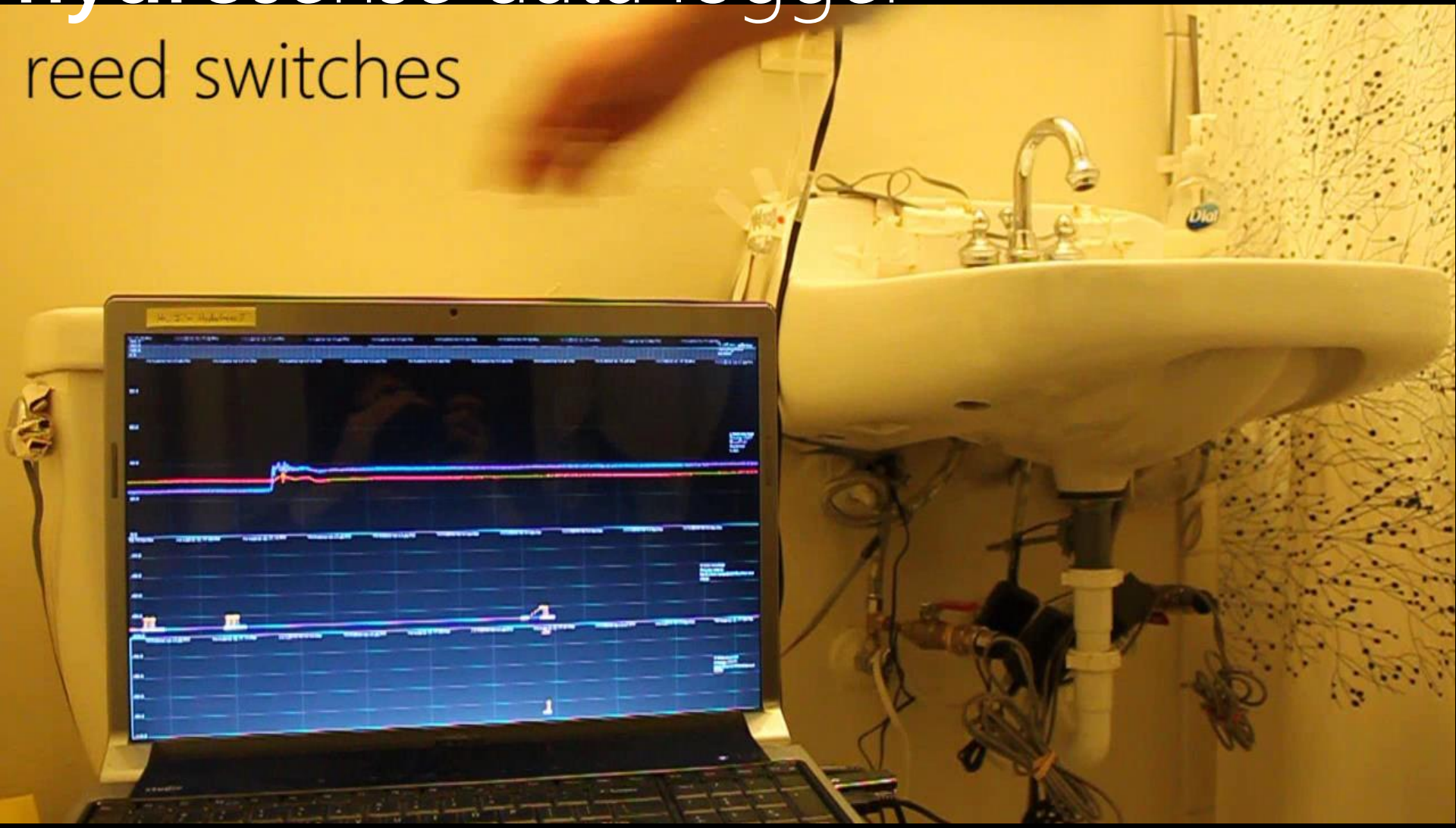


pressure stream
red = hot line
blue = cold line

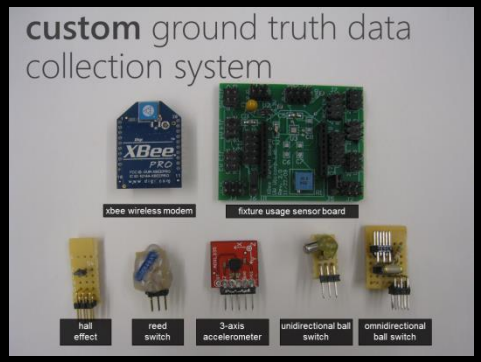
reed switches
high = active
low = inactive

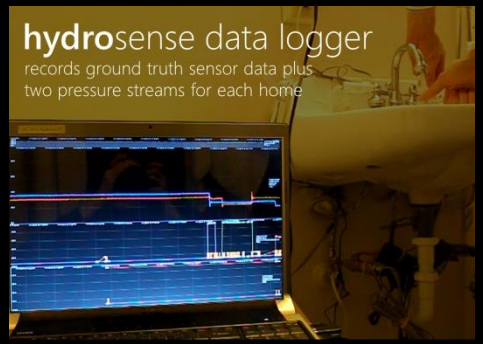
hydrosense data logger

reed switches

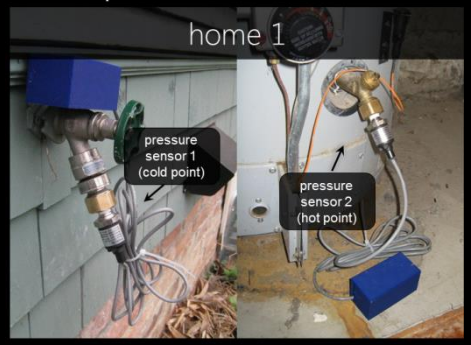


hydro deployment infrastructure

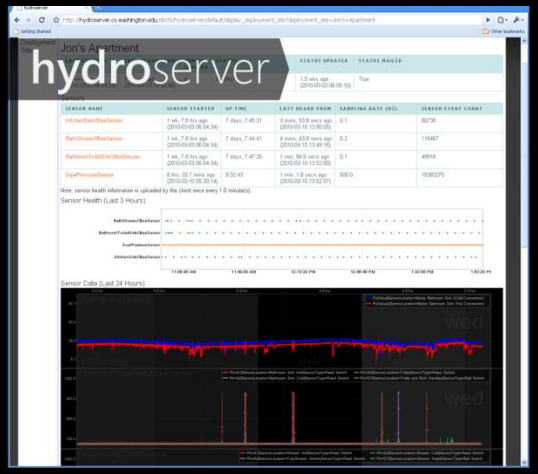




two pressure sensors

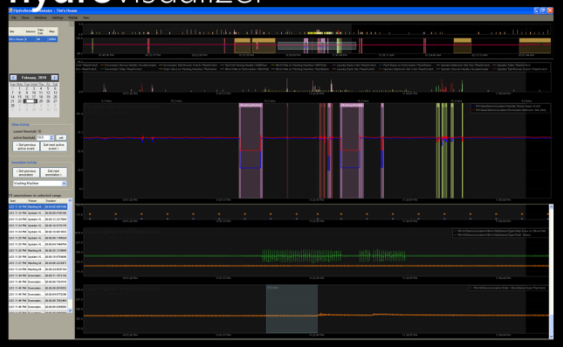


on-site sensing infrastructure

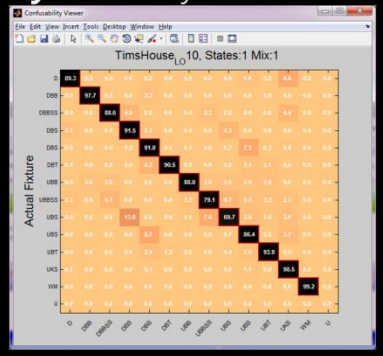


python web backend

hydrovisualizer

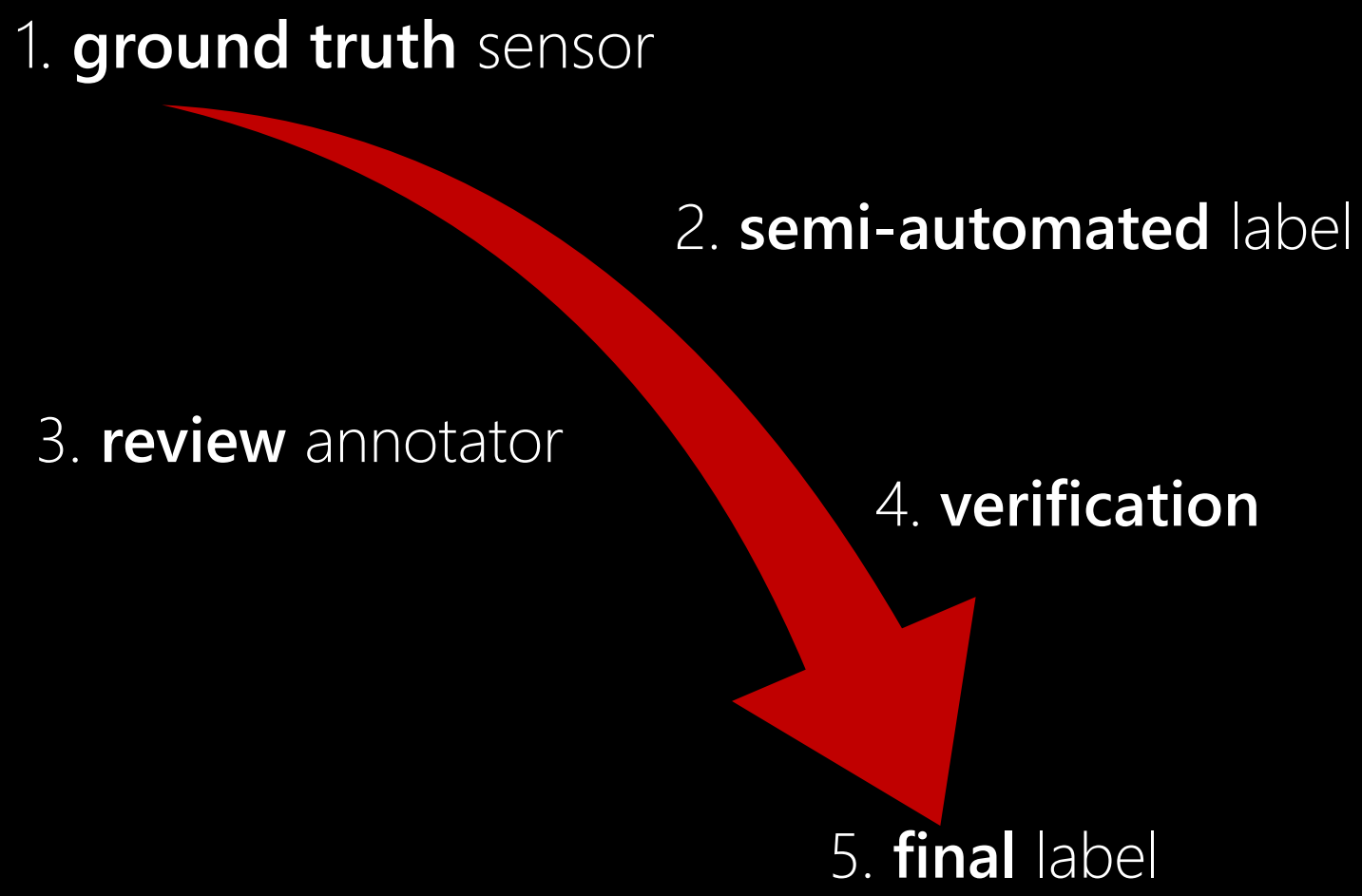


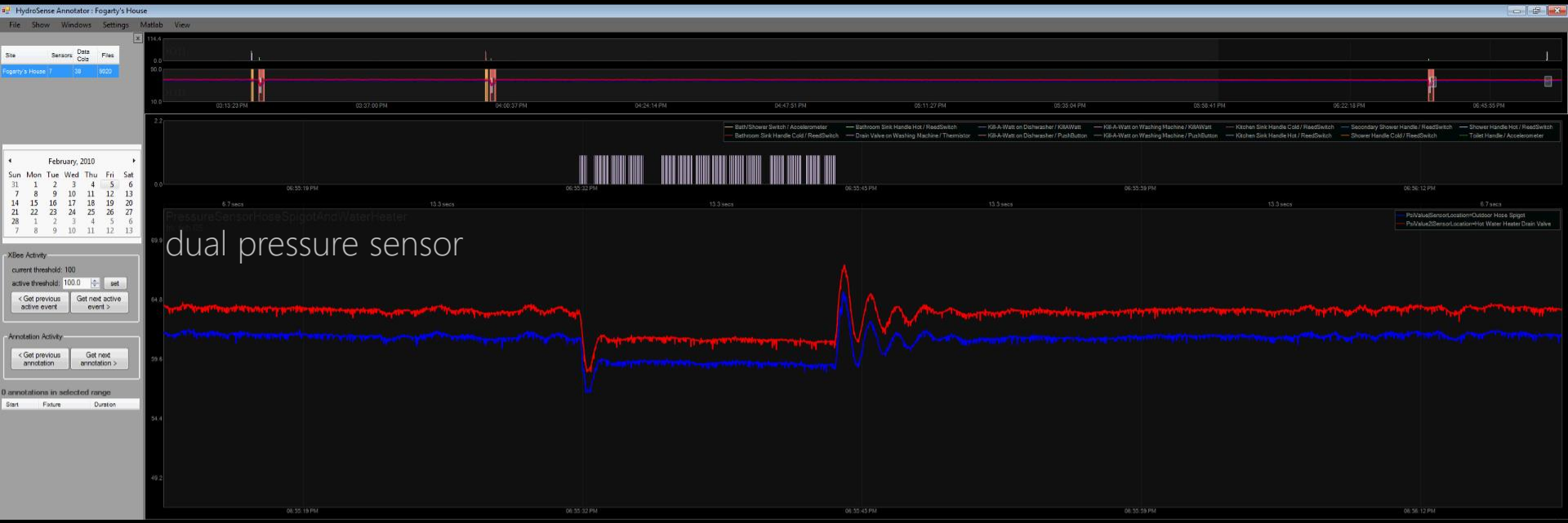
hydroanalyzer



c# and matlab analysis tools

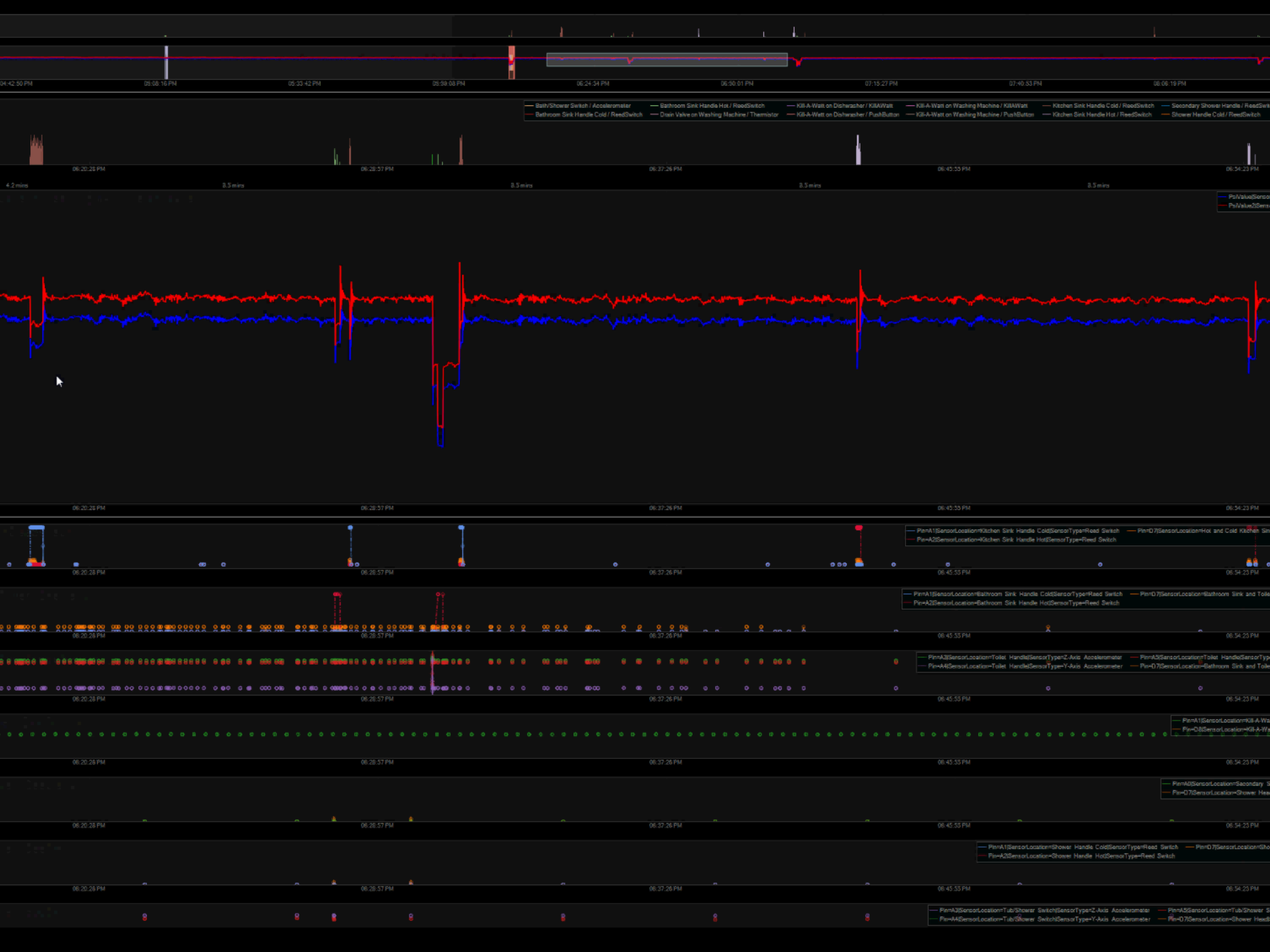
hydrosense annotations




HydroSense Annotator : Fogarty's House
File
Show
Windows
Settings
Matlab
View
Site
Sensors
Data Cols
Files
Fogarty's House
7
38
9020
February, 2010
Sun Mon Tue Wed Thu Fri Sat
XBee Activity
current threshold: 100
active threshold:
100.0
set
< Get previous active event
Get next active event >
Annotation Activity
< Get previous annotation
Get next annotation >
0 annotations in selected range
Start
Fixture
Duration
Bath/Shower Switch / Accelerometer
Bathroom Sink Handle Hot / ReedSwitch
Kill-A-Watt on Dishwasher / KillAWatt
Kill-A-Watt on Washing Machine / KillAWatt
Kitchen Sink Handle Cold / ReedSwitch
Secondary Shower Handle / ReedSwitch
Shower Handle Hot / ReedSwitch
Bathroom Sink Handle Cold / ReedSwitch
Drain Valve on Washing Machine / Thermistor
Kill-A-Watt on Dishwasher / PushButton
Kill-A-Watt on Washing Machine / PushButton
Kitchen Sink Handle Hot / ReedSwitch
Shower Handle Cold / ReedSwitch
Toilet Handle / Accelerometer
PressureSensorHoseSpigotAndWaterHeater
dual pressure sensor
PsiValue1SensorLocation=Outdoor Hose Spigot
PsiValue2SensorLocation=Hot Water Heater Drain Valve


HydroSense Annotator : Fogarty's House
File
Show
Windows
Settings
Matlab
View
Site
Sensors
Data Cols
Files
Fogarty's House
7
38
9020
February, 2010
Sun Mon Tue Wed Thu Fri Sat
XBee Activity
current threshold: 100
active threshold:
100.0
set
< Get previous active event
Get next active event >
Annotation Activity
< Get previous annotation
Get next annotation >
0 annotations in selected range
Start
Fixture
Duration
dual pressure sensor
toilet
bathroom faucet
kitchen faucet
dishwasher
washing machine
bath/shower
bath/shower diverter

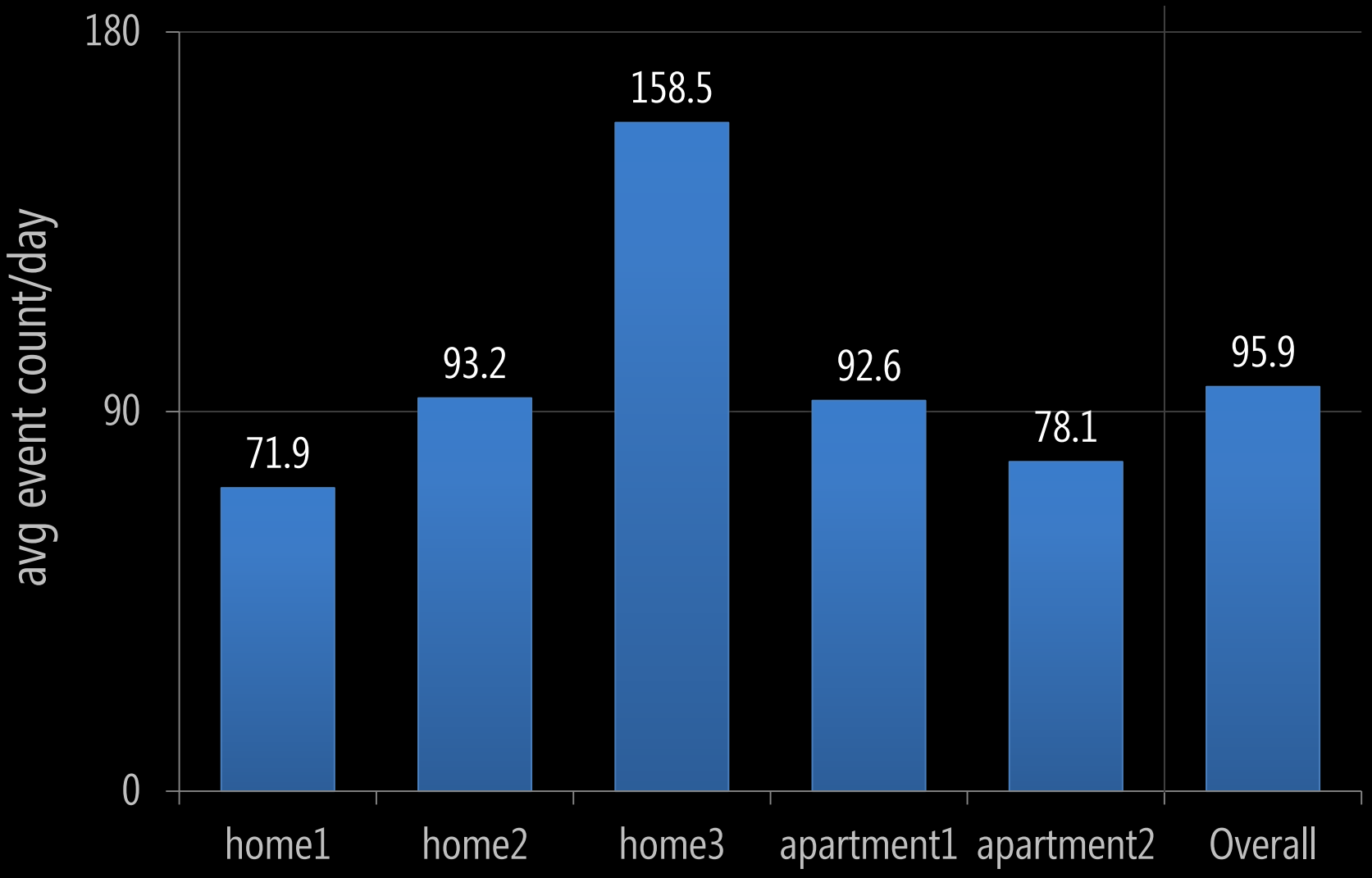

06:55:32 PM
06:55:45 PM
06:55:59 PM
13.3 secs
13.3 secs
13.3 secs
WaterHeater
06:55:32 PM
06:55:45 PM
06:55:59 PM
Pin=A3|SensorLocation=Toilet Handle|SensorTyp
Pin=A4|SensorLocation=Toilet Handle|SensorTyp
06:55:32 PM
06:55:45 PM
06:55:59 PM
Pin=A1|SensorLocation=Bathroom Sink Handle Cold|S
Pin=A2|SensorLocation=Bathroom Sink Handle Hot|Se
06:55:32 PM
06:55:45 PM
06:55:59 PM
Pin=A1|SensorLocation=Kitchen Sink Handle Cold|Se
Pin=A2|SensorLocation=Kitchen Sink Handle Hot|Sen
06:55:32 PM
06:55:45 PM
06:55:59 PM
06:55:32 PM
06:55:45 PM
06:55:59 PM


Bath/Shower Switch / Accelerometer
Bathroom Sink Handle Cold / ReedSwitch
Bathroom Sink Handle Hot / ReedSwitch
Drain Valve on Washing Machine / Thermistor
Kill-A-Watt on Dishwasher / KillAWatt
Kill-A-Watt on Dishwasher / PushButton
Kill-A-Watt on Washing Machine / KillAWatt
Kill-A-Watt on Washing Machine / PushButton
Kitchen Sink Handle Cold / ReedSwitch
Kitchen Sink Handle Hot / ReedSwitch
Secondary Shower Handle / ReedSwitch
Shower Handle Cold / ReedSwitch
4.2 mins
8.5 mins
8.5 mins
8.5 mins
8.5 mins
Pin=A1|SensorLocation=Kitchen Sink Handle Cold|SensorType=Reed Switch
Pin=A2|SensorLocation=Kitchen Sink Handle Hot|SensorType=Reed Switch
Pin=A1|SensorLocation=Bathroom Sink Handle Cold|SensorType=Reed Switch
Pin=A2|SensorLocation=Bathroom Sink Handle Hot|SensorType=Reed Switch
Pin=A3|SensorLocation=Toilet Handle|SensorType=Z-Axis Accelerometer
Pin=A4|SensorLocation=Toilet Handle|SensorType=Y-Axis Accelerometer
Pin=A1|SensorLocation=Shower Handle Cold|SensorType=Reed Switch
Pin=A2|SensorLocation=Shower Handle Hot|SensorType=Reed Switch
Pin=A3|SensorLocation=Tub/Shower Switch|SensorType=Z-Axis Accelerometer
Pin=A4|SensorLocation=Tub/Shower Switch|SensorType=Y-Axis Accelerometer

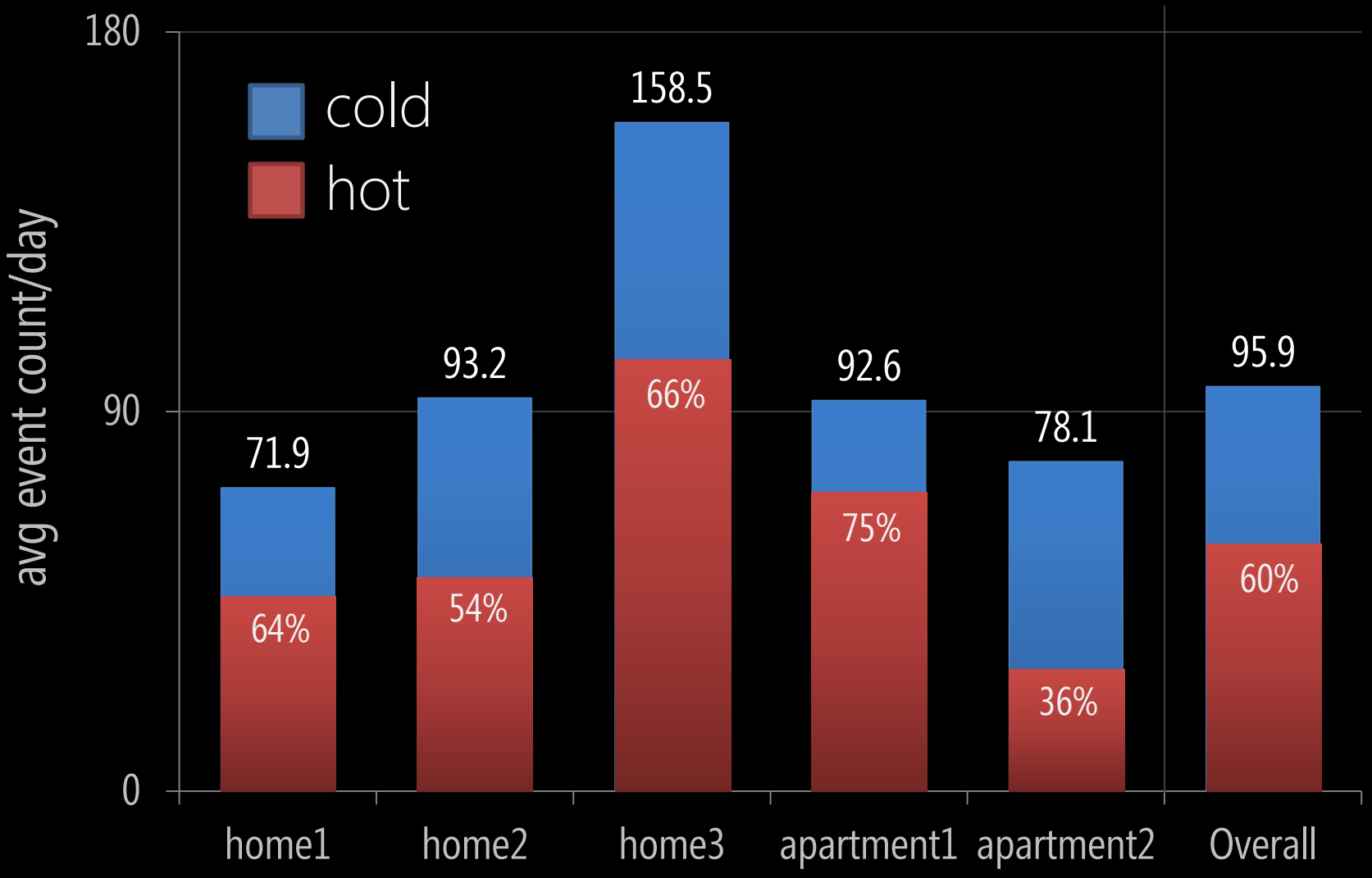
5-week dataset

						totals
days	33	33	30	27	33	156
events	2374	3075	4754	2499	2578	14,960
events/day	71.9	93.2	158.5	92.6	78.1	95.9

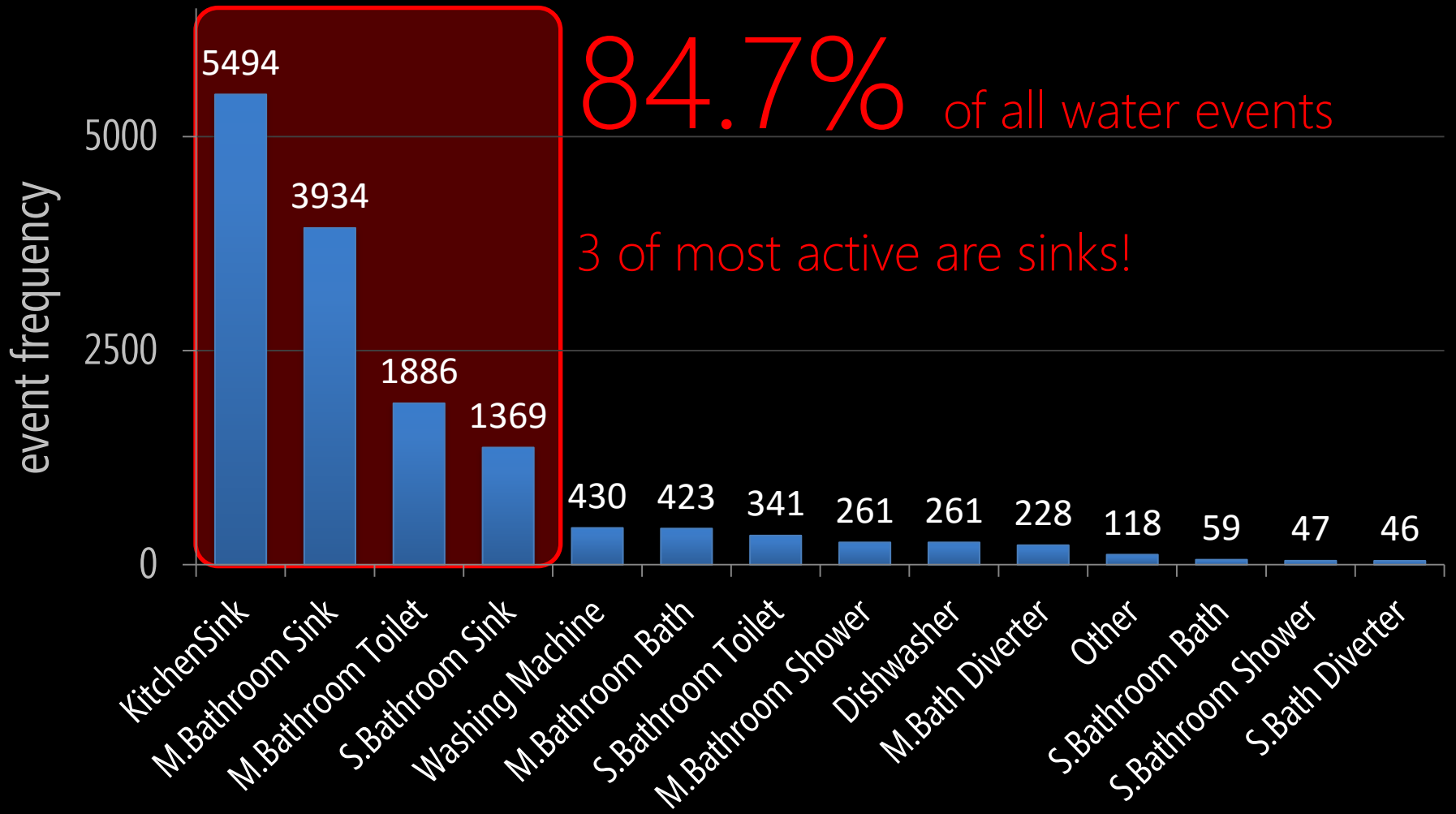
avg num water events/day

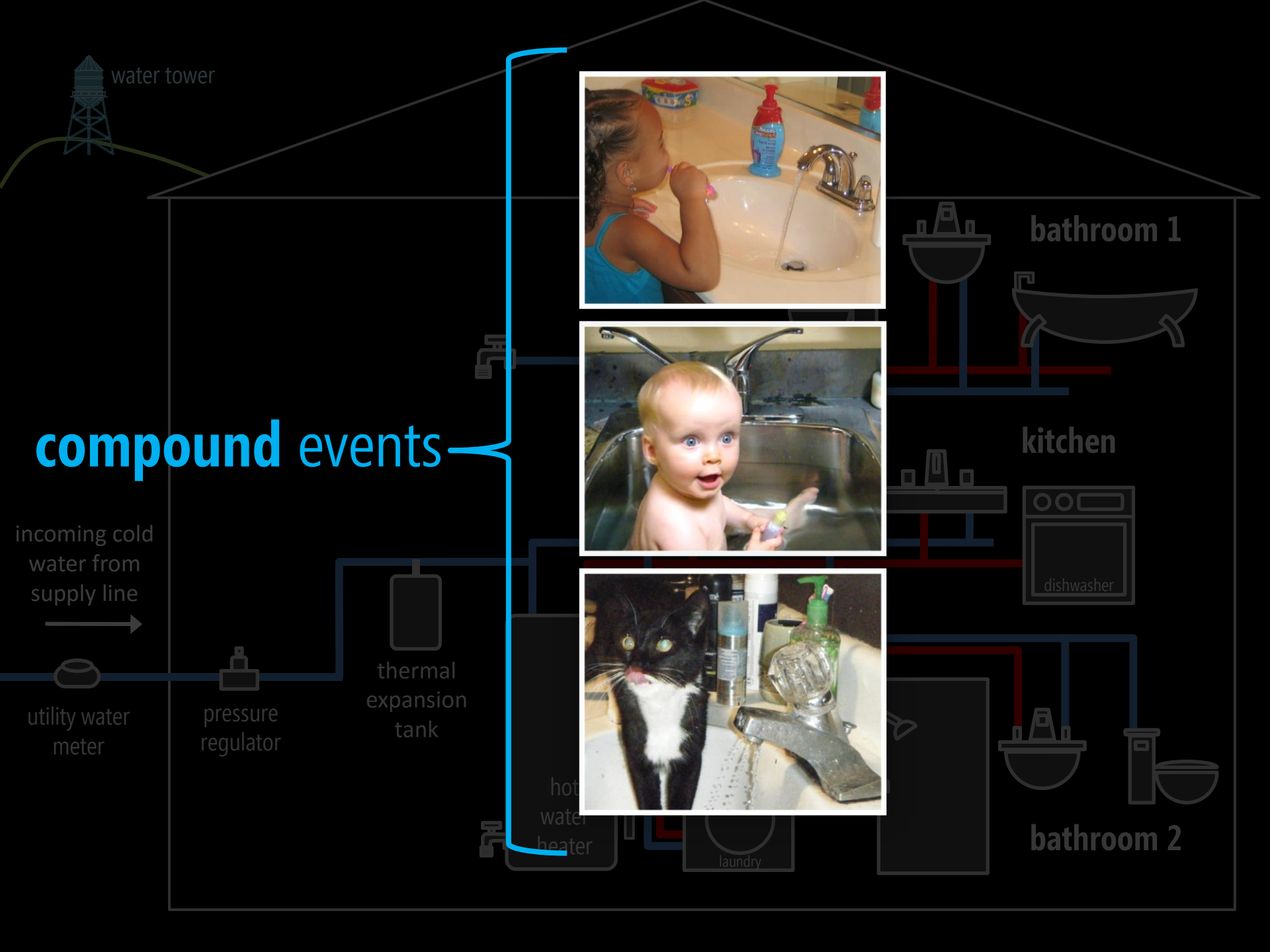


avg num water events/day



fixture activity frequency




water tower
compound events
incoming cold water from supply line
utility water meter
pressure regulator
thermal expansion tank
hot water heater
laundry
bathroom 1
kitchen
dishwasher
bathroom 2

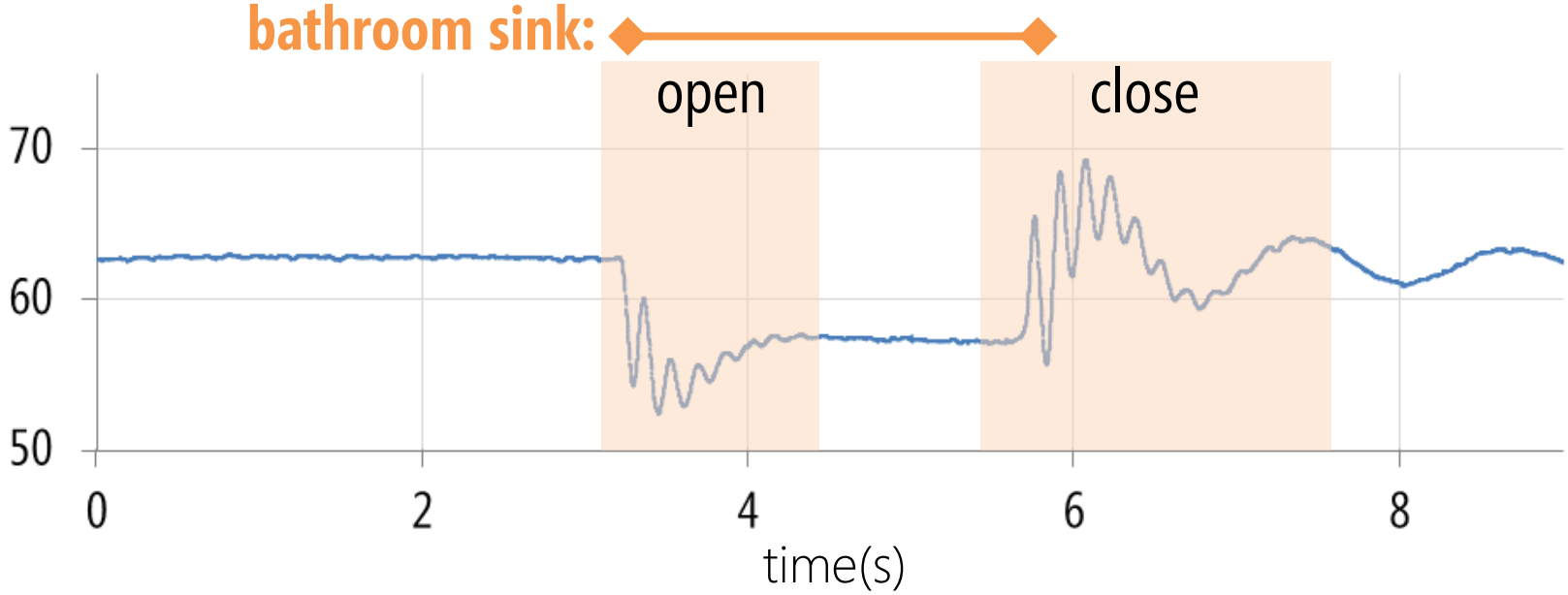
22%

of all water events were compound

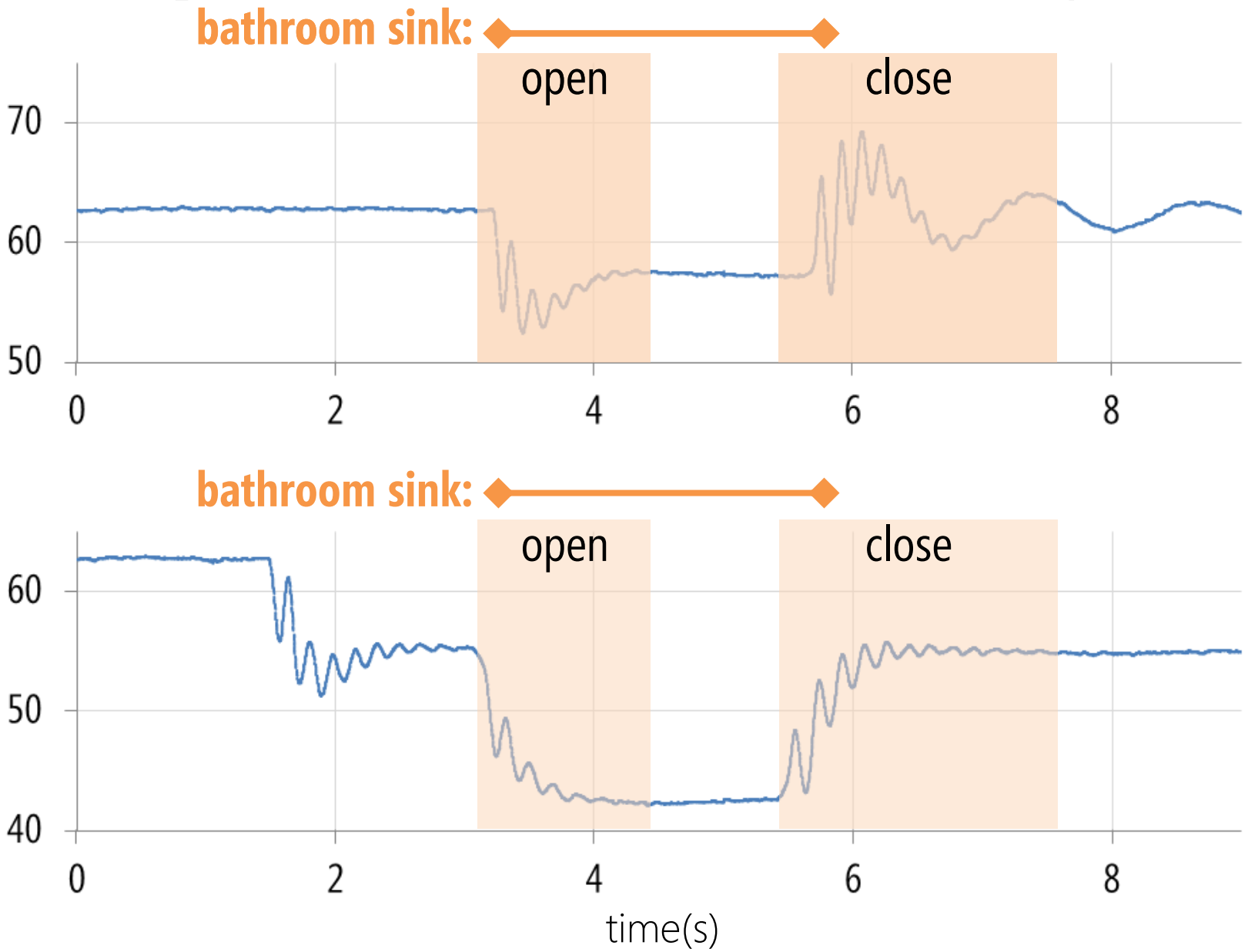
41.8%

of all bathroom sink events were compound

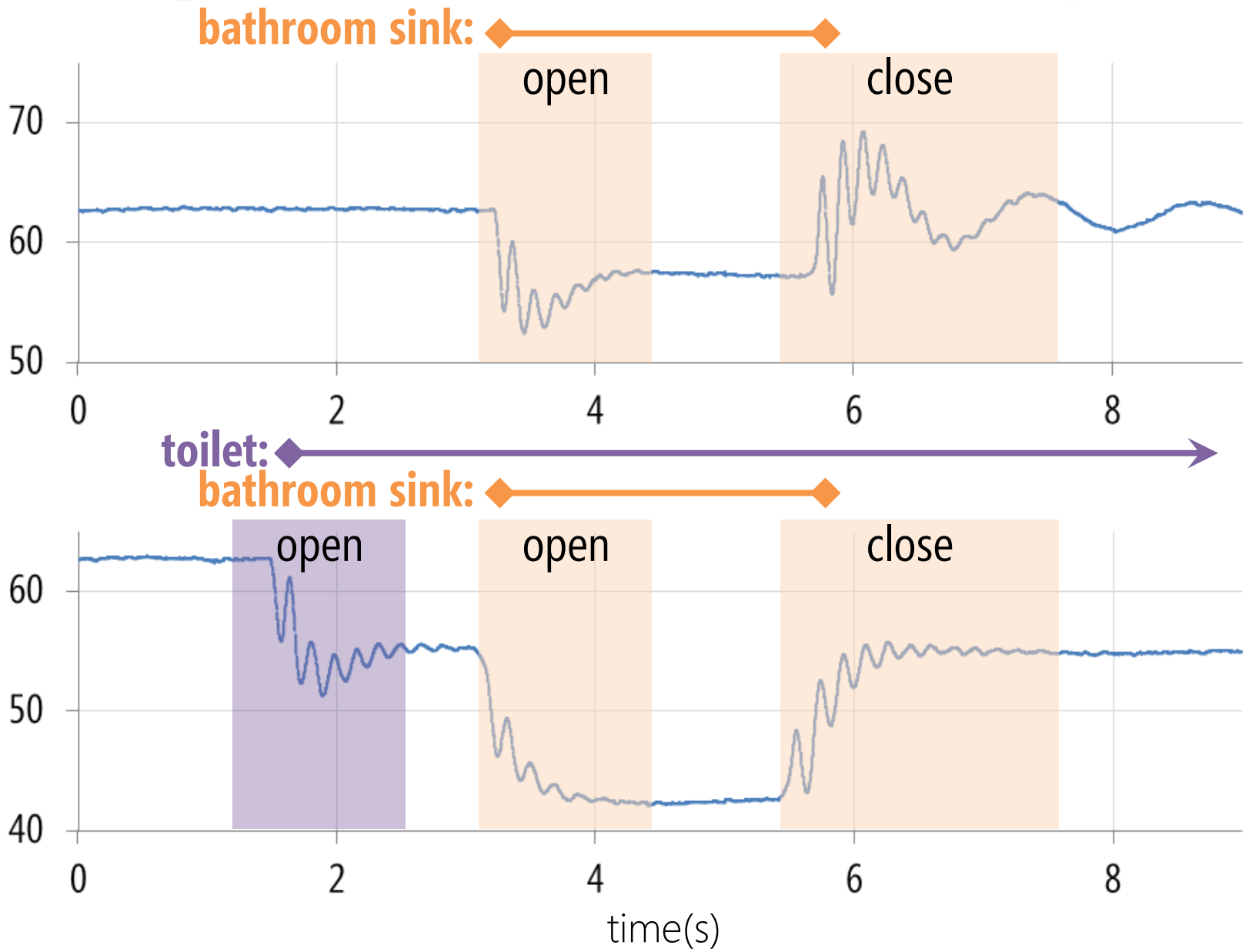
compound event example



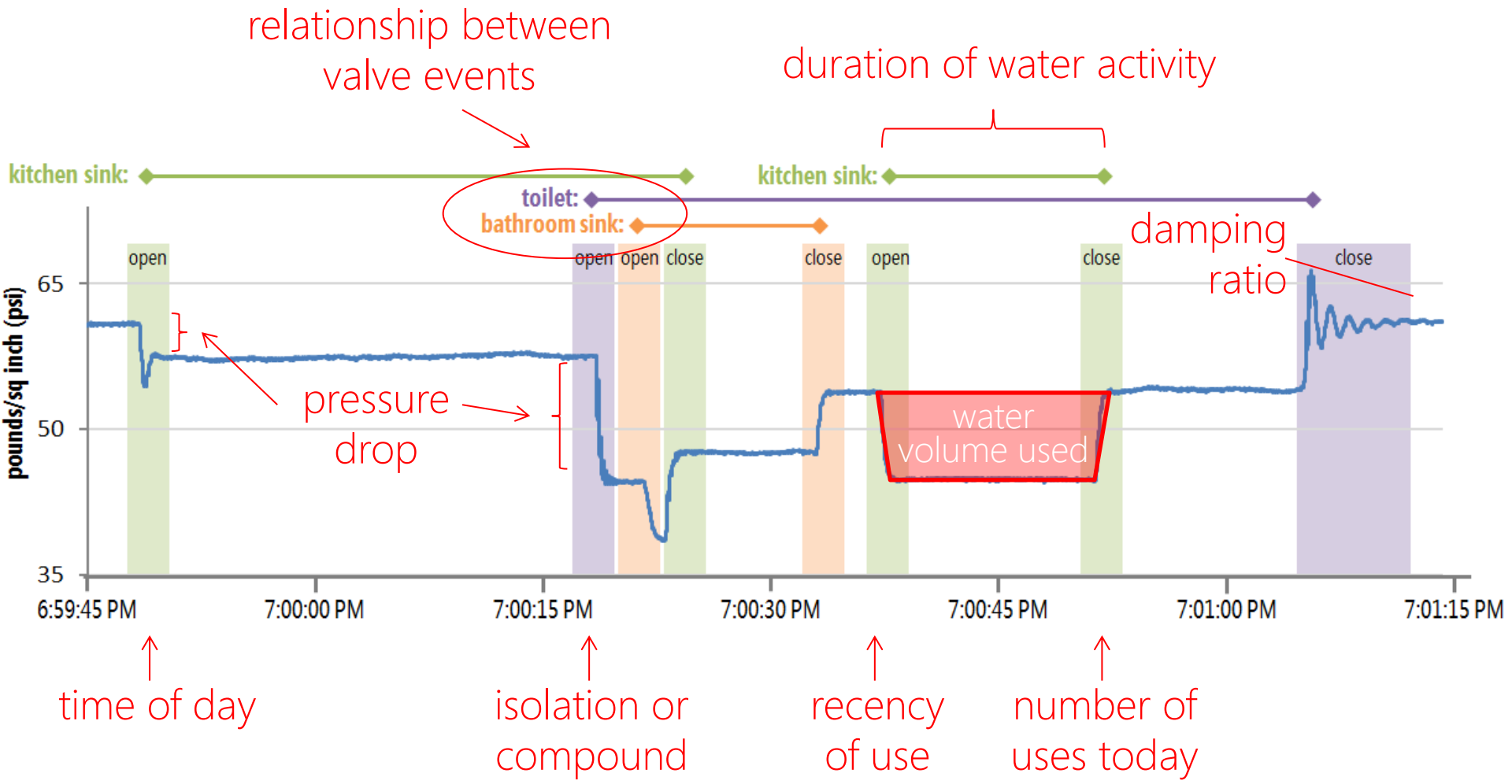
compound event example



compound event example



beyond **template matching**



bayesian approach

New algorithm borrows from Bayesian inference in speech recognition

signal

behavior

$$P(\mathbf{S}|\mathbf{V}) \qquad P(\mathbf{V})$$

$$\underbrace{\prod_{r=0}^{R-1} f_r(\hat{\mathbf{S}}_r \mid \hat{\mathbf{V}}_r)}_{\text{(i) templates and signal features}} \underbrace{\prod_{n=0}^{N-1} P(v_n \mid v_{n-1})}_{\text{(ii) bigram language model}} \underbrace{\prod_{i \notin \beta} f_p(v_i)}_{\text{(iii) grammar}} \underbrace{\prod_{k=0}^{K-1} \prod_{\langle a,b \rangle \in \beta} f_k(\langle v_a, v_b \rangle)}_{\text{(iv) paired valve priors}}$$

bayesian approach

V = pressure signature library

S = sequence of unknown pressure transients

most likely valve sequence

$$\hat{V} = \arg\max P(\mathbf{V} \mid \mathbf{S}) = \arg\max \frac{P(\mathbf{S} \mid \mathbf{V})P(\mathbf{V})}{P(\mathbf{S})}$$

bayesian approach

V = pressure signature library

S = sequence of unknown pressure transients

conditional probability term

$$\hat{V} = \arg\max P(\mathbf{V} \mid \mathbf{S}) = \arg\max \frac{P(\mathbf{S} \mid \mathbf{V}) P(\mathbf{V})}{P(\mathbf{S})}$$

$$\overbrace{\prod_{r=0}^{R-1} f_r(\hat{\mathbf{S}}_r \mid \hat{\mathbf{V}}_r)}^{P(\mathbf{S}|\mathbf{V})}$$

(i) templates and signal features

e.g., matched filtering and stabilized pressure drop

bayesian approach

V = pressure signature library

S = sequence of unknown pressure transients

prior probability term

$$\hat{V} = \arg\max P(\mathbf{V} \mid \mathbf{S}) = \arg\max \frac{P(\mathbf{S} \mid \mathbf{V}) P(\mathbf{V})}{P(\mathbf{S})}$$

$$\overbrace{\underbrace{\prod_{r=0}^{R-1} f_r(\hat{\mathbf{S}}_r \mid \hat{\mathbf{V}}_r)}_{\text{(i) templates and signal features}} \underbrace{\prod_{n=0}^{N-1} P(v_n \mid v_{n-1})}_{\text{(ii) bigram language model}}}^{P(\mathbf{S}|\mathbf{V})}$$

e.g., transition probability for toilet open->bathroom sink open

bayesian approach

V = pressure signature library

S = sequence of unknown pressure transients

prior probability term

$$\hat{V} = \arg\max P(\mathbf{V} \mid \mathbf{S}) = \arg\max \frac{P(\mathbf{S} \mid \mathbf{V}) P(\mathbf{V})}{P(\mathbf{S})}$$

$$\overbrace{\underbrace{\prod_{r=0}^{R-1} f_r(\hat{\mathbf{S}}_r \mid \hat{\mathbf{V}}_r)}_{\text{(i) templates and signal features}} \underbrace{\prod_{n=0}^{N-1} P(v_n \mid v_{n-1})}_{\text{(ii) bigram language model}} \underbrace{\prod_{i \notin \beta} f_p(v_i)}_{\text{(iii) grammar}}}^{P(\mathbf{S}|\mathbf{V})}$$

e.g., opening of valve v_x must be followed by closing of v_x

bayesian approach

V = pressure signature library

S = sequence of unknown pressure transients

prior probability term

$$\hat{V} = \arg\max P(\mathbf{V} \mid \mathbf{S}) = \arg\max \frac{P(\mathbf{S} \mid \mathbf{V}) P(\mathbf{V})}{P(\mathbf{S})}$$

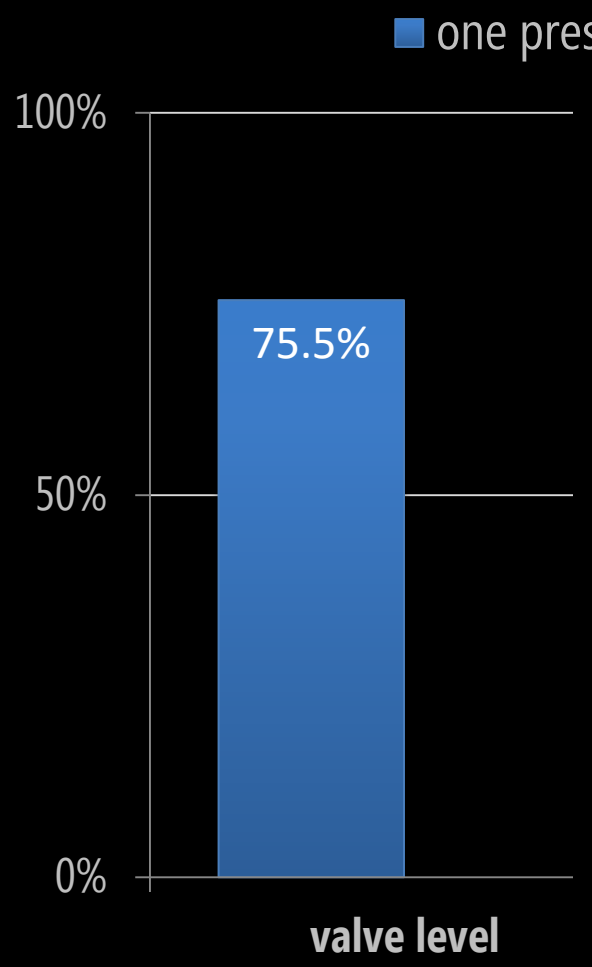
$P(\mathbf{S}|\mathbf{V})$ $P(\mathbf{V})$

$$\underbrace{\prod_{r=0}^{R-1} f_r(\hat{\mathbf{S}}_r \mid \hat{\mathbf{V}}_r)}_{\text{(i) templates and signal features}} \underbrace{\prod_{n=0}^{N-1} P(v_n \mid v_{n-1})}_{\text{(ii) bigram language model}} \underbrace{\prod_{i \notin \beta} f_p(v_i)}_{\text{(iii) grammar}} \underbrace{\prod_{k=0}^{K-1} \prod_{\langle a,b \rangle \in \beta} f_k(\langle v_a, v_b \rangle)}_{\text{(iv) paired valve priors}}$$

e.g., water usage duration

hydrosense classification results

real-world water usage data



hydrosense classification results

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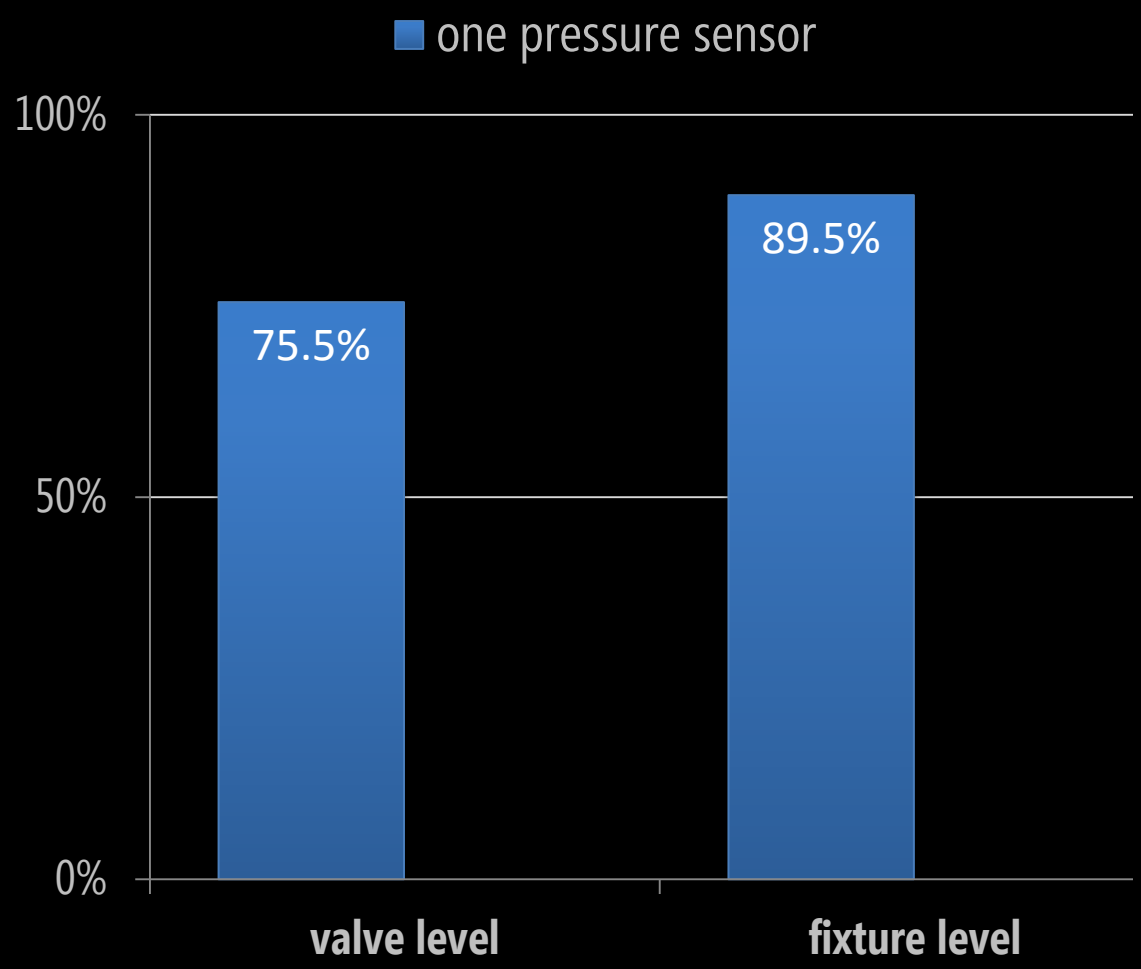

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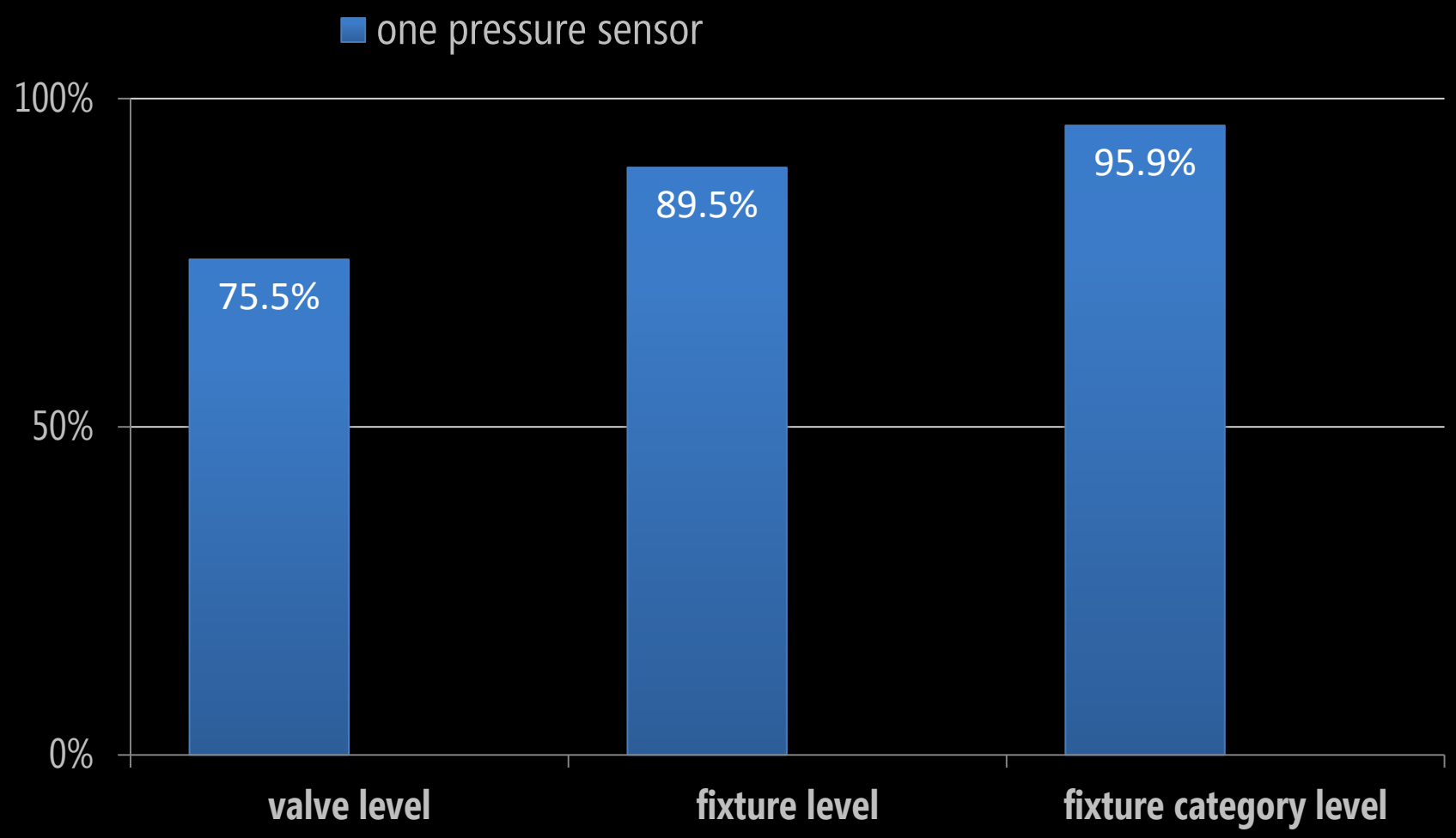

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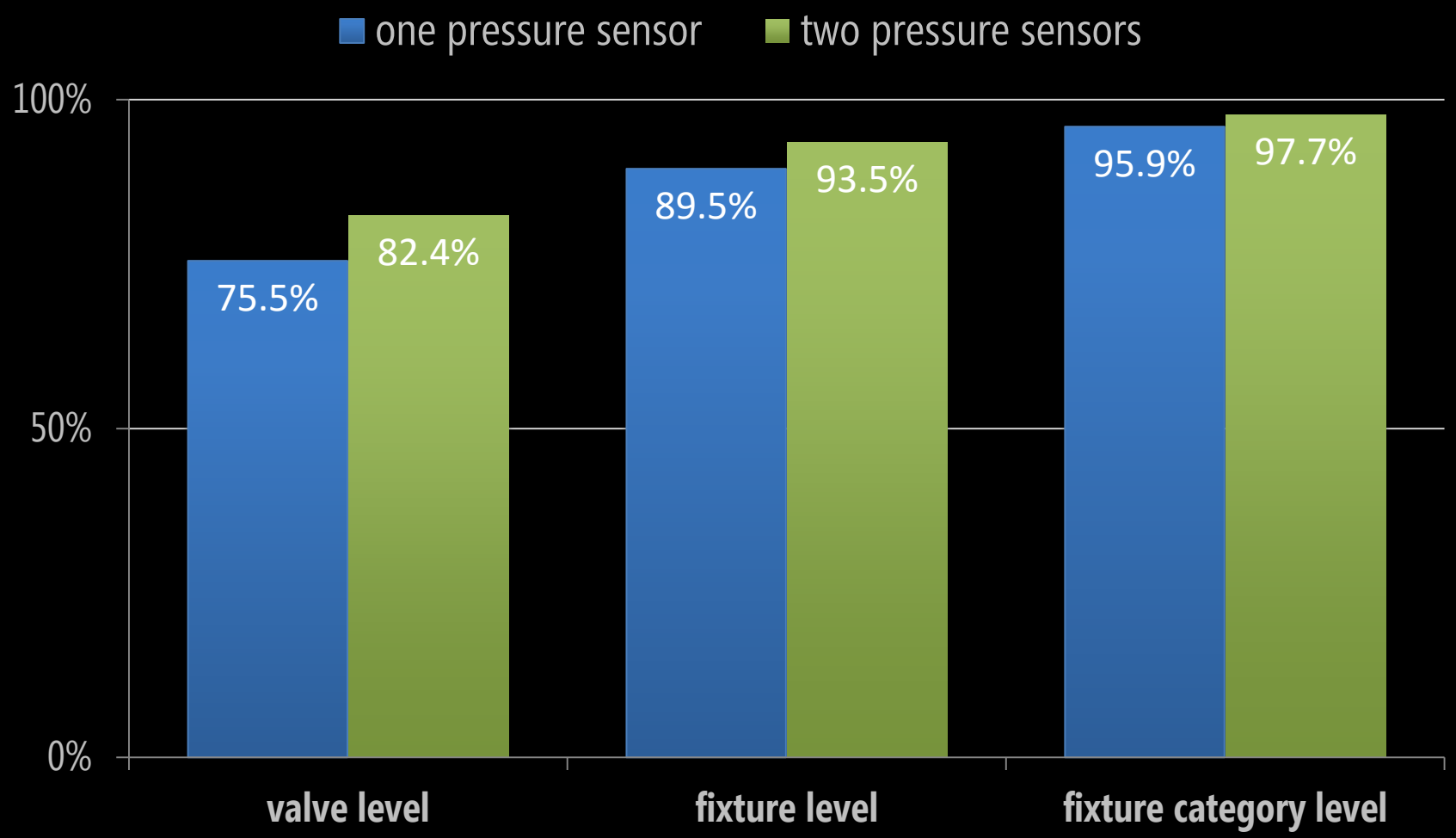
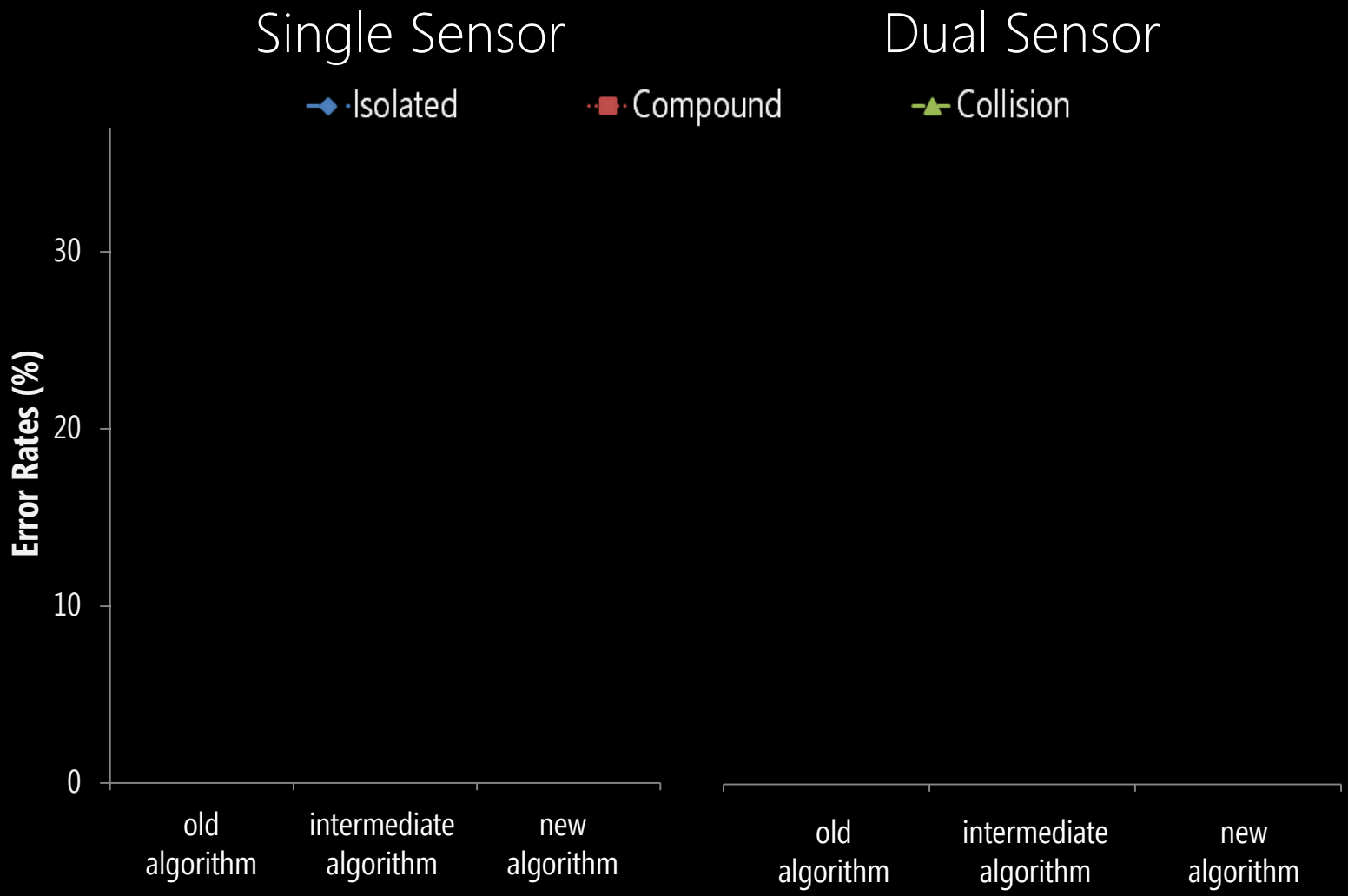


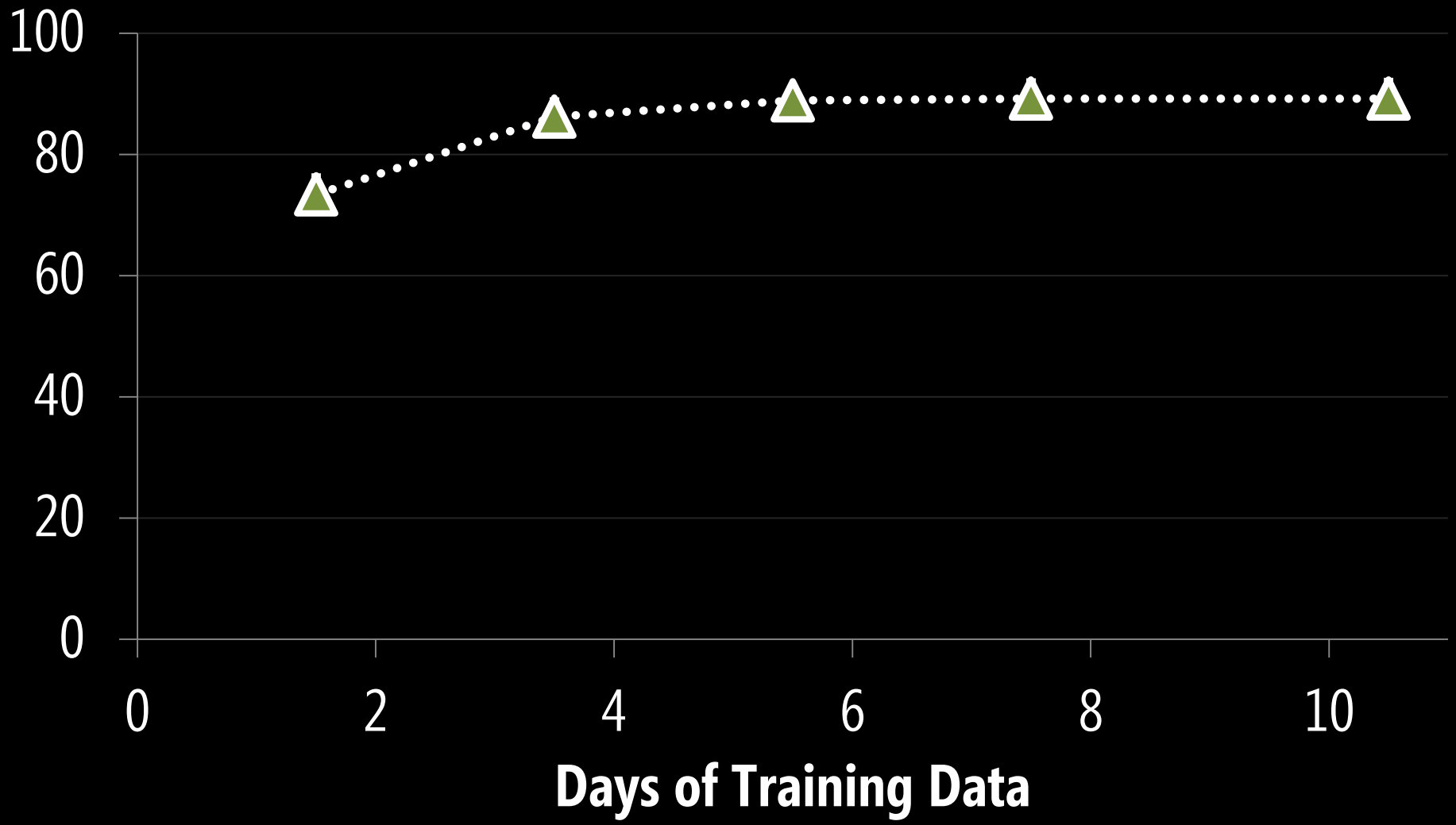
compound events results

real-world water usage data



hydrosense training results

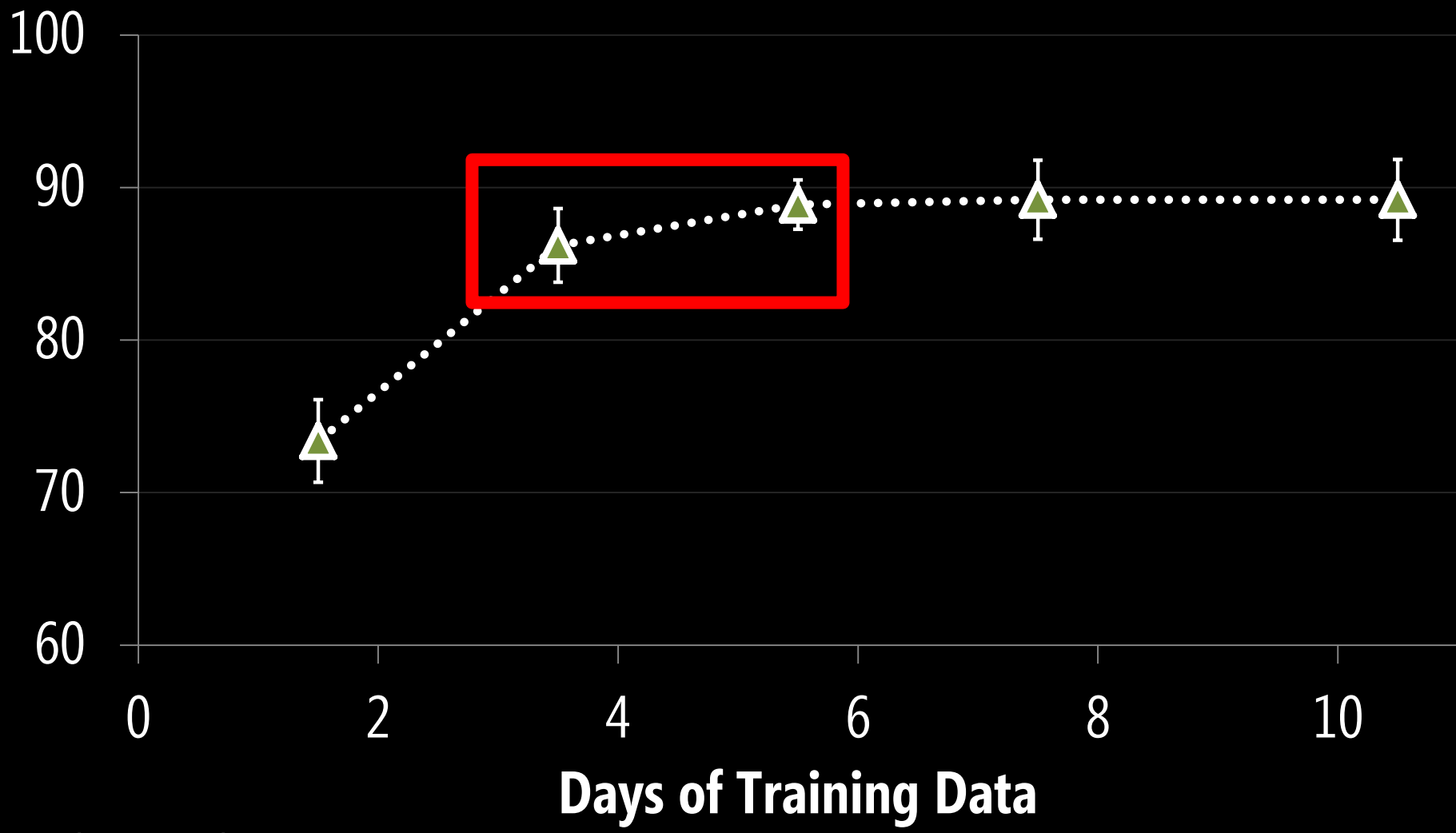
real-world water usage data



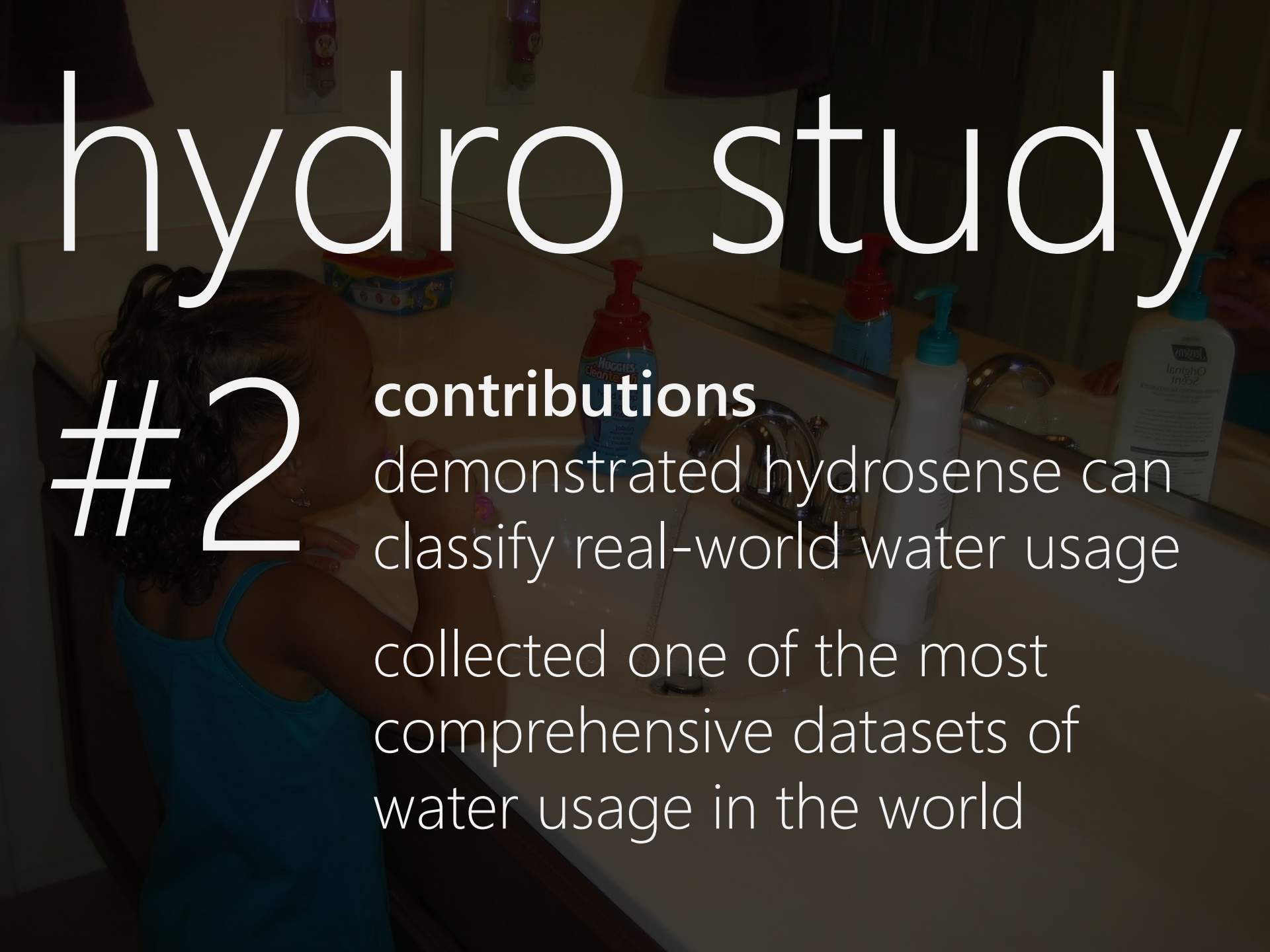
*error bars = std error

hydrosense training results

real-world water usage data



*error bars = std error



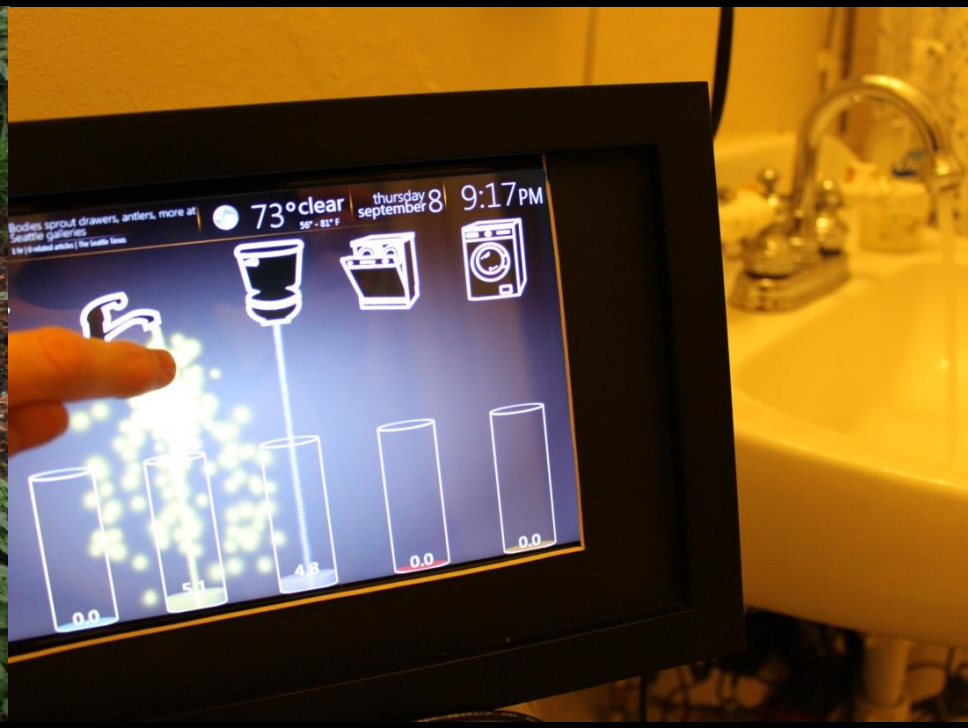
hydro study #2

contributions

demonstrated hydrosense can classify real-world water usage

collected one of the most comprehensive datasets of water usage in the world

HydroSense + **Reflect**$_2$O



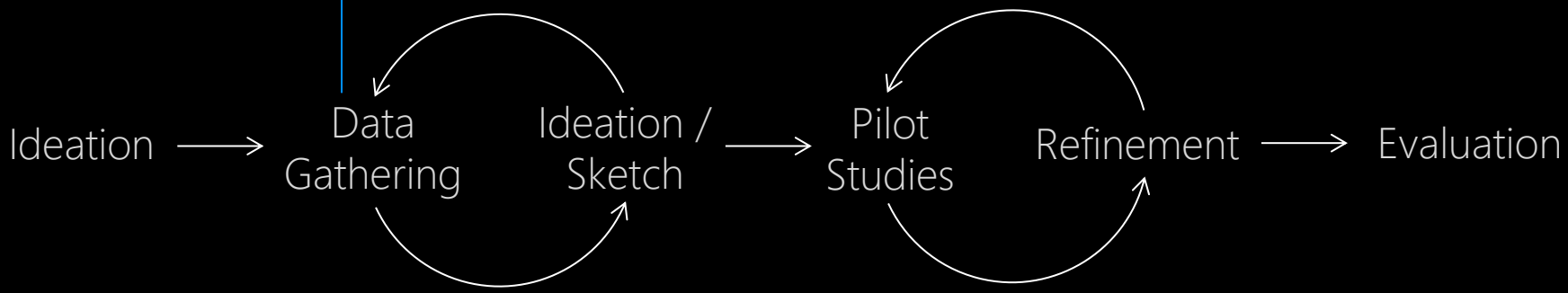
sensingfeedback

Two sets of designs:

1 **Design Dimensions**
Isolate eco-feedback design dimensions in the context of water usage

2 **Design Probes**
Meant to elicit reactions about how displays would fit within a household and investigate issues such as privacy, competition, family dynamics.

Informal interviews with water experts (e.g., SPU, Amy Vickers)
UW Environmental Practicum on water
Literature review of water resource management, environmental psychology
Our own online survey of water usage attitudes & knowledge (N=656 respondents)



Respondents (N=651) dramatically **underestimated** the amount of water used in common everyday activities.

	underestimate
toilet :	by 15%
shower :	by 30%
bath :	by 55%
low-flow shower :	by 60%
outdoor yard watering :	by 83% to 95%

[Froehlich, UW PhD Dissertation, 2011]

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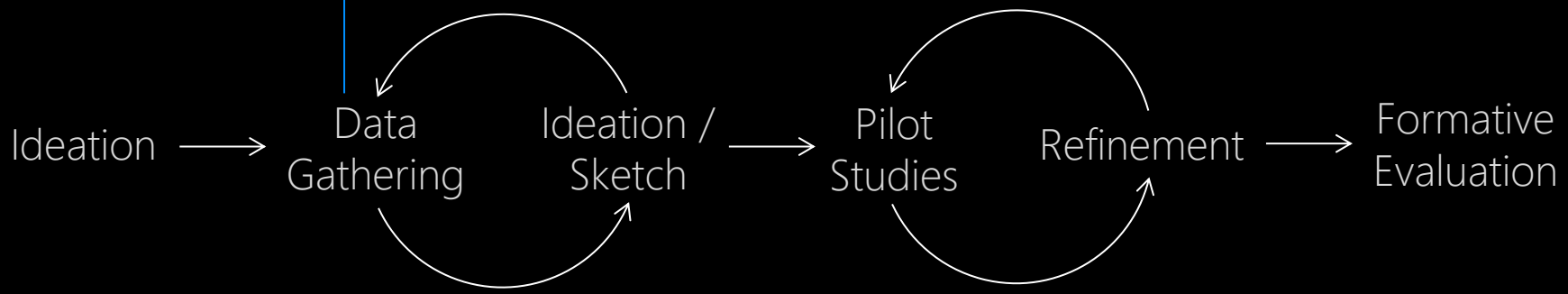

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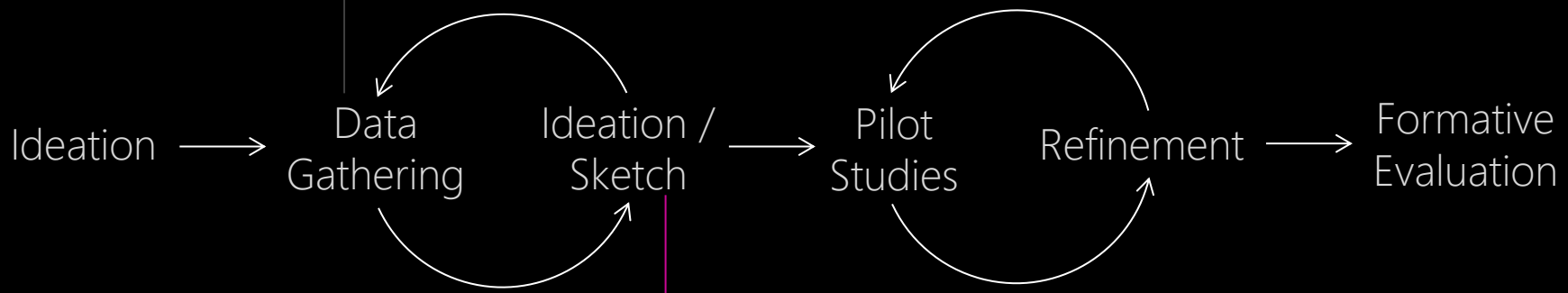


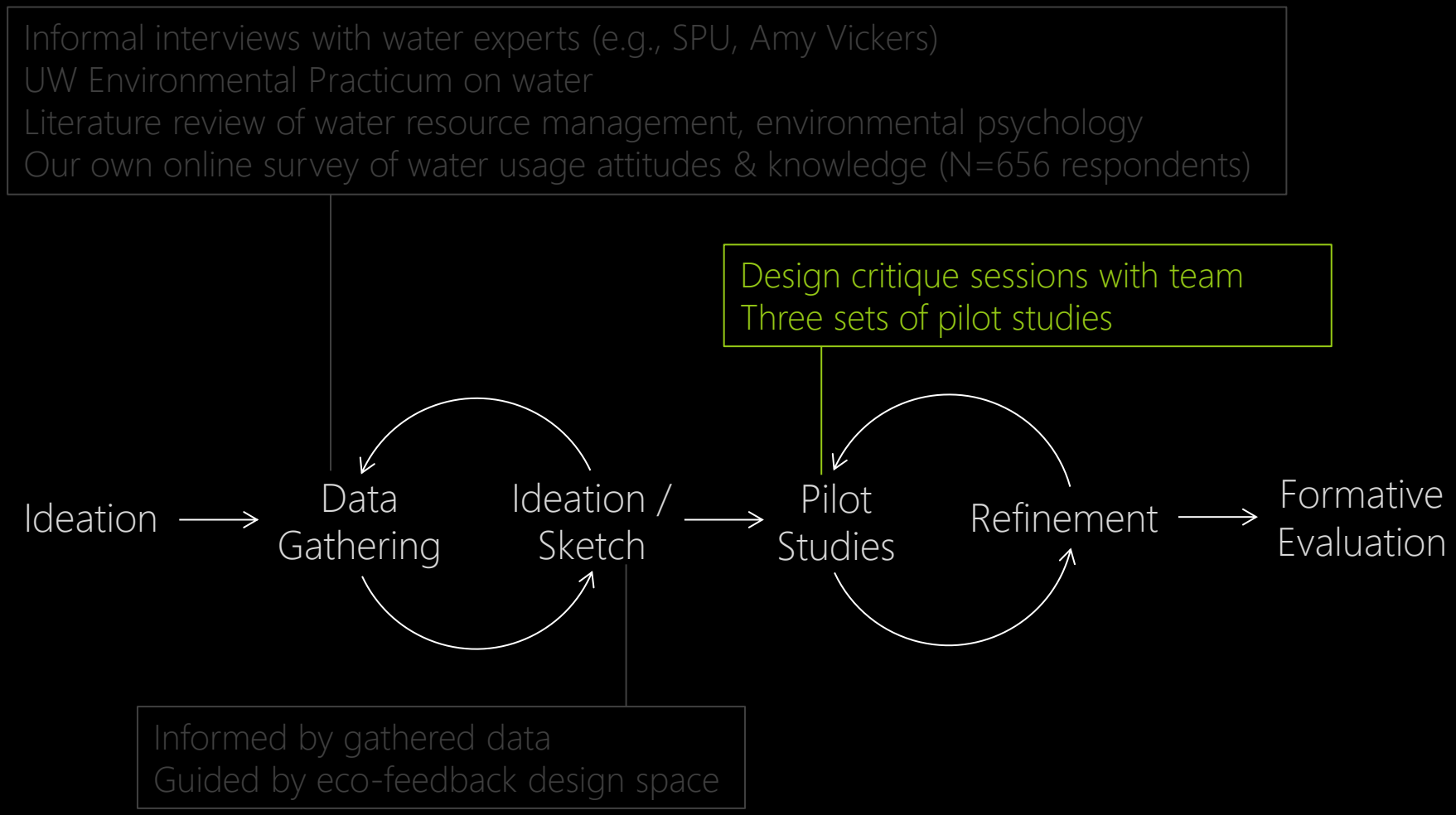
Informed by gathered data
Guided by eco-feedback design space

Iterative Design Process

Sketch

Lo-to-Mid Fidelity Mockup

Higher Fidelity Mockup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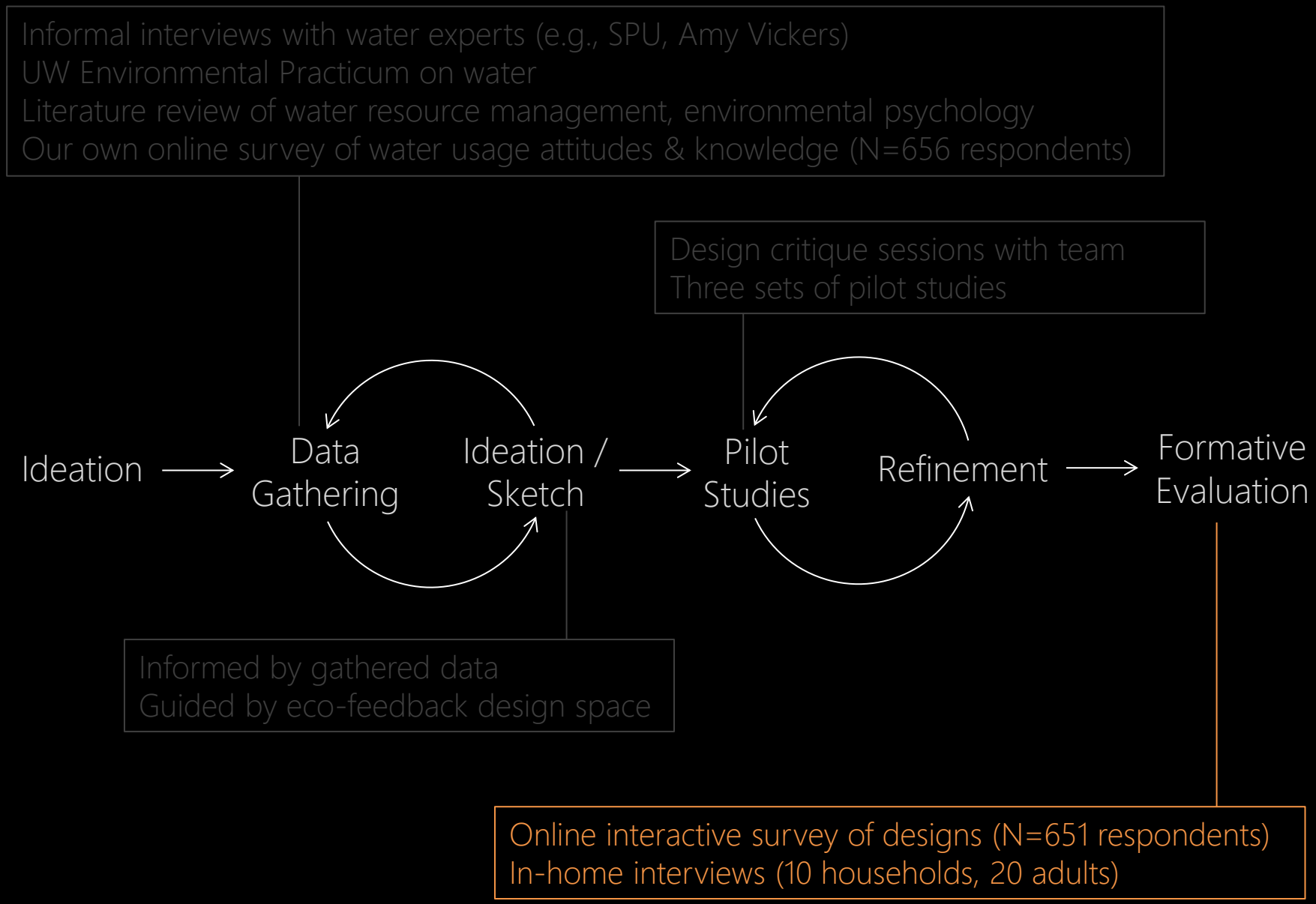
Our own online survey of water usage attitudes & knowledge (N=656 respondents)
Design critique sessions with team
Three sets of pilot studies
Ideation
Data Gathering
Ideation / Sketch
Pilot Studies
Refinement
Formative Evaluation
Informed by gathered data
Guided by eco-feedback design space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Design critique sessions with team
Three sets of pilot studies
Ideation
Data Gathering
Ideation / Sketch
Pilot Studies
Refinement
Formative Evaluation
Informed by gathered data
Guided by eco-feedback design space
Online interactive survey of designs (N=651 respondents)
In-home interviews (10 households, 20 adults)

Two sets of designs:

1 **Design Dimensions**
Isolate eco-feedback design dimensions in the context of water usage

2 **Design Probes**
Meant to elicit reactions about how displays would fit within a household and investigate issues such as privacy, competition, family dynamics.

DESIGN SET 1: ISOLATING DESIGN DIMENSIONS

Design Dimensions Explored

① **Data** Granularity

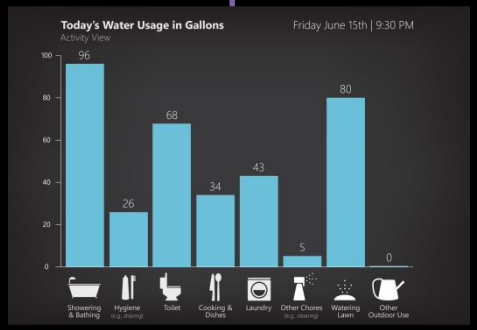
② **Time** Granularity

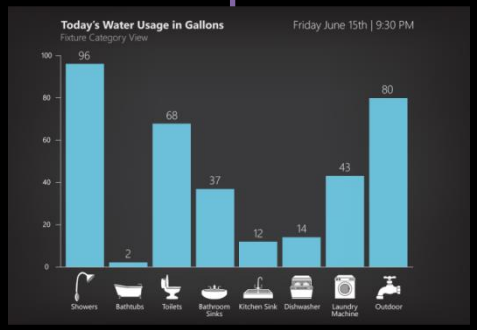
③ **Measurement** Unit

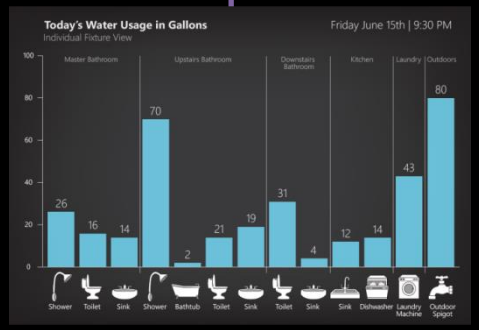
④ **Comparison**

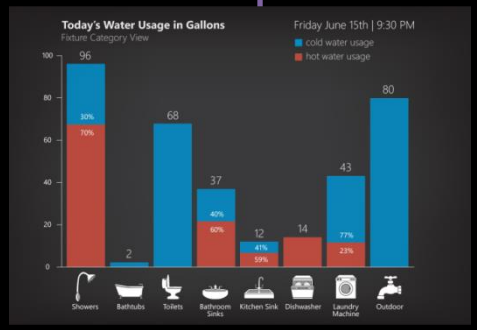
Data Granularity

coarse-grain ⟵ ≥neighbor-hood — home — room — activity — fixture category — fixture — ≤ valve ⟶ **fine-grain**





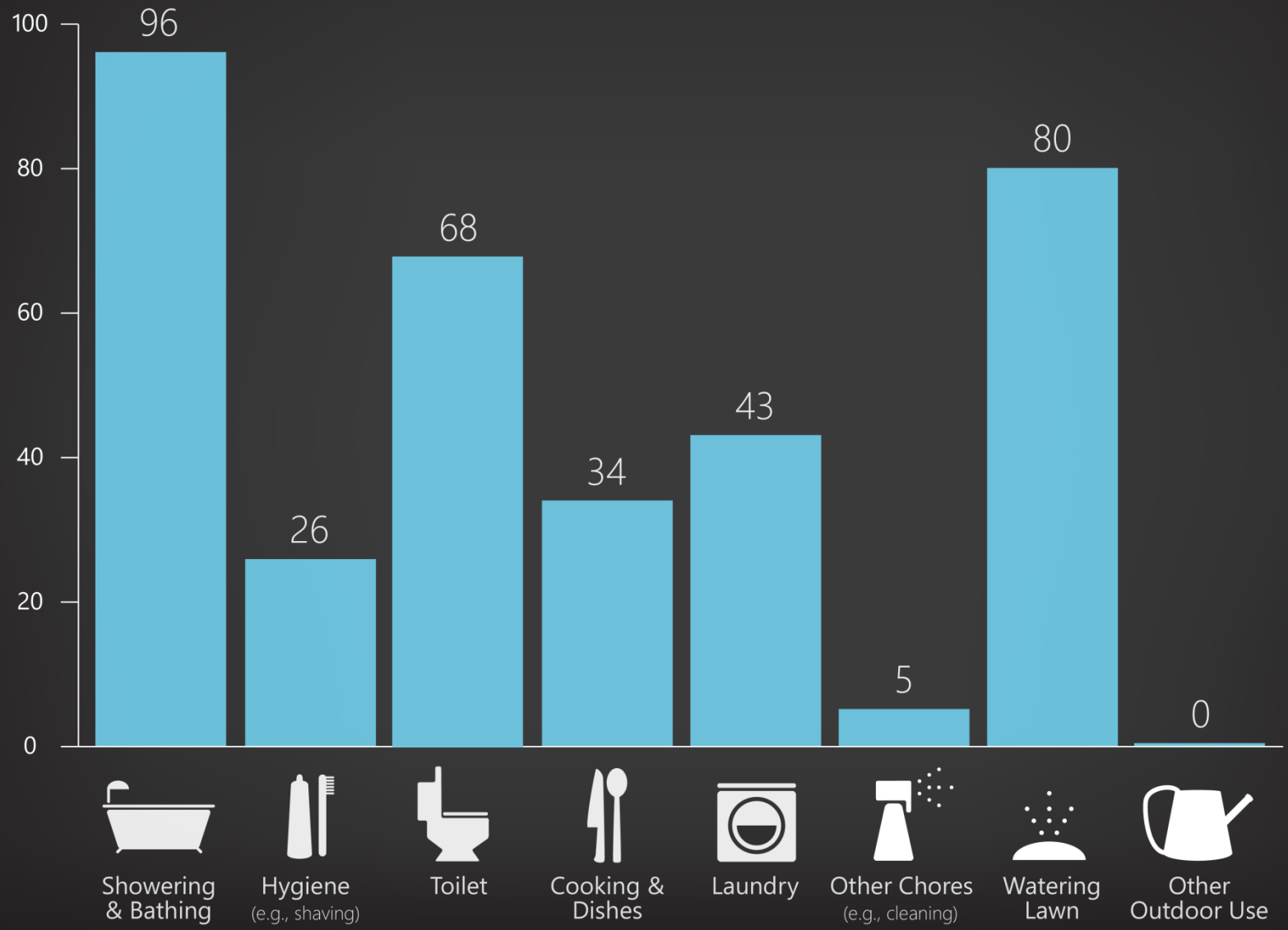




Today's Water Usage in Gallons

Activity View

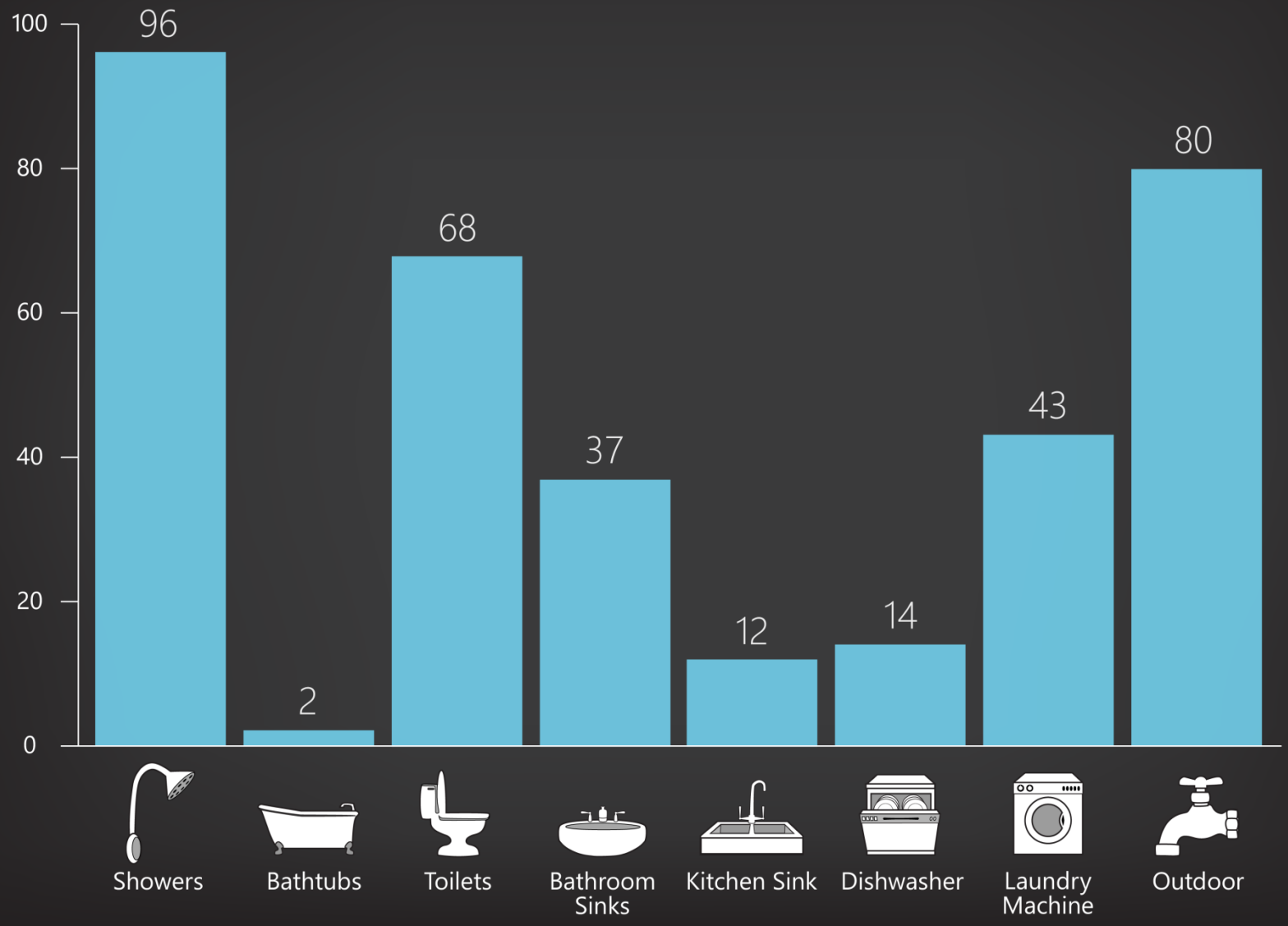
Friday June 15th | 9:30 PM



Today's Water Usage in Gallons

Fixture Category View

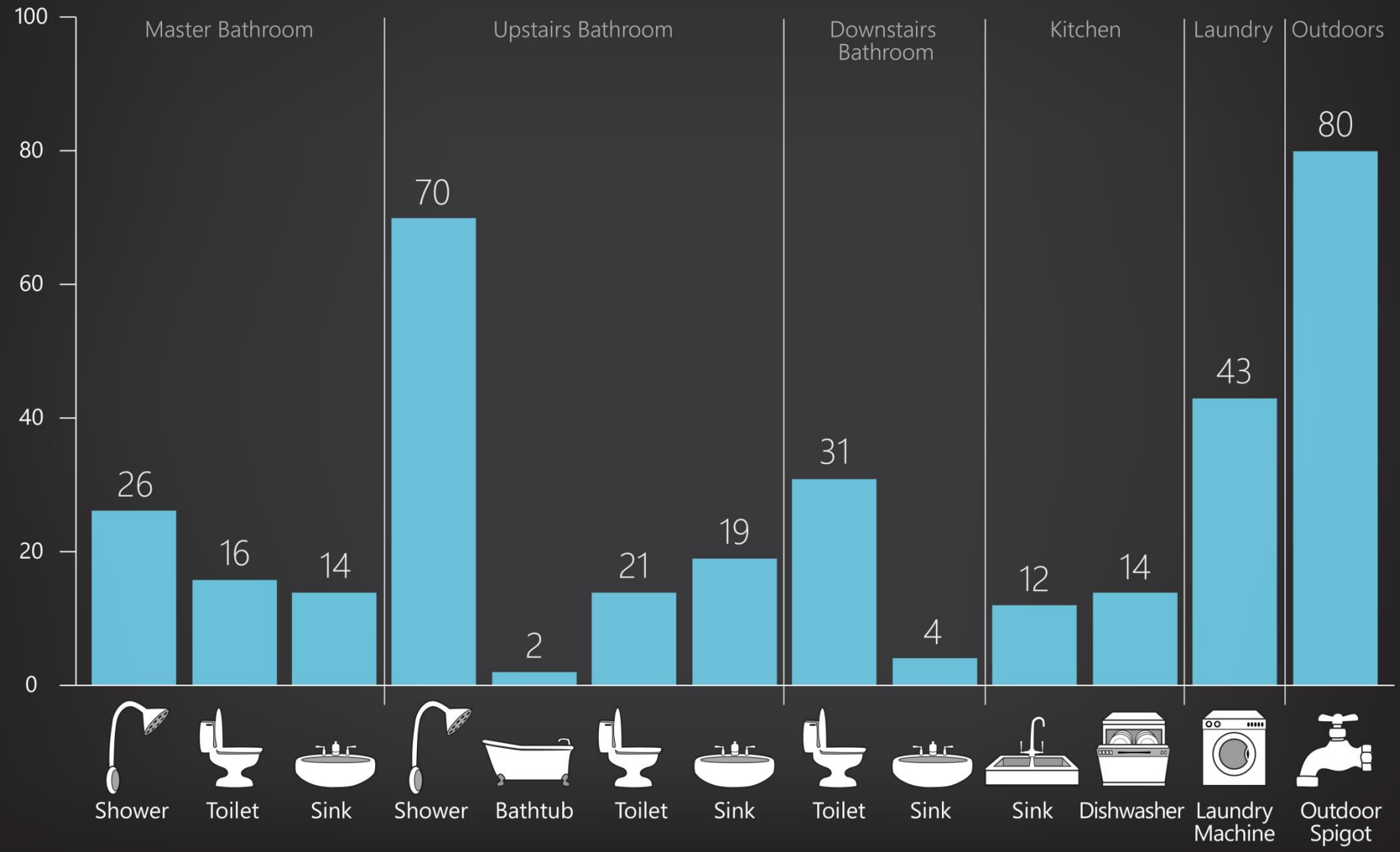
Friday June 15th | 9:30 PM



Today's Water Usage in Gallons

Individual Fixture View

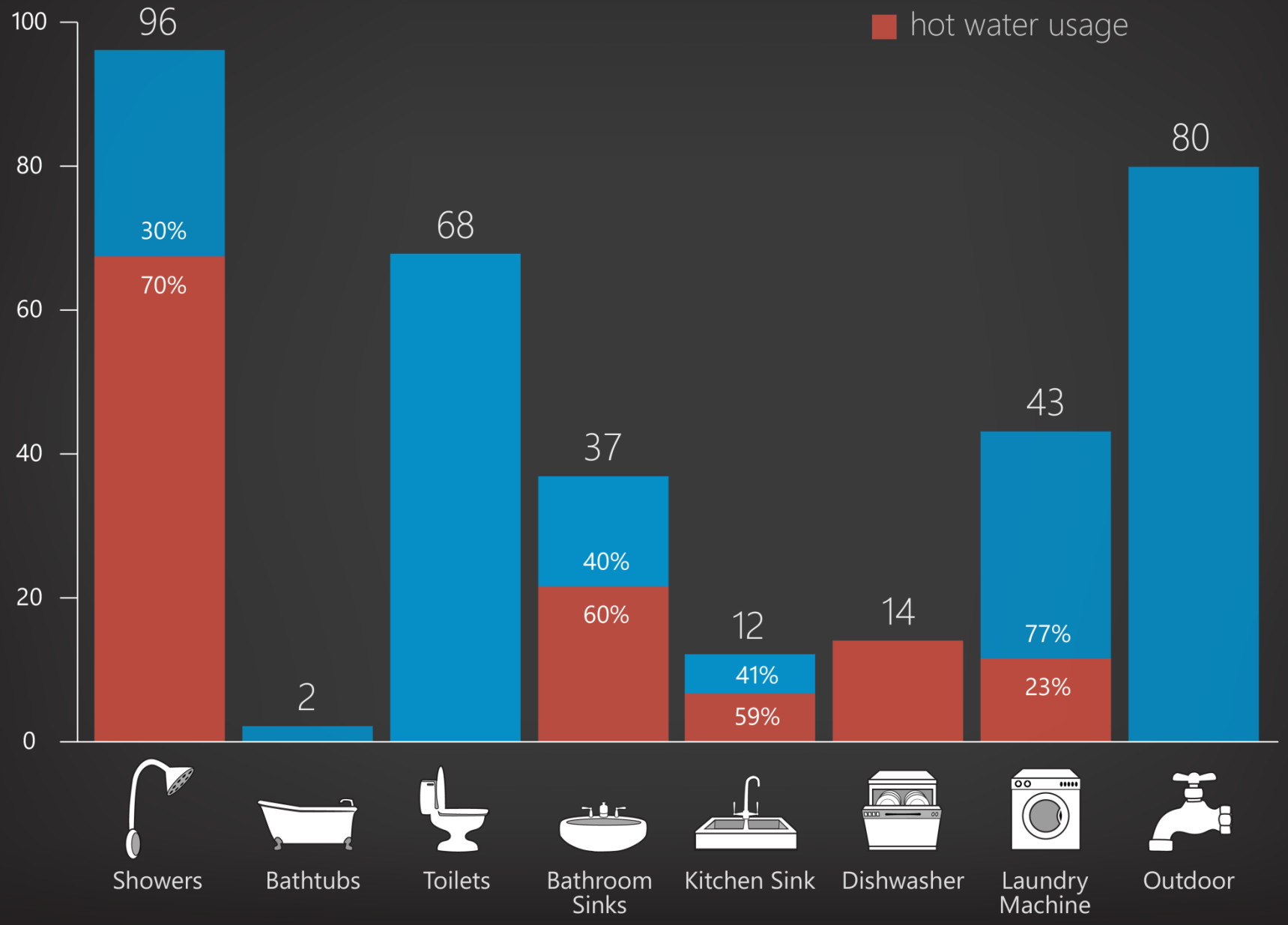
Friday June 15th | 9:30 PM



Today's Water Usage in Gallons

Fixture Category View: Hot vs Cold

Friday June 15th | 9:30 PM



Measurement Unit

resource — rate of consumption — cost — time — activity — metaphor

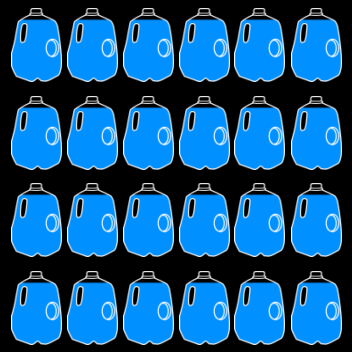
36 gallons of water

3 gpm

9 cents

12 minutes

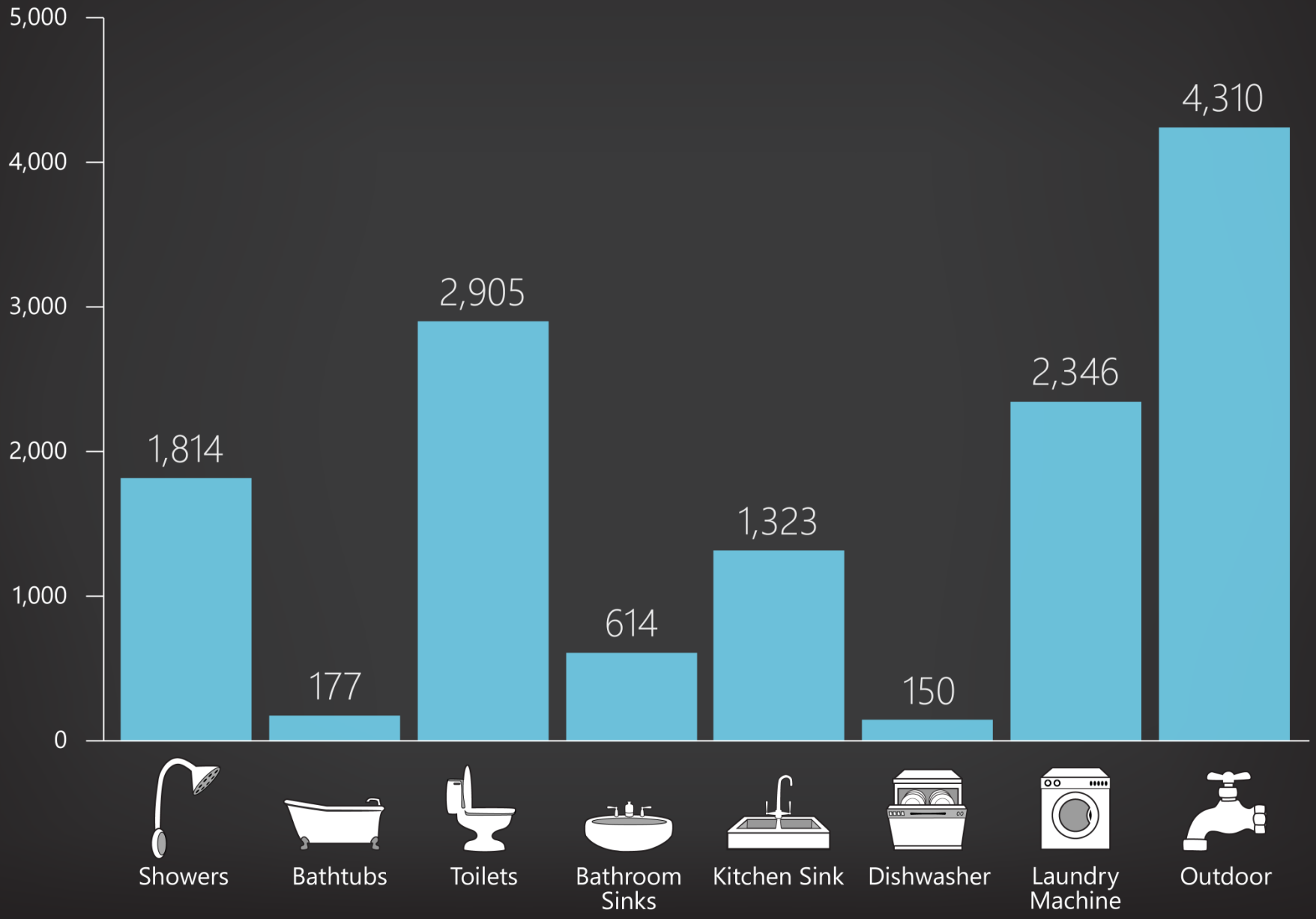
1 shower



This Month's Water Usage

Fixture Category View | In Gallons

Friday June 15th | 9:30 PM

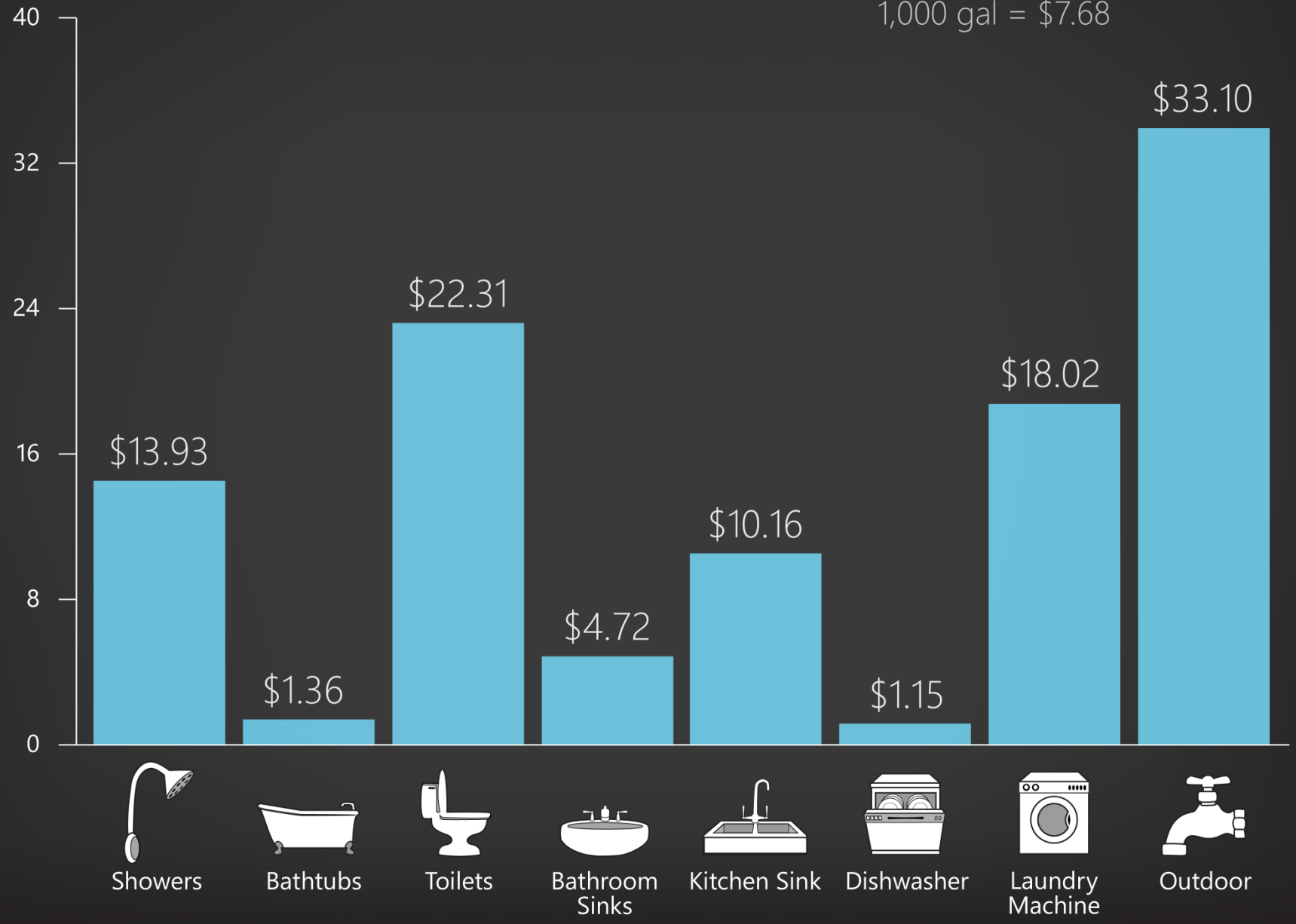


This Month's Water Usage

Fixture Category View | In Dollars

Friday June 15th | 9:30 PM

Your Current Water Rate:
1,000 gal = $7.68

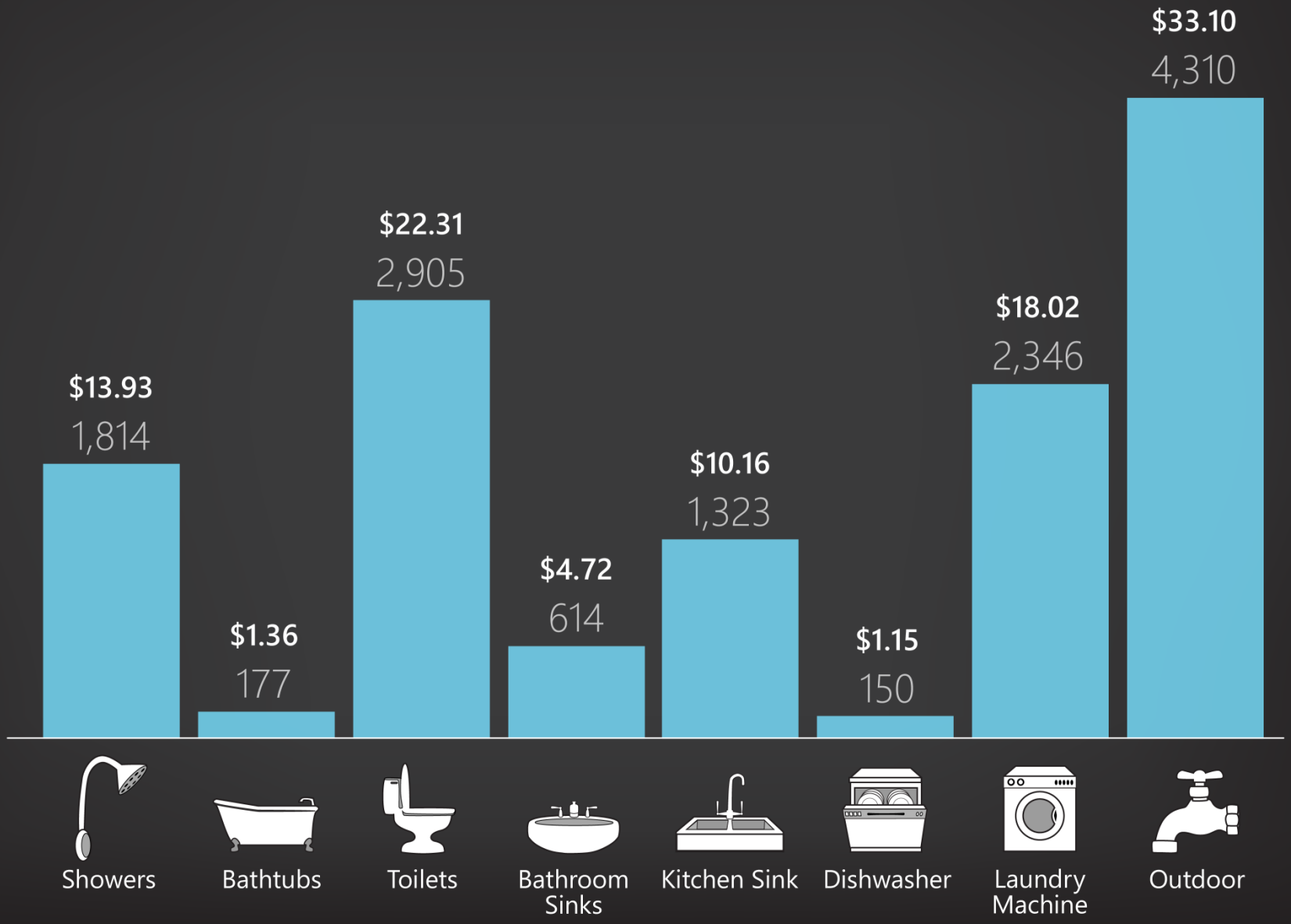


This Month's Water Usage

Fixture Category View | In Dollars & Gallons

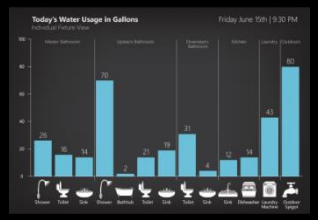
Friday June 15th | 9:30 PM

Your Current Water Rate:
1,000 gal = $7.68

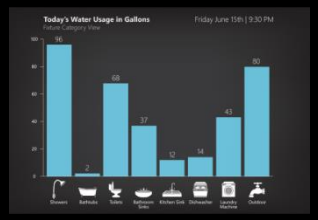


Design Dimensions Explored

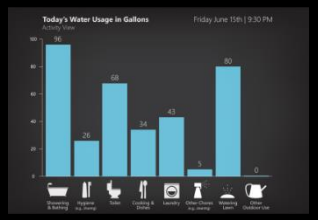
Data Granularity



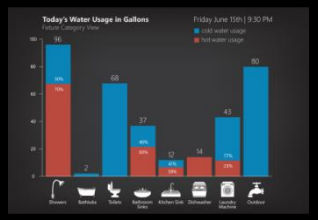
Individual Fixture



Fixture Category

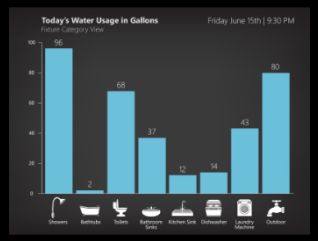


Activity

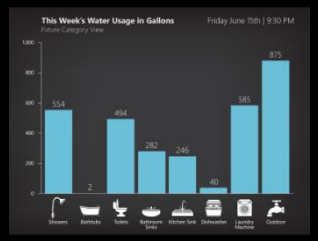


Hot and Cold

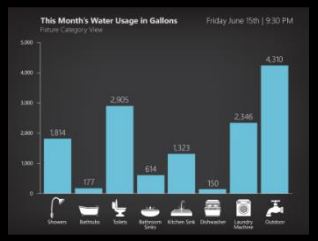
Time Granularity



So Far Today

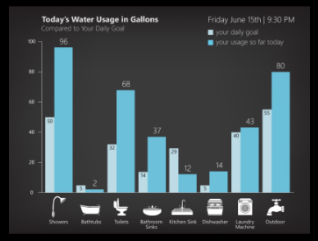


So Far This Week

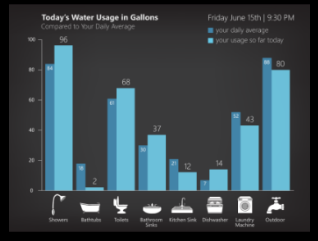


So Far This Month

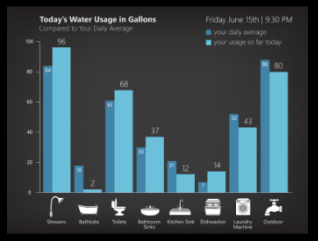
Comparison



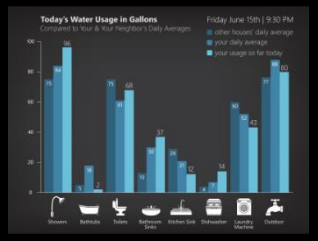
Self Comparison



To Others

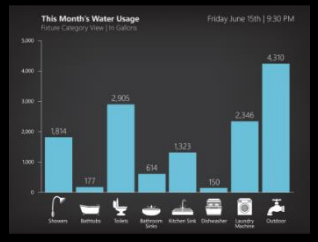


To A Goal



Social/Self

Measurement Unit



In Gallons

In Dollars

Dollars / Gallons

Including Sewage

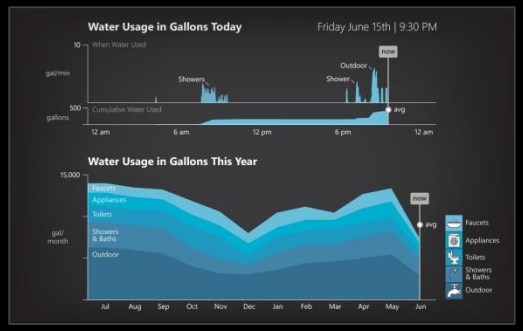
Two sets of designs:

1 **Design Dimensions**
Isolate eco-feedback design dimensions in the context of water usage

2 **Design Probes**
Meant to elicit reactions about how displays would fit within a household and investigate issues such as privacy, competition, family dynamics.

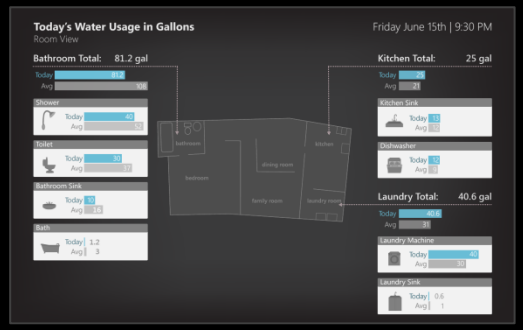
DESIGN SET 2: DESIGN PROBES

Design Probes Explored

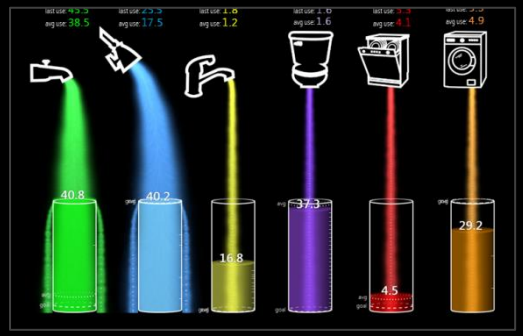


Time-Series

Aquatic Eco-system

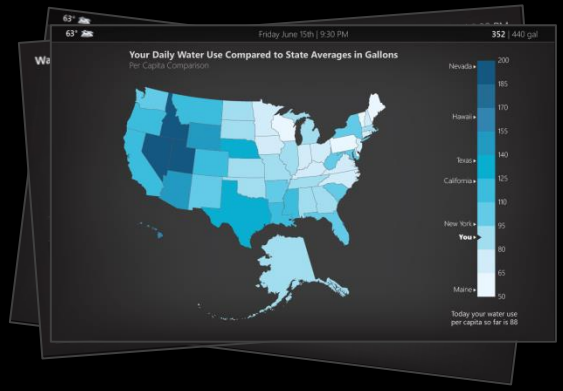


Spatial



Rainflow

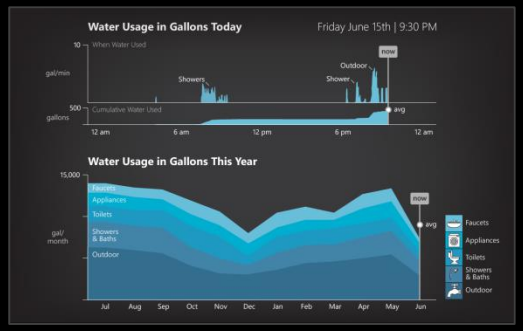
Per-Occupant



Other

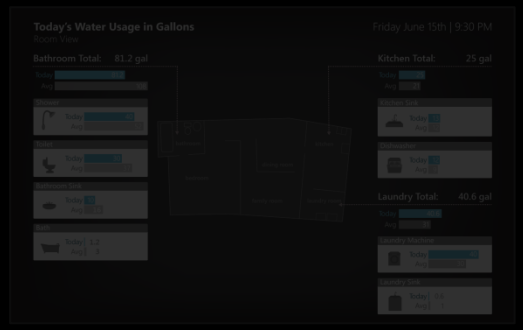
DESIGN SET 2: DESIGN PROBES

Design Probes Explored



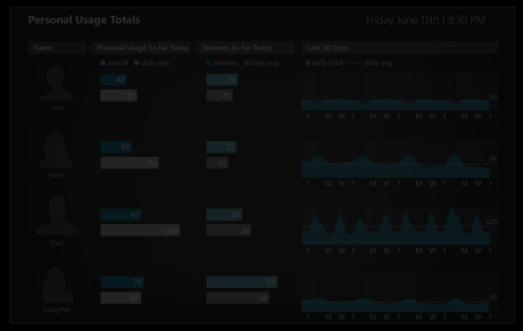
Time-Series

Aquatic Eco-system

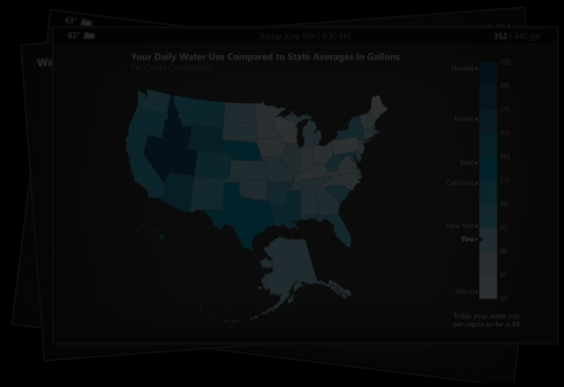


Spatial

Rainflow

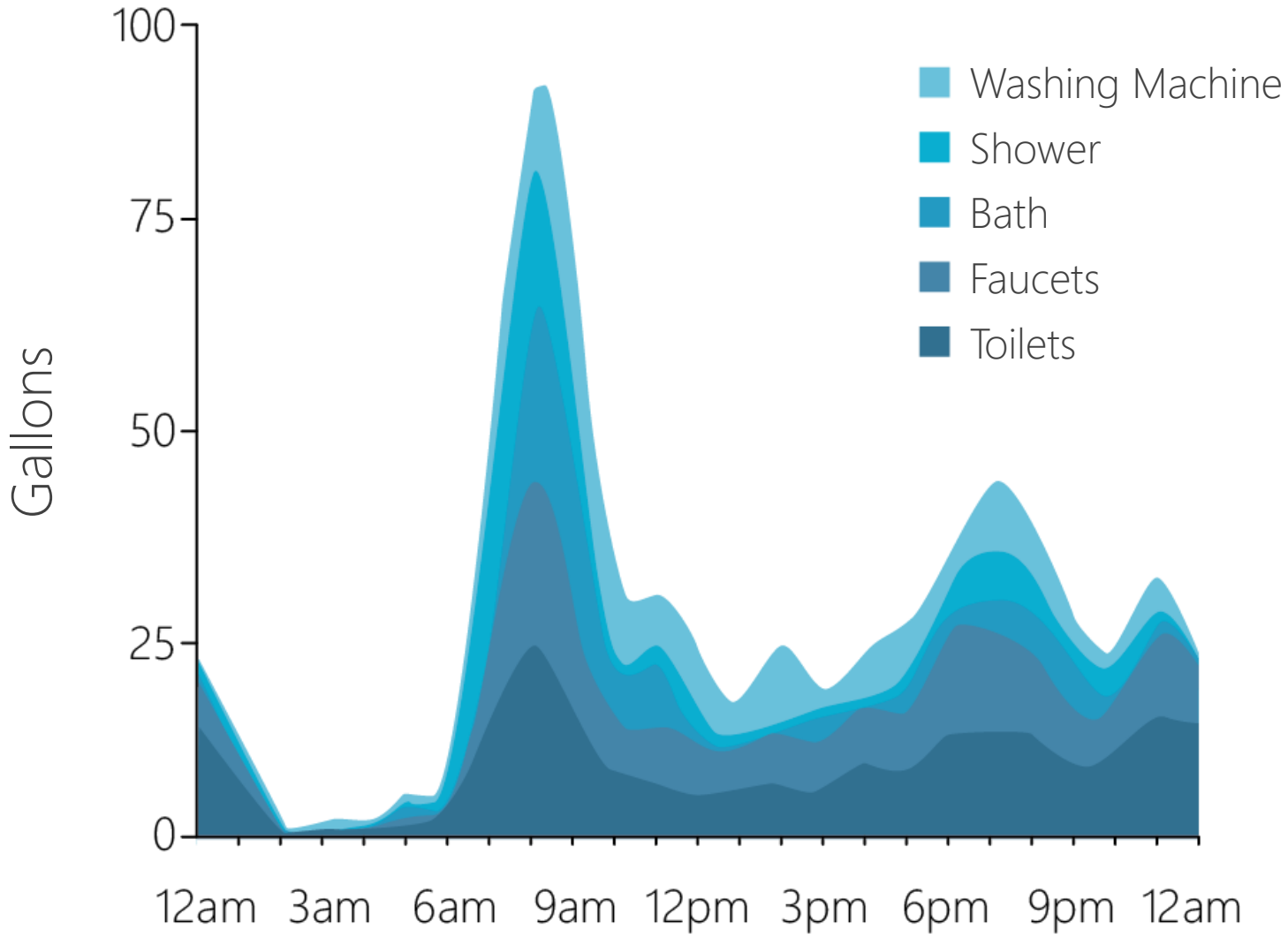


Per-Occupant



Other

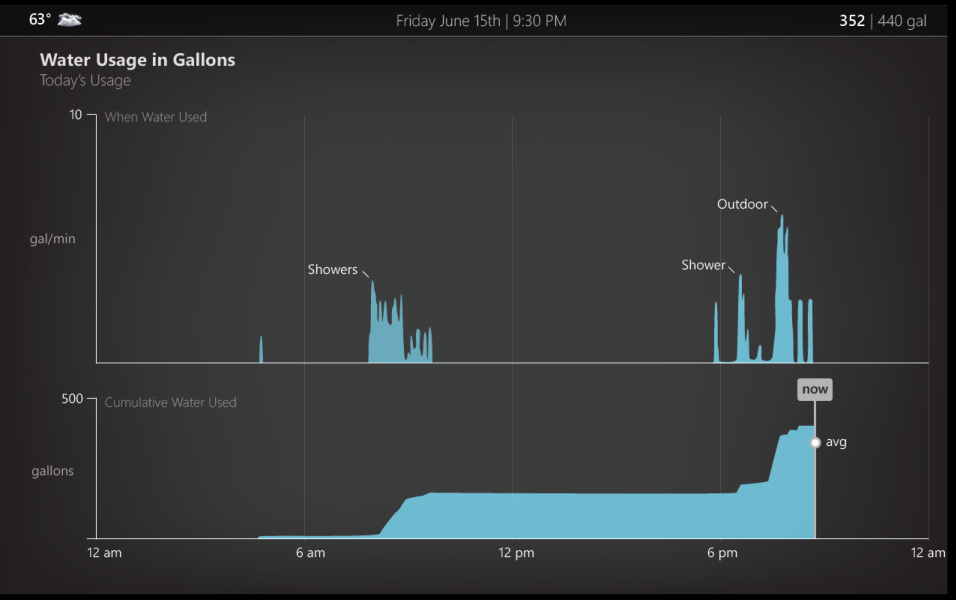
Daily Patterns of Water Usage

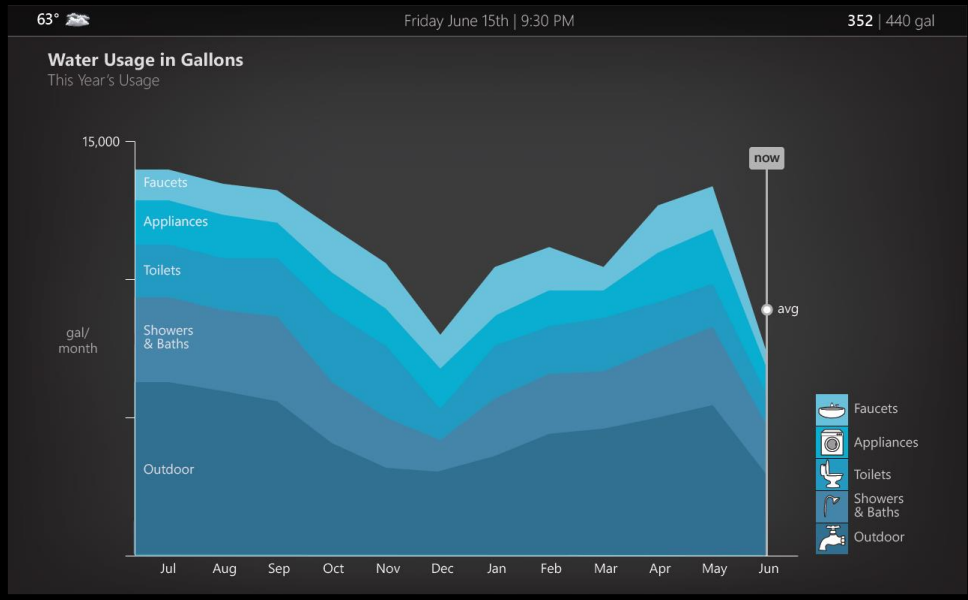


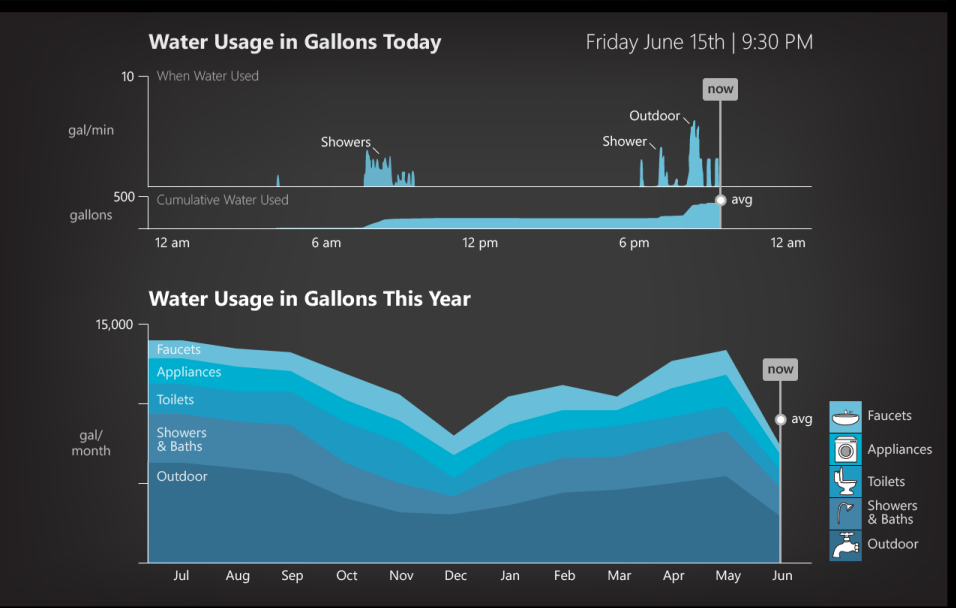
[Adapted from Butler, Building and Environment, 1993]

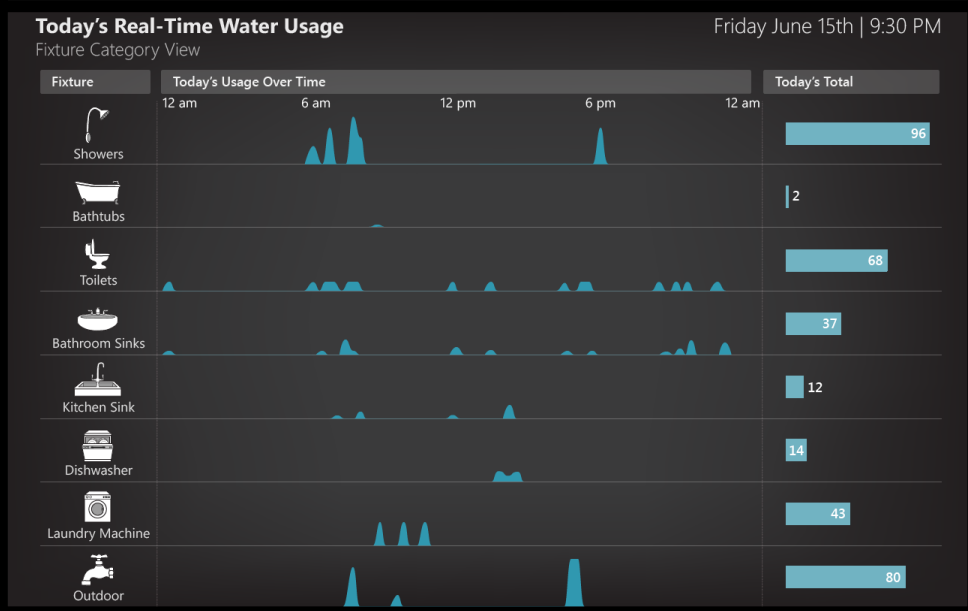
DESIGN SET 2: DESIGN PROBES

Time-Series Views



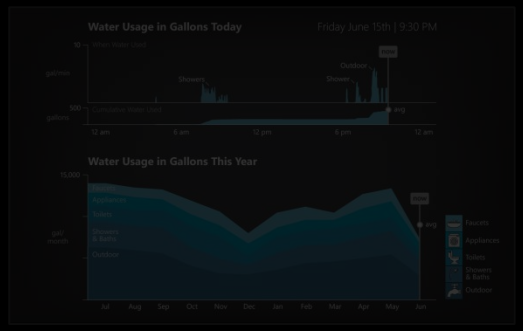






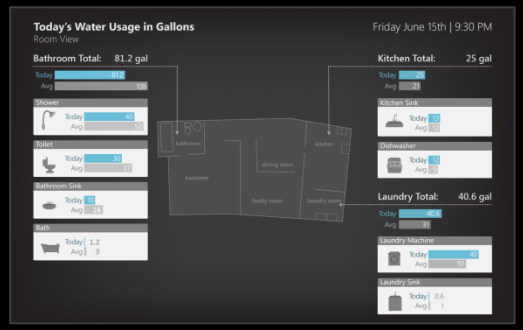
DESIGN SET 2: DESIGN PROBES

Design Probes Explored

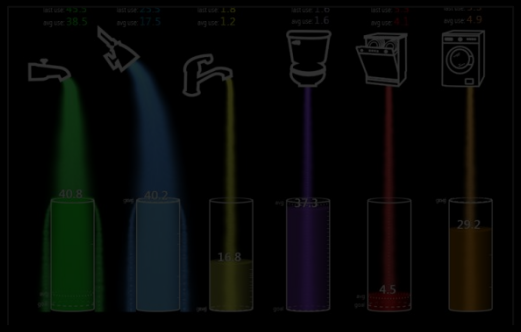


Time-Series

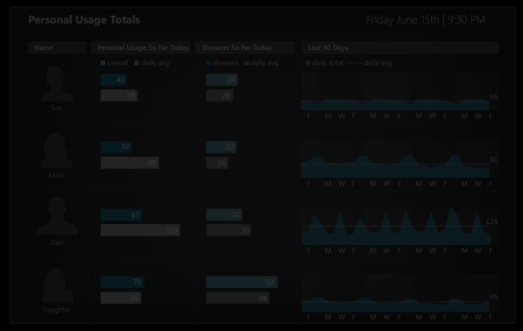
Aquatic Eco-system



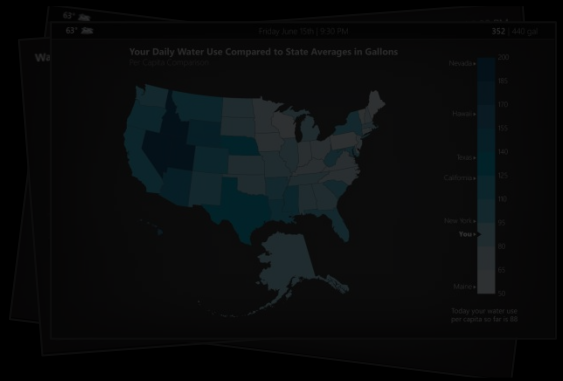
Spatial



Rainflow



Per-Occupant



Other

Spatial View

Today's Water Usage in Gallons

Room View

Friday June 15th | 9:30 PM

Bathroom Total: 81.2 gal

Today 81.2
Avg 108

Shower
Today 40
Avg 52

Toilet
Today 30
Avg 37

Bathroom Sink
Today 10
Avg 16

Bath
Today 1.2
Avg 3

Kitchen Total: 25 gal

Today 25
Avg 21

Kitchen Sink
Today 13
Avg 12

Dishwasher
Today 12
Avg 9

Laundry Total: 40.6 gal

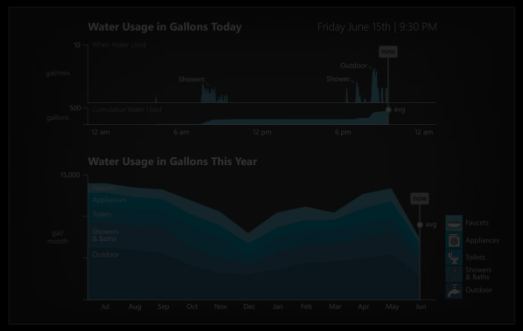
Today 40.6
Avg 31

Laundry Machine
Today 40
Avg 30

Laundry Sink
Today 0.6
Avg 1

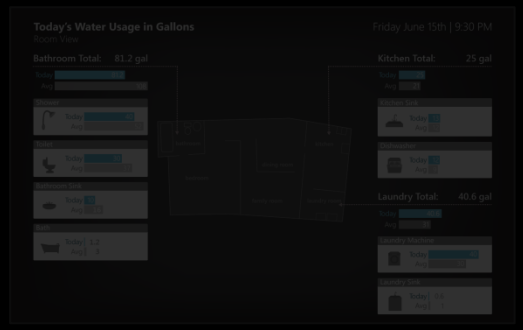
DESIGN SET 2: DESIGN PROBES

Design Probes Explored

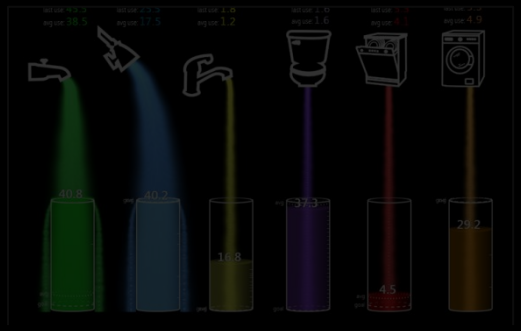


Time-Series

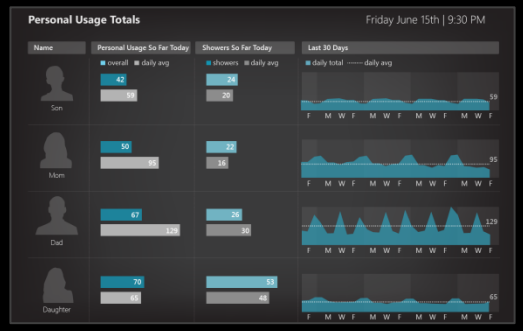
Aquatic Eco-system



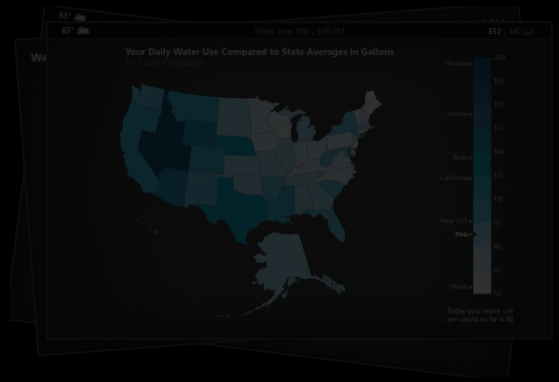
Spatial



Rainflow



Per-Occupant



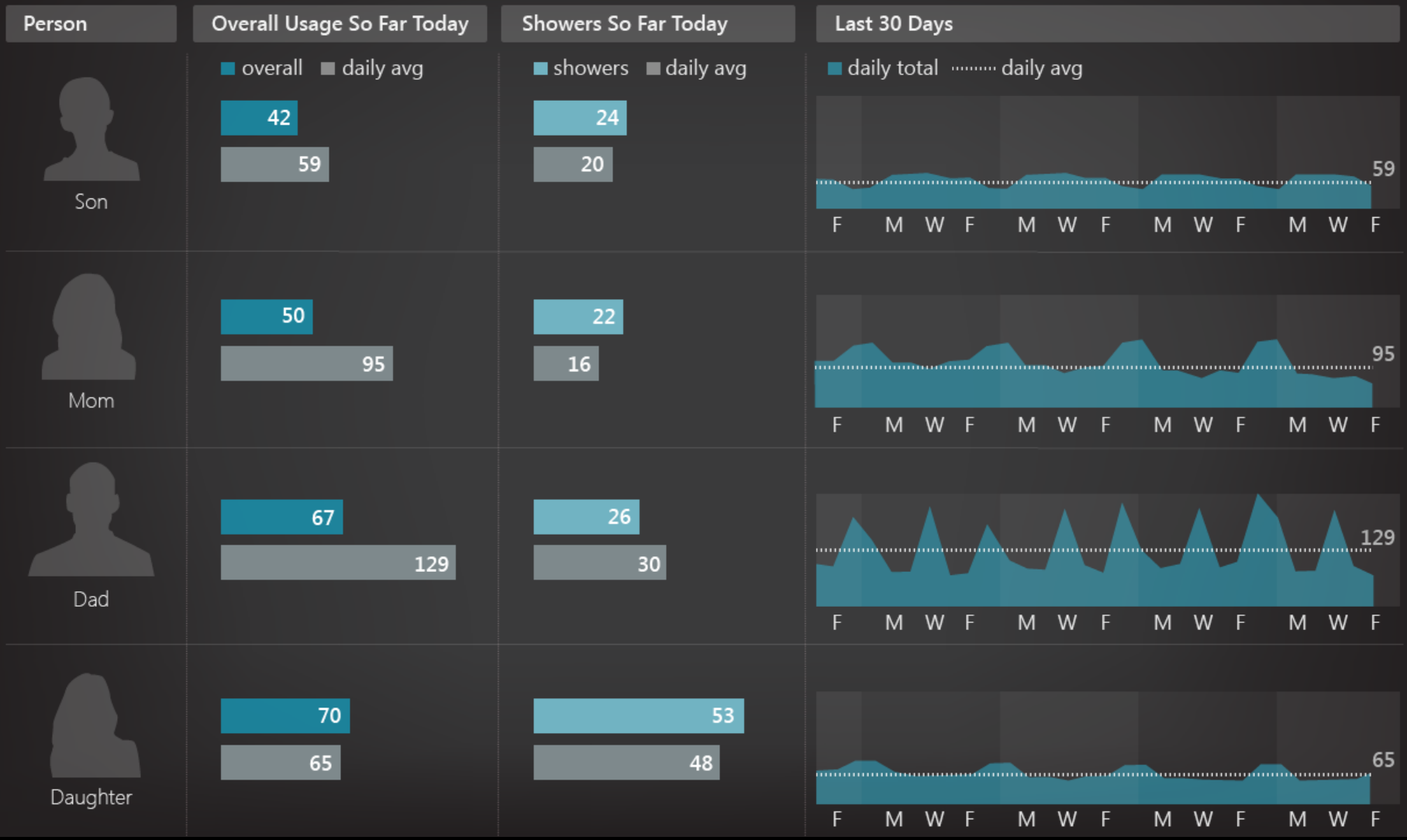
Other

DESIGN SET 2: DESIGN PROBES

Per-Occupant View

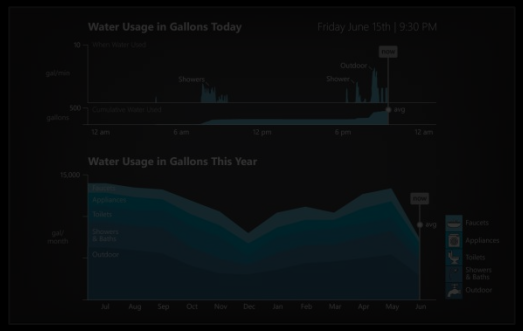
Personal Usage Totals

Friday June 15th | 9:30 PM



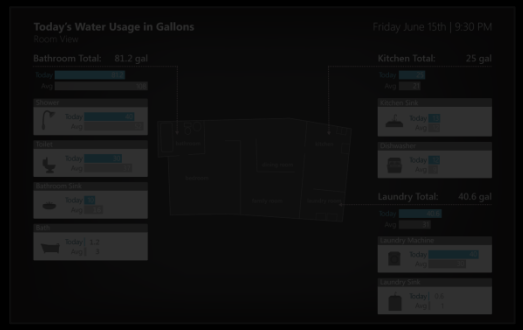
DESIGN SET 2: DESIGN PROBES

Design Probes Explored

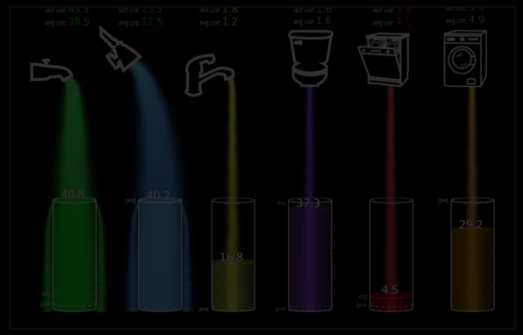


Time-Series

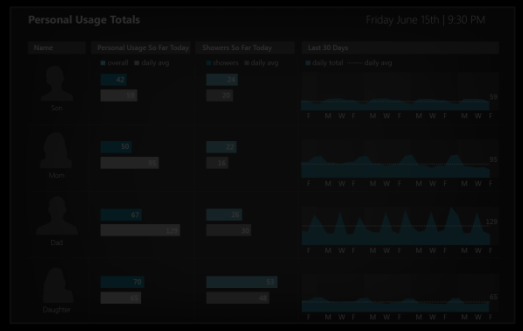
Aquatic Eco-system



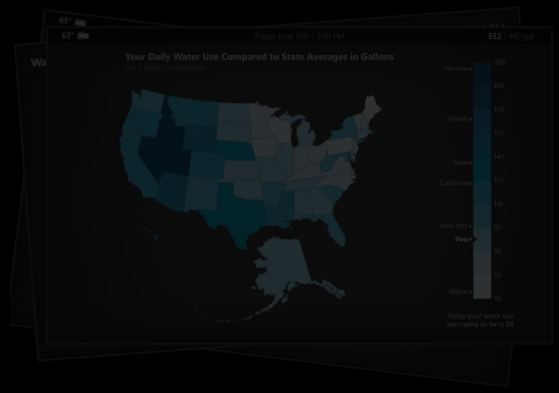
Spatial



Rainflow



Per-Occupant



Other

Aquatic Ecosystem Design Influences

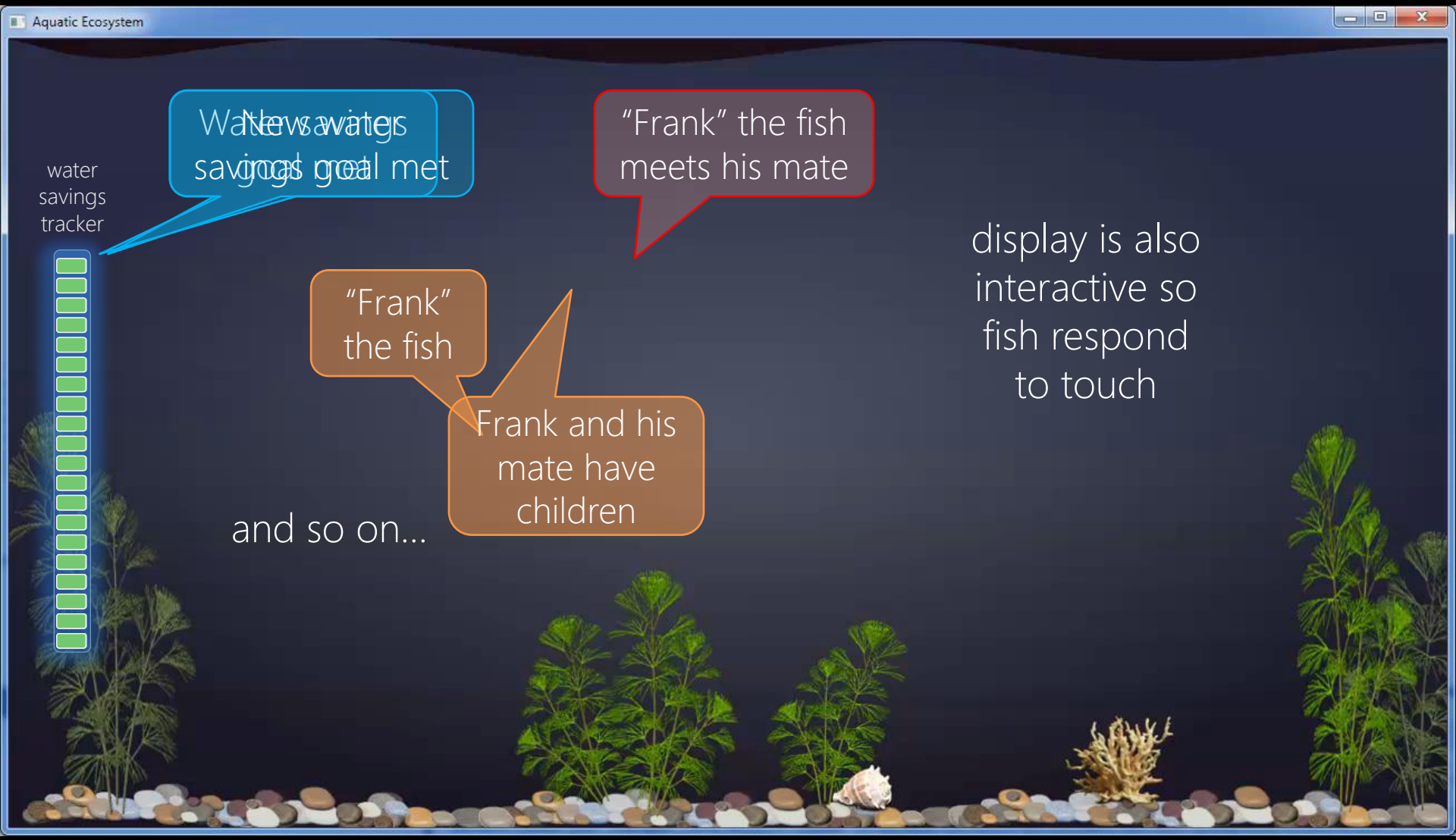
ubifit

Consolvo *et al.*, CHI2008
Consolvo *et al.*, UbiComp2008

ubigreen

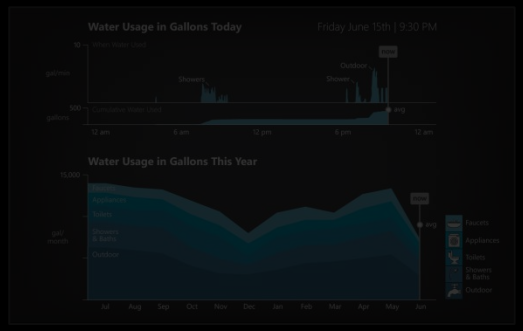
Froehlich *et al.*, CHI 2009

Aquatic Ecosystem View



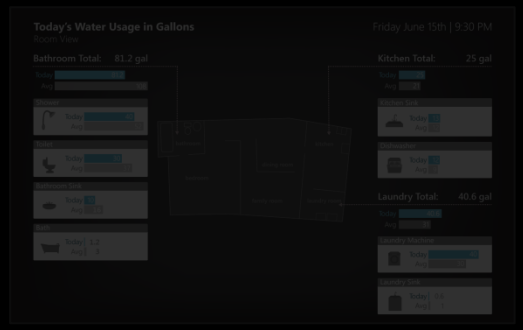
DESIGN SET 2: DESIGN PROBES

Design Probes Explored

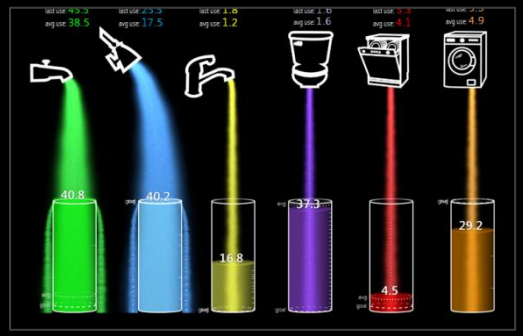


Time-Series

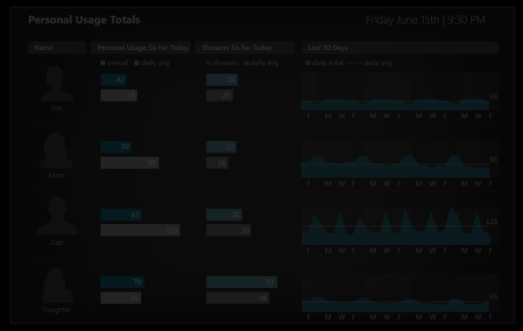
Aquatic Eco-system



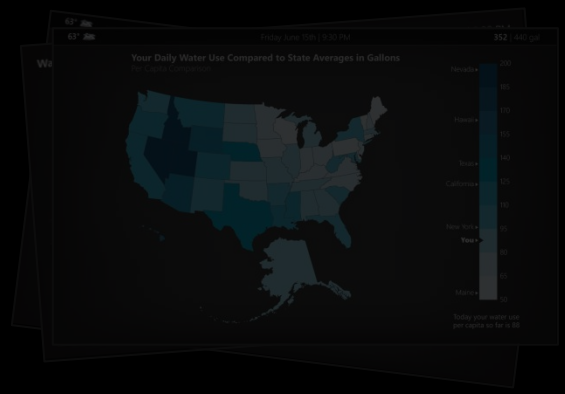
Spatial



Rainflow



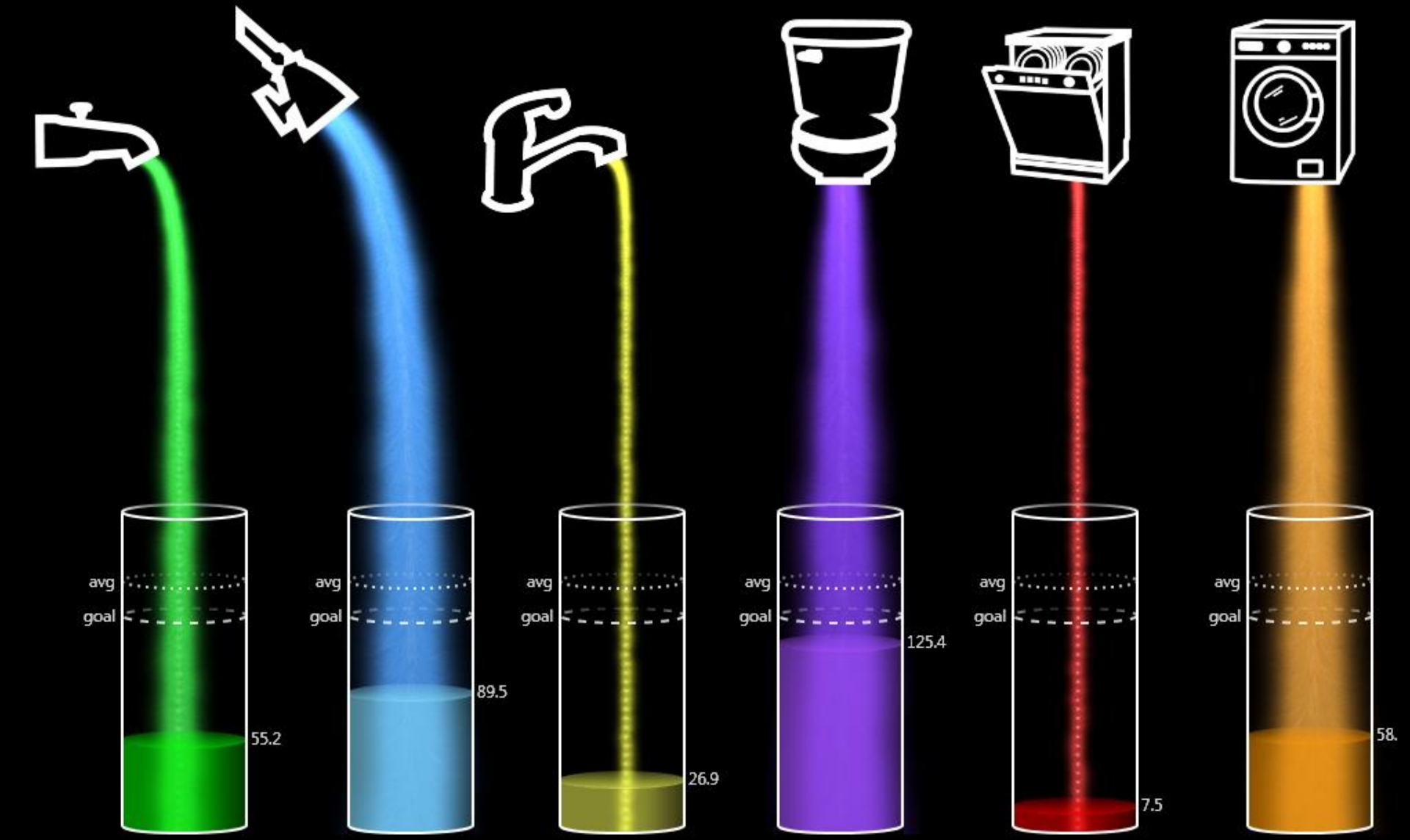
Per-Occupant



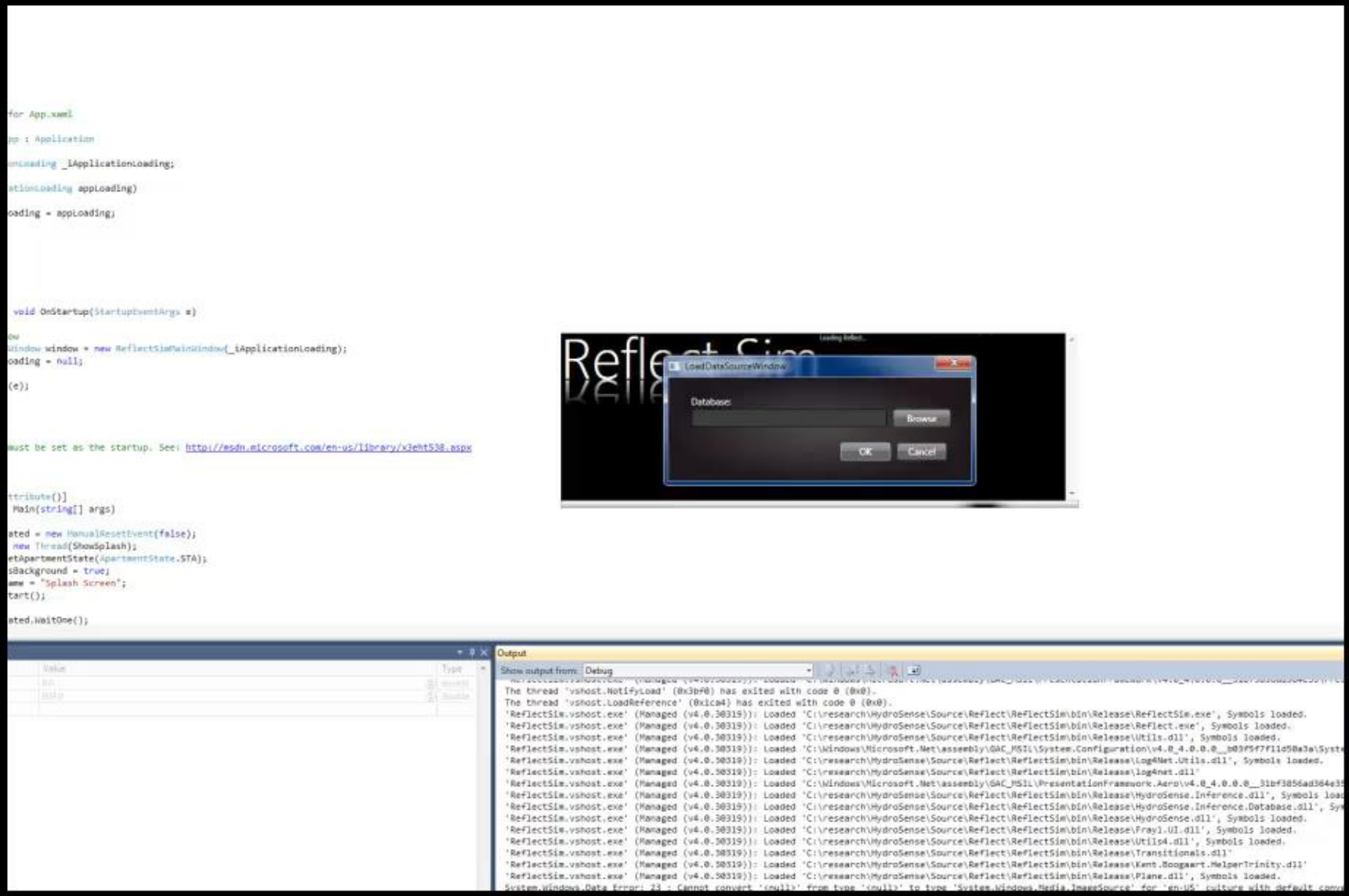
Other

DESIGN SET 2: DESIGN PROBES

Rainflow View

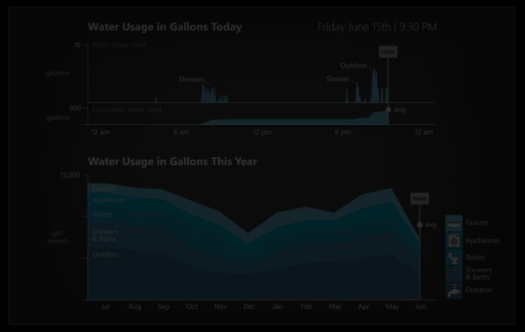


Rainflow View Movie



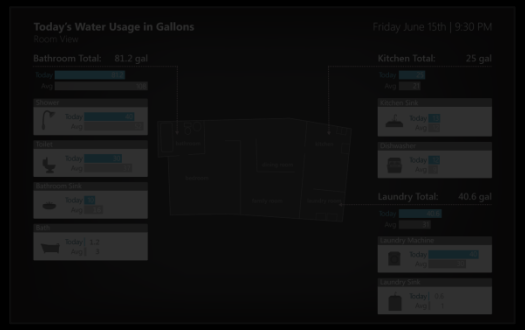
DESIGN SET 2: DESIGN PROBES

Design Probes Explored

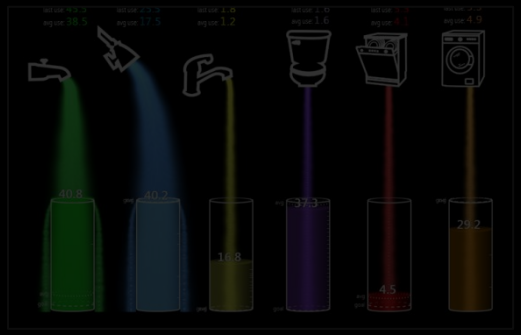


Time-Series

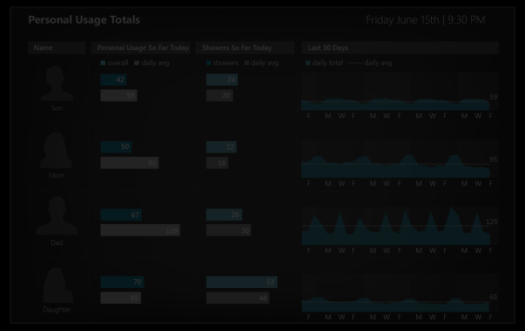
Aquatic Eco-system



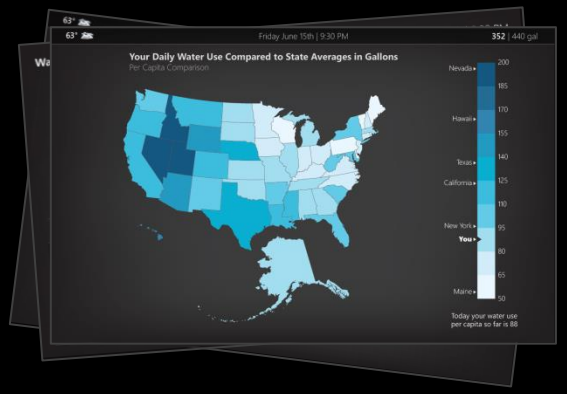
Spatial



Rainflow



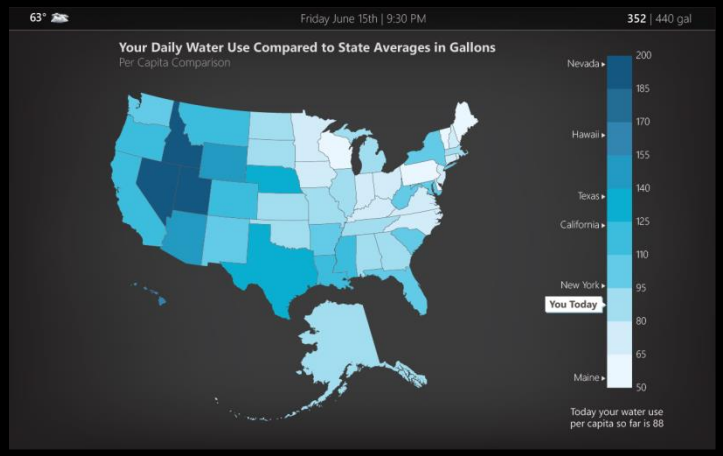
Per-Occupant



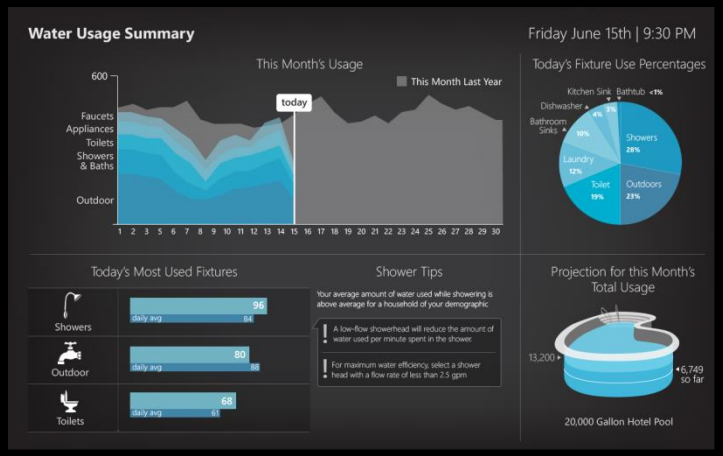
Other

DESIGN SET 2: DESIGN PROBES

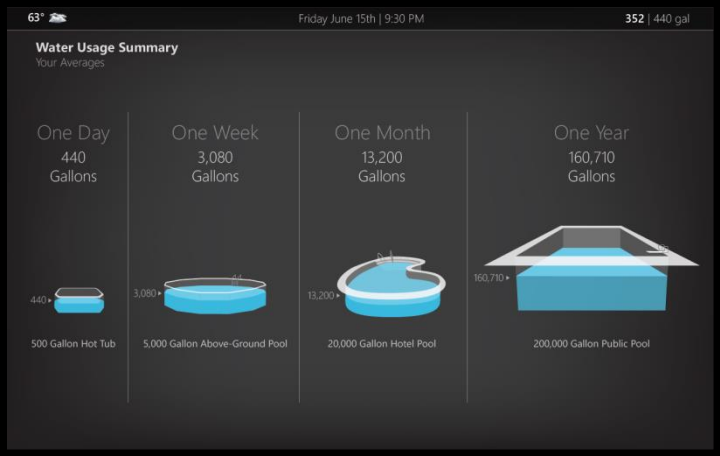
Other Design Probes



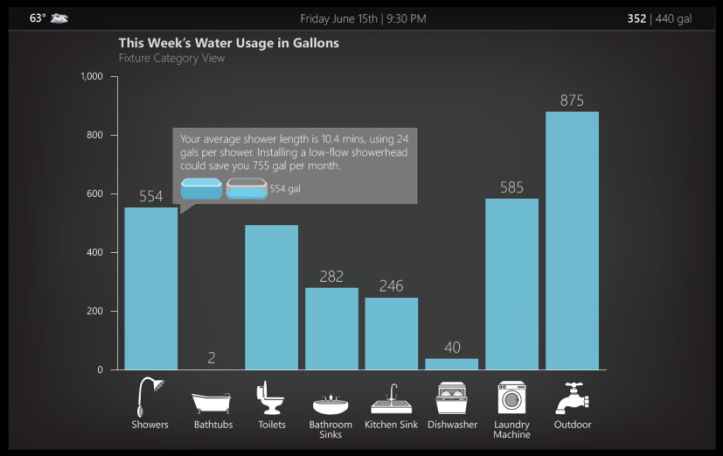
Geographic Comparisons



Dashboards

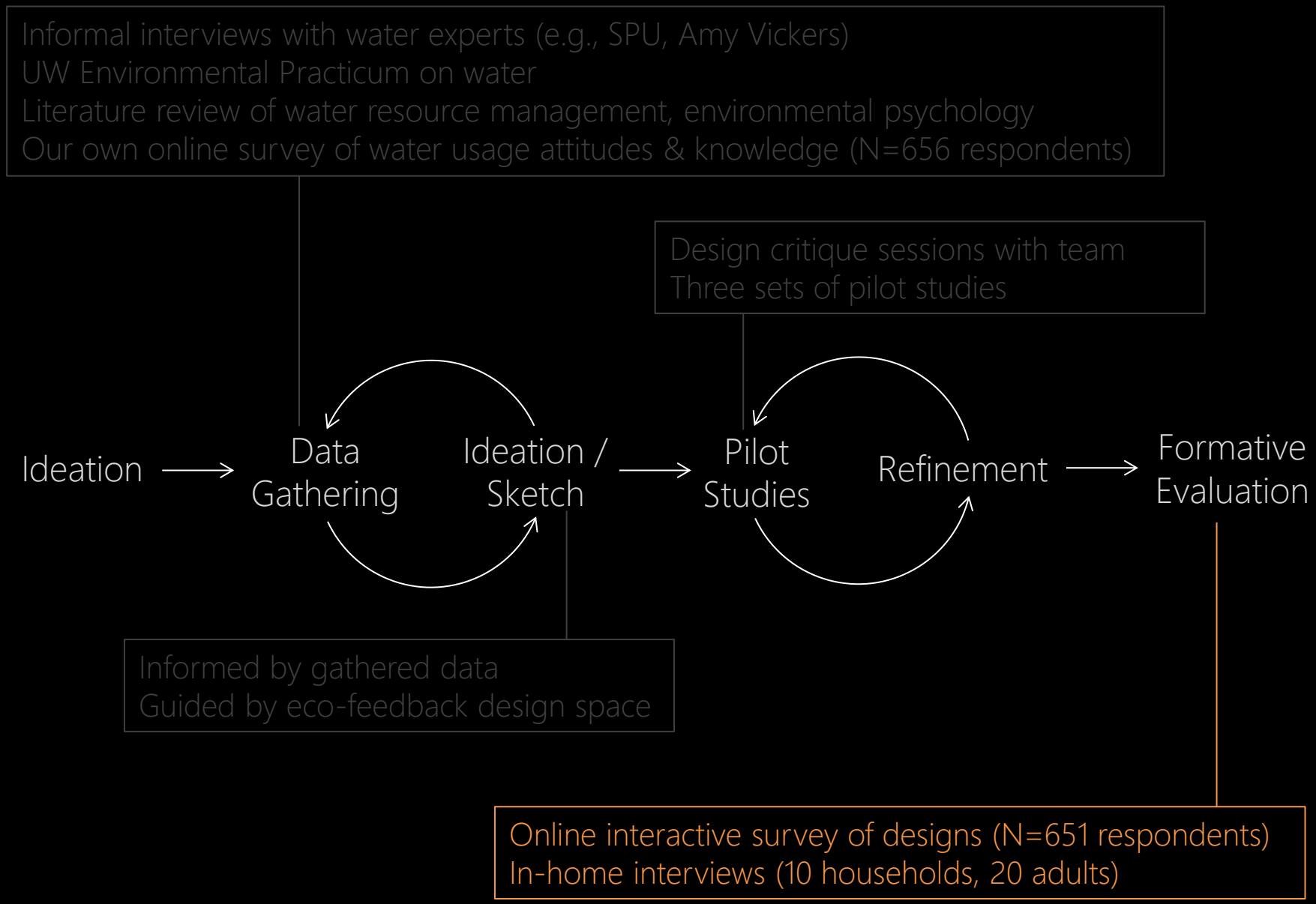


Metaphorical Unit Designs



Recommendations

Evaluation


Informal interviews with water experts (e.g., SPU, Amy Vickers)
UW Environmental Practicum on water
Literature review of water resource management, environmental psychology
Our own online survey of water usage attitudes & knowledge (N=656 respondents)
Design critique sessions with team
Three sets of pilot studies
Ideation
Data Gathering
Ideation / Sketch
Pilot Studies
Refinement
Formative Evaluation
Informed by gathered data
Guided by eco-feedback design space
Online interactive survey of designs (N=651 respondents)
In-home interviews (10 households, 20 adults)

Online Survey

Water Feedback Evaluation Survey

Consent Form

0%

Hi, my name is Jon Froehlich and I'm a graduate student at the University of Washington. The survey you are about to take is for my PhD dissertation on water usage information systems. Your responses will help inform the design of future water conservation programs.

I appreciate you taking the time to fill out this survey,

Jon E. Froehlich
PhD Candidate
University of Washington

RESEARCHERS' STATEMENT
We are asking you to be in a research study. The purpose of this consent form is to give you the information you will need to help you decide whether to be in the study or not. Please read the form carefully. You may ask questions about the purpose of the research, the possible risks and benefits, your rights as a volunteer, and anything else about the research or this form that is not clear by emailing jfroehli@uw.edu. After reading this form, you can decide if you want to be in the study or not. This process is called "informed consent." You can print a copy of this form for your records.

PURPOSE OF THE STUDY
We are studying how computer displays (interfaces) can help inform people about their energy, water, and gas usage in the home.

STUDY PROCEDURES
To participate in this study, you simply need to fill out the forthcoming online survey. Please try to answer each question carefully and honestly. The survey should take between 20-35 minutes to complete. At the end of the survey, we will ask you for your email address. You do not need to provide this information. Those respondents that do supply their email addresses will be entered in a raffle to win a **$100 gift certificate** to Amazon.com. We will not use your email for any other purpose or give out you email address to anyone for any reason.

RISKS, STRESS, OR DISCOMFORT
We do not expect any risks, stresses, or discomforts as a result of this research.

BENEFITS OF THE STUDY
Although you may not directly benefit from this study, we hope that the findings of this study will help to develop new technology that will help the environment.

OTHER INFORMATION
Taking part in this study is voluntary. You can stop filling out the survey at any time. Information about you is anonymous. The information you provide is not linked to your name.

SUBJECT'S STATEMENT
This study has been explained to me. I volunteer to take part in this research. If I have questions later about the research, I can email one of the researchers listed above. If I have questions about my rights as a research subject, I can call the University of Washington Human Subjects Division at (206) 543-0098.

The survey should take between **20-35 minutes** to fill out. If you would like to go back to a previous page once you start the survey, please **do not hit the "back" button on your browser**. Instead, use the "back" button located at the bottom of each survey page.

By clicking 'Yes' below, you consent to take part in this study. *

Yes

Recruitment

- Online postings and word-of-mouth

Survey Design

- 63 questions (10 optional)
- Question and answer order randomized when possible

Collected Data

- 712 completed surveys (651 from US or Canada)
- Nearly 6,000 qualitative responses

Water Feedback Evalu ×

edu.surveygizmo.com/s3/632637/CHI2012-WaterFeedbackSurveyDemo

Water Feedback Evaluation Survey

Introduction

6%

Most people receive information on their water usage from a monthly or bi-monthly bill. We are working on a new type of system that can **immediately show people how much water they are using** at each fixture in their home. This information could be viewed, for example, on a mobile phone, on a laptop, a digital picture frame, or on an in-home touchscreen display.

In this survey, we'll explore different ways of visually displaying water usage information. Unless otherwise noted, each design is based on an average North American household of four people with two adults and two teenagers.

First, though, we need to ask some demographic questions.

Back Next

6%

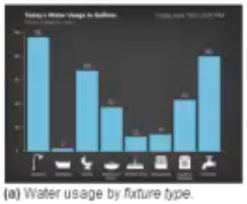
Water Feedback Evaluation Survey

Hot and Cold Breakdown

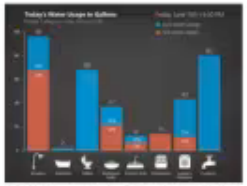
44%

We are also interested in whether people want **information on hot water usage vs. cold water usage**. Display (a) treats all water usage the same (whether hot or cold), while display (b) breaks down water usage by hot water and cold water amounts.

Like before, please mouse over the thumbnails on the left below to see enlarged versions of the display so that you can easily compare the two designs.



(a) Water usage by *fixture type*.

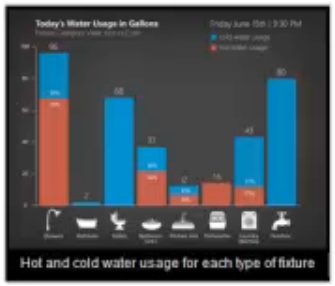


(b) Water usage by fixture type with *hot and cold breakdown*.

Move your mouse cursor over the image thumbnails on the left to see enlarged versions here.

22. Which display do you prefer? *

Click on the image below to make your selection.



I would prefer to have both displays and be able to switch between them

All of the above

In-Home Interviews

Recruitment

- Online postings and word-of-mouth
- Specifically recruited families

Interview Method

- Semi-structured with two researchers
- 90-minutes, 3-phases
- Data coded by two researchers into themes

Participants

- 10 households (20 adults)
- 11 female/9 male
- Diff. socio-economic backgrounds & occupations
- 18 had college degrees





CLAUSING





Daily average consumption by fixture for the month of May
69.3 gallons
of water consumed per day on average
Weekly consumption pattern for the month of May
average consumption for this day of the week
average daily consumption
M T W T F S S

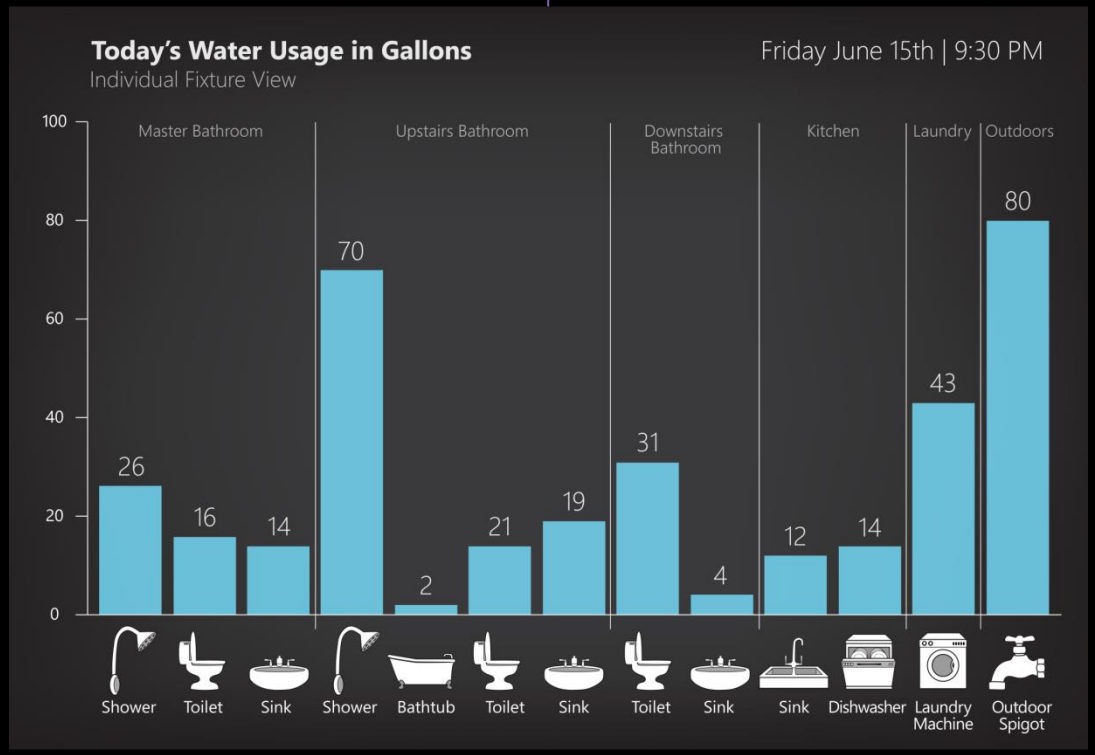
For both the survey and interviews, **90%** of participants indicated an interest in **conserving water**

Average morning shower uses 400 gallons of water

Findings

Data Granularity

coarse-grain ≥neighbor-hood | home | room | activity | fixture category | fixture | ≤ valve **fine-grain**



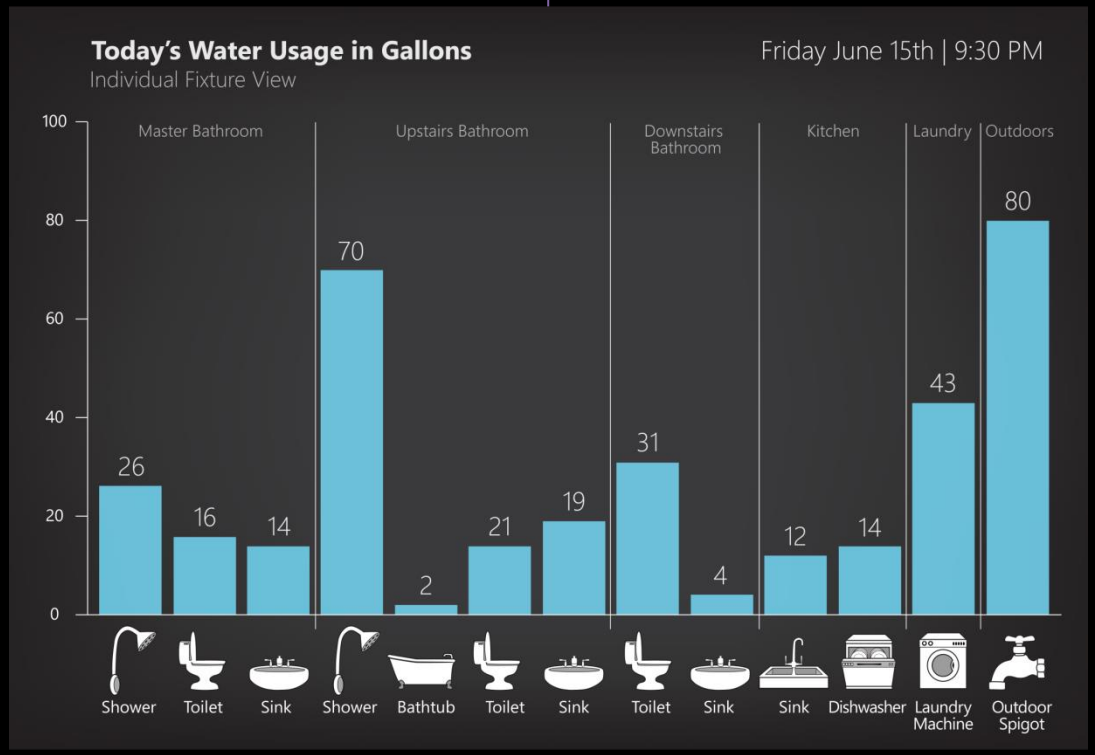
"This display lets you more easily identify the specific areas that need attention"

R536

Majority preferred the *Individual Fixture Display*

Data Granularity

coarse-grain ≥neighbor-hood | home | room | activity | fixture category | fixture | ≤ valve **fine-grain**



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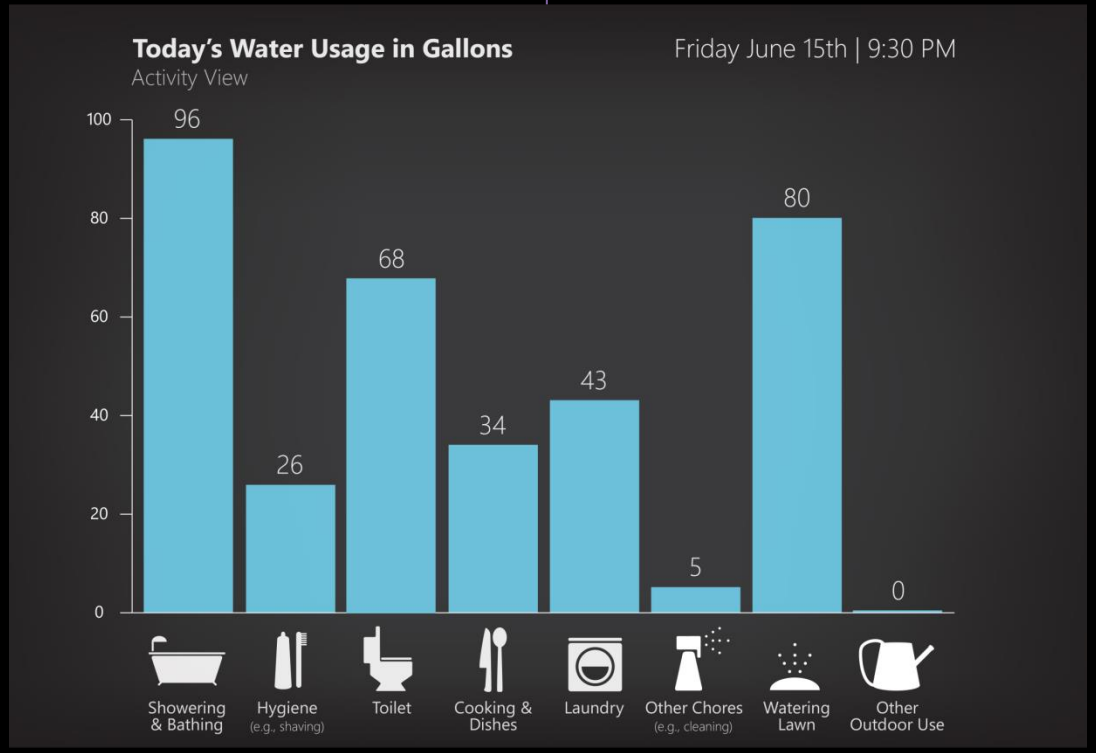


20% preferred the *Activity Display*

Measurement Unit

71% of respondents preferred to see both gallons and cost

> Seeing the gallon amount triggers the 'save the environment' impulse to conserve, while the dollar amount is helpful because almost everyone is motivated by money to some extent

R143

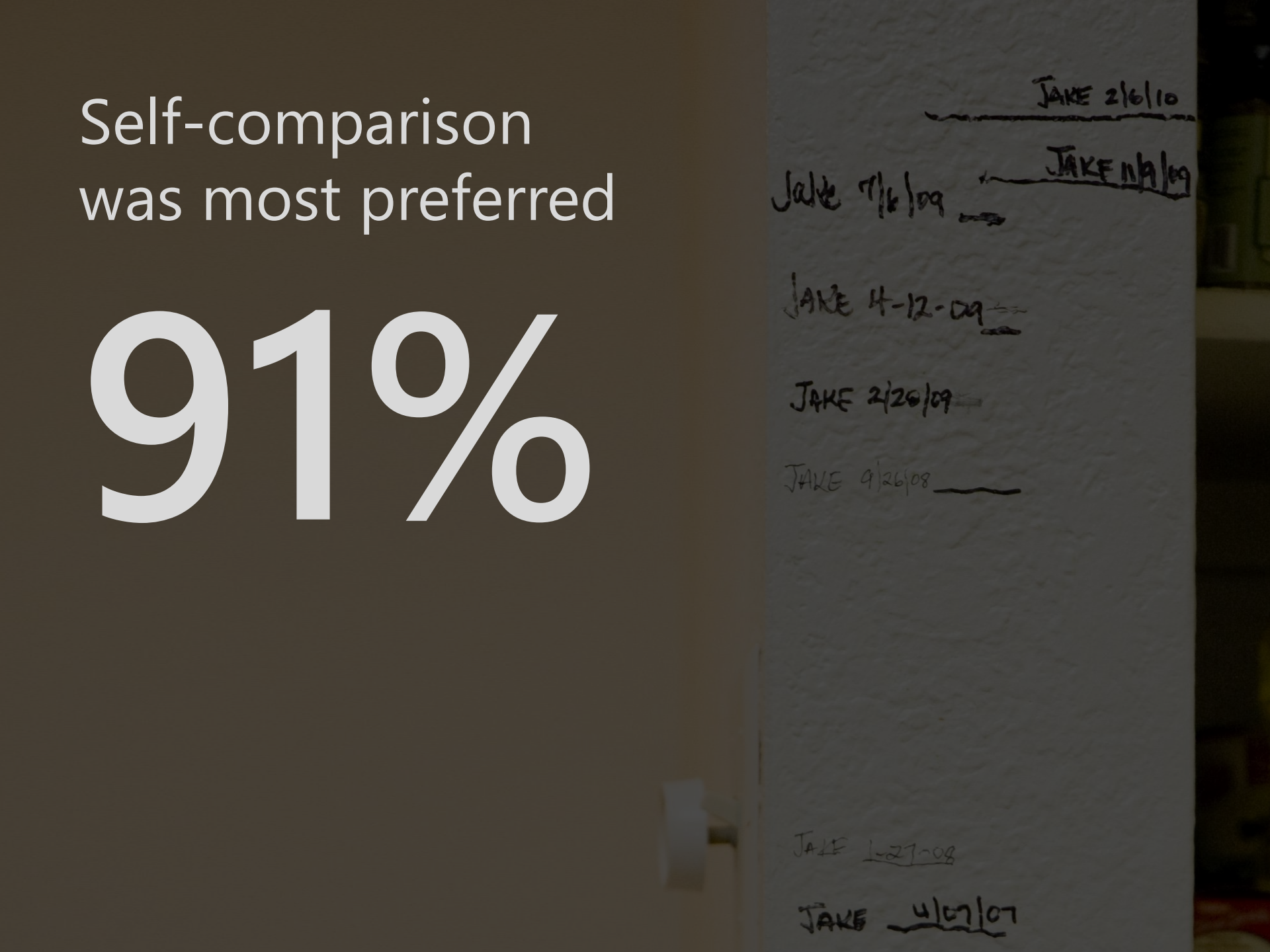
> I don't think very well in 'thousands of gallons', but $20 I can understand. That's a case of beer down the drain, if you will

R48


Comparisons were the most
uniformly desired pieces of
information of all the dimensions

Self-comparison
was most preferred

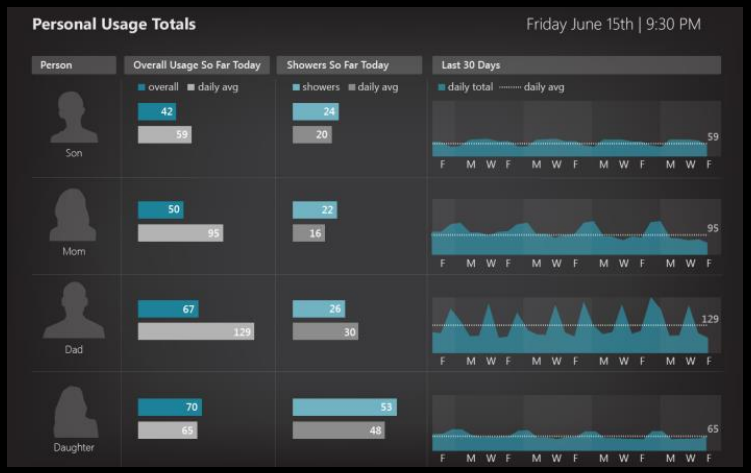
91%



Emergent Themes

1. **Competition** and Cooperation
2. **Accountability** and Blame
3. **Playfulness** and Functionality
4. Sense of **Privacy**
5. **Display** Placement

Competition and Cooperation



> You can compare usage to others, and create friendly competition

R220

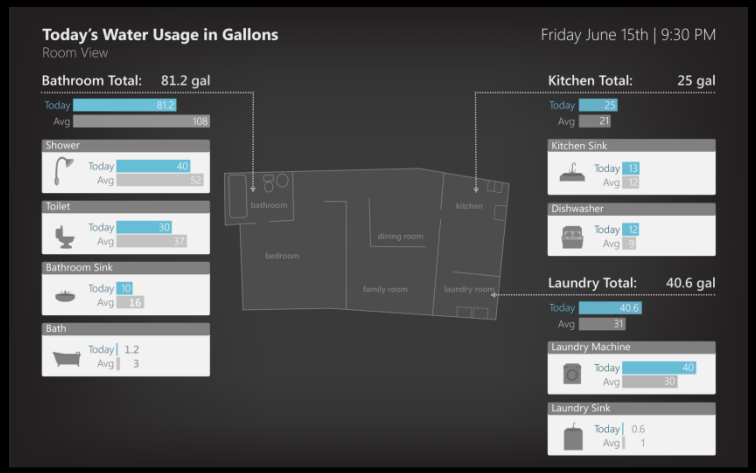
> It pits the family members against each other rather than encouraging collaboration

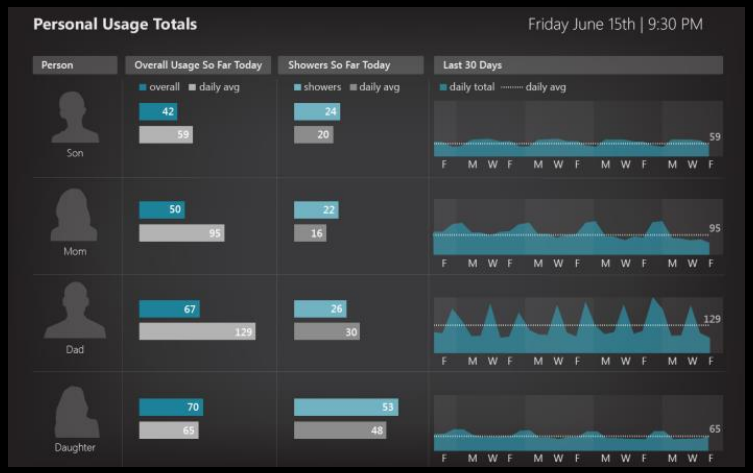
R485

> [It] sets up a 'competitive' environment that we are trying not to create in our household

R493

Accountability and Blame





"It holds each individual accountable for water usage"

R354

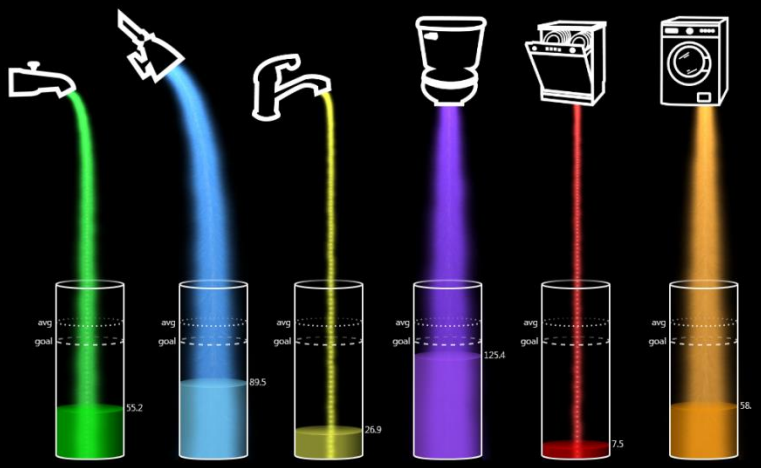
"There's no reason to add an element of 'blame' to conservation efforts within a family"

R98

"Would seem to lead to plenty of arguments about usage

R144

Playfulness and Functionality



"I like the idea of getting rewards for saving water"

I8.2

"It's like unlocking badges in Foursquare. No matter how trivial it can be to make a fish appear on this screen, you still want to do it"

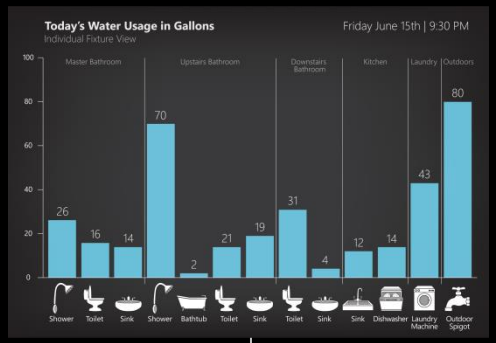
I4.1

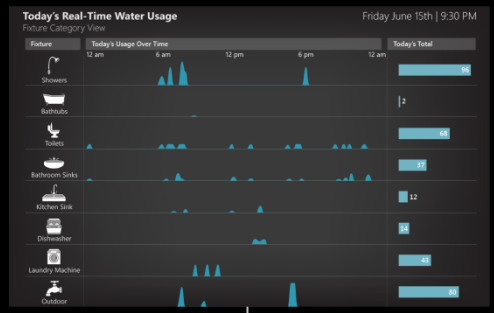
"It doesn't appeal to me as much. I don't do Foursquare. This distracts me a little bit and it doesn't make me think about my usage"

I4.2

Useful as an educational tool?

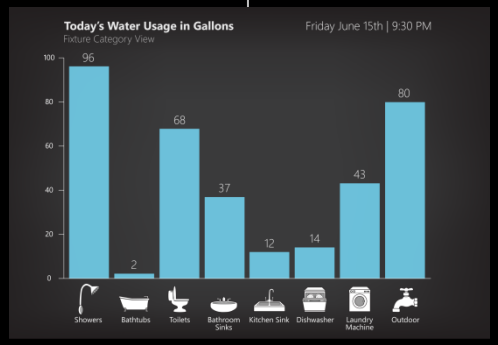
Privacy Spectrum

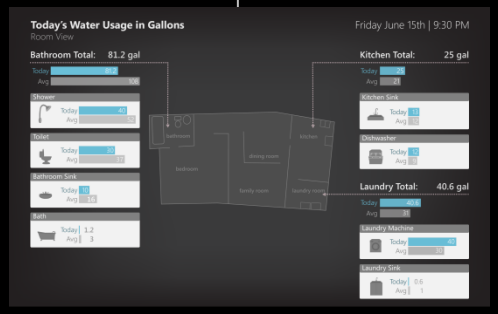




Least Invasive

Most Invasive





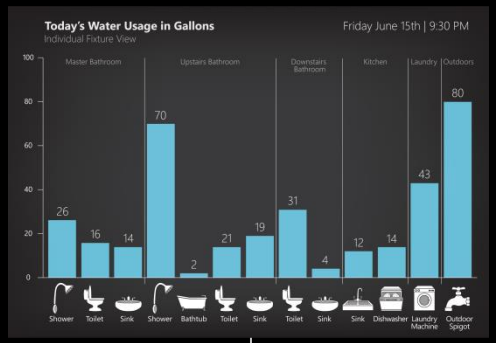
“It’s incredibly invasive. And other people’s water consumption is not my business.”

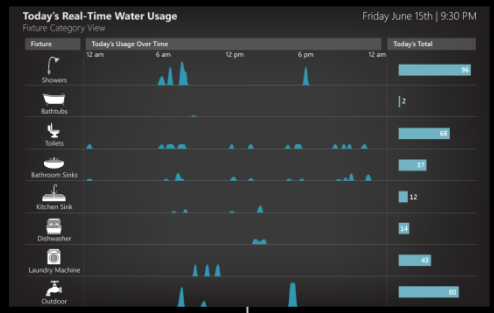
R25

“Water usage for many purposes can be very personal, and shouldn’t be automatically shared”

R25

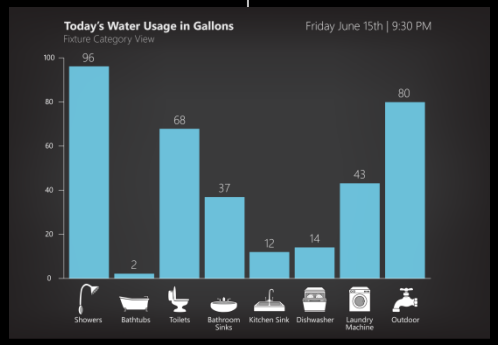
Privacy Spectrum

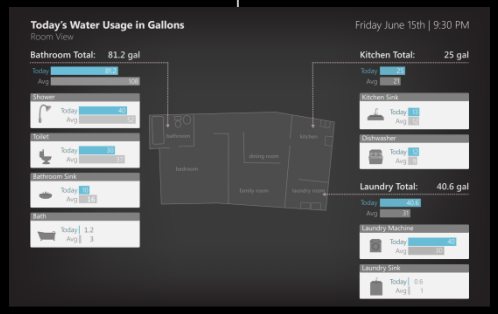




Least Invasive

Most Invasive





Display Location Preferences

“If we placed the display here, the kids couldn’t see it.”

I2.1

Display Location Preferences

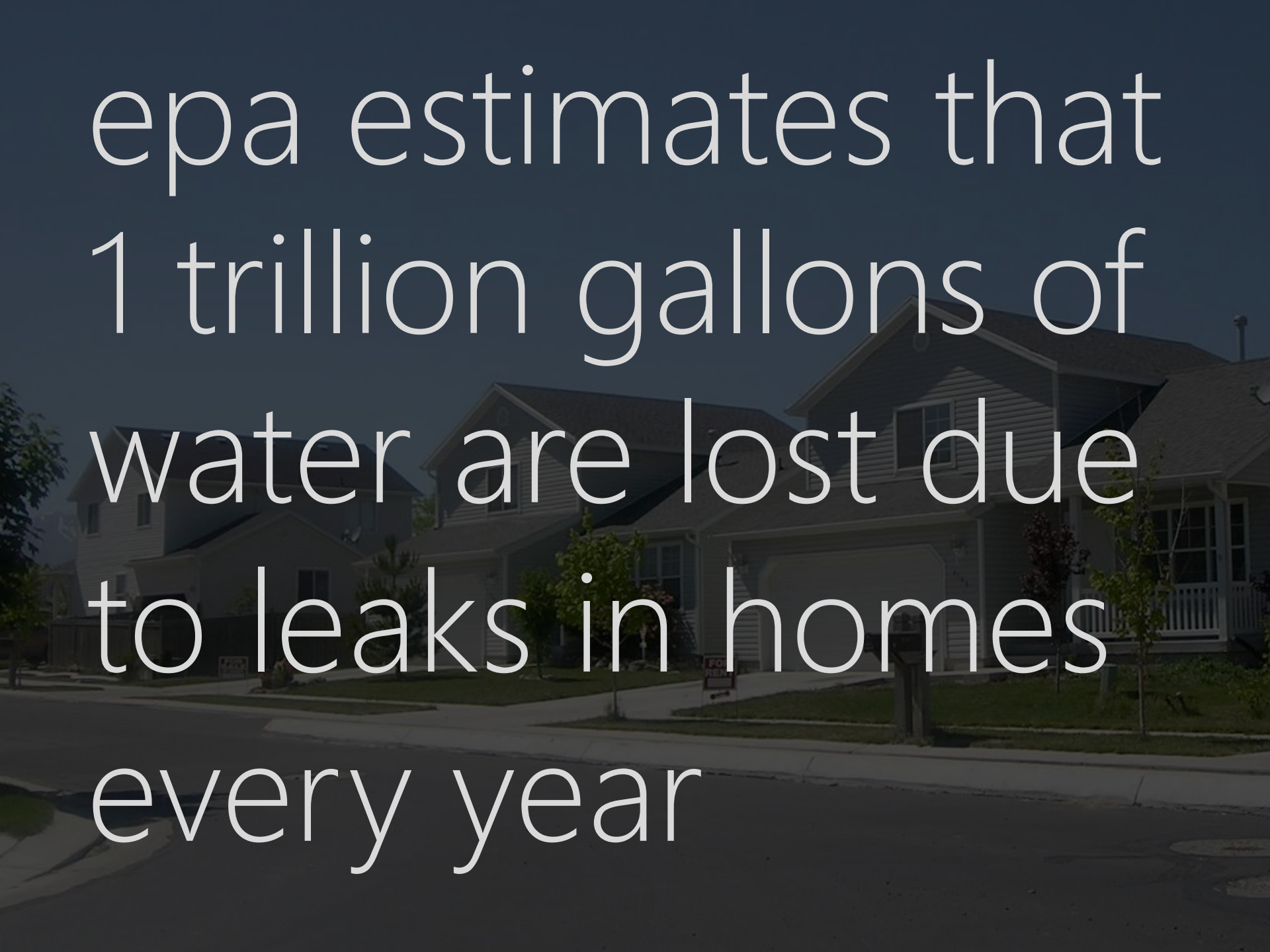
kitchen

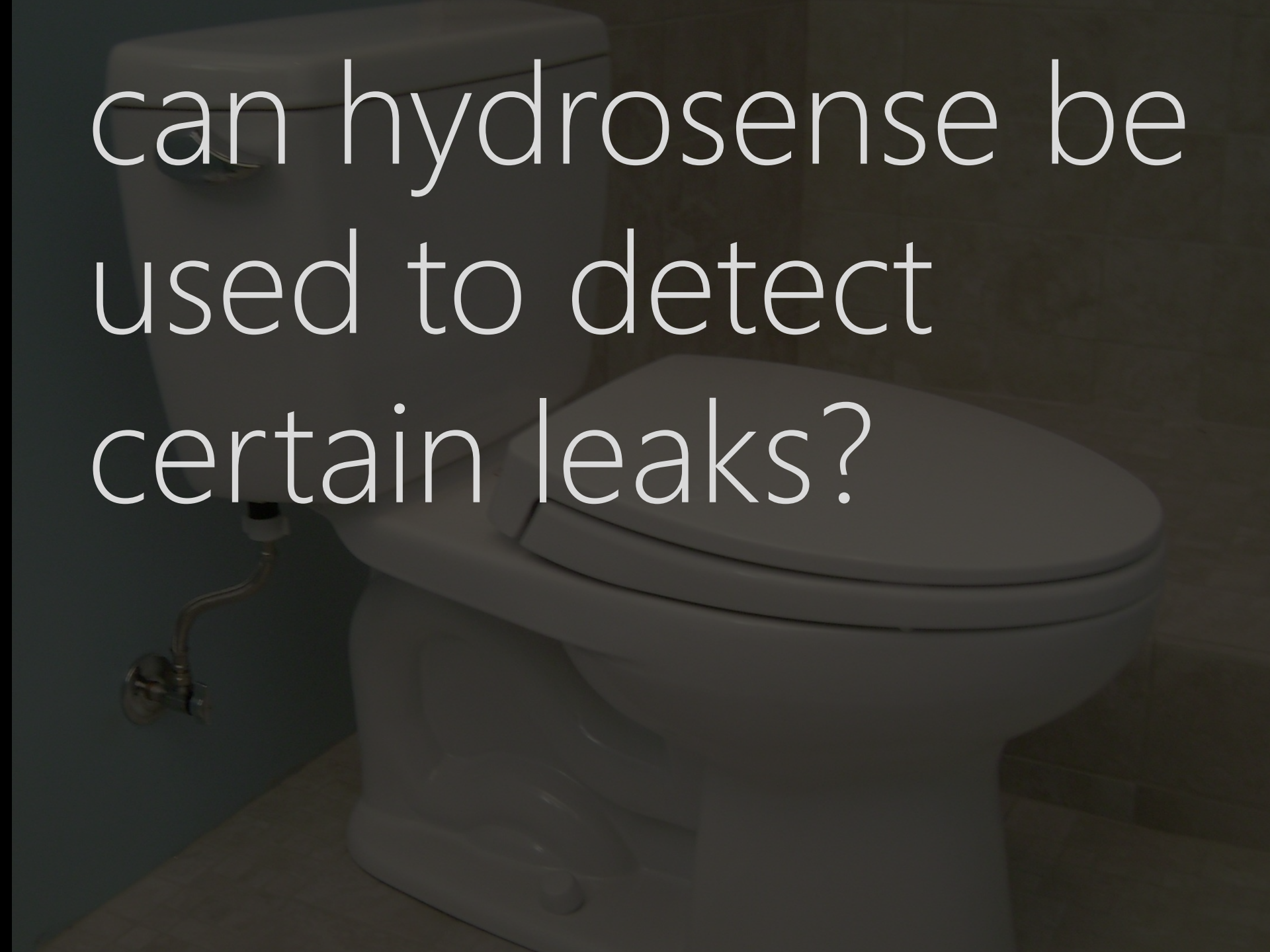
near thermostat

high traffic areas

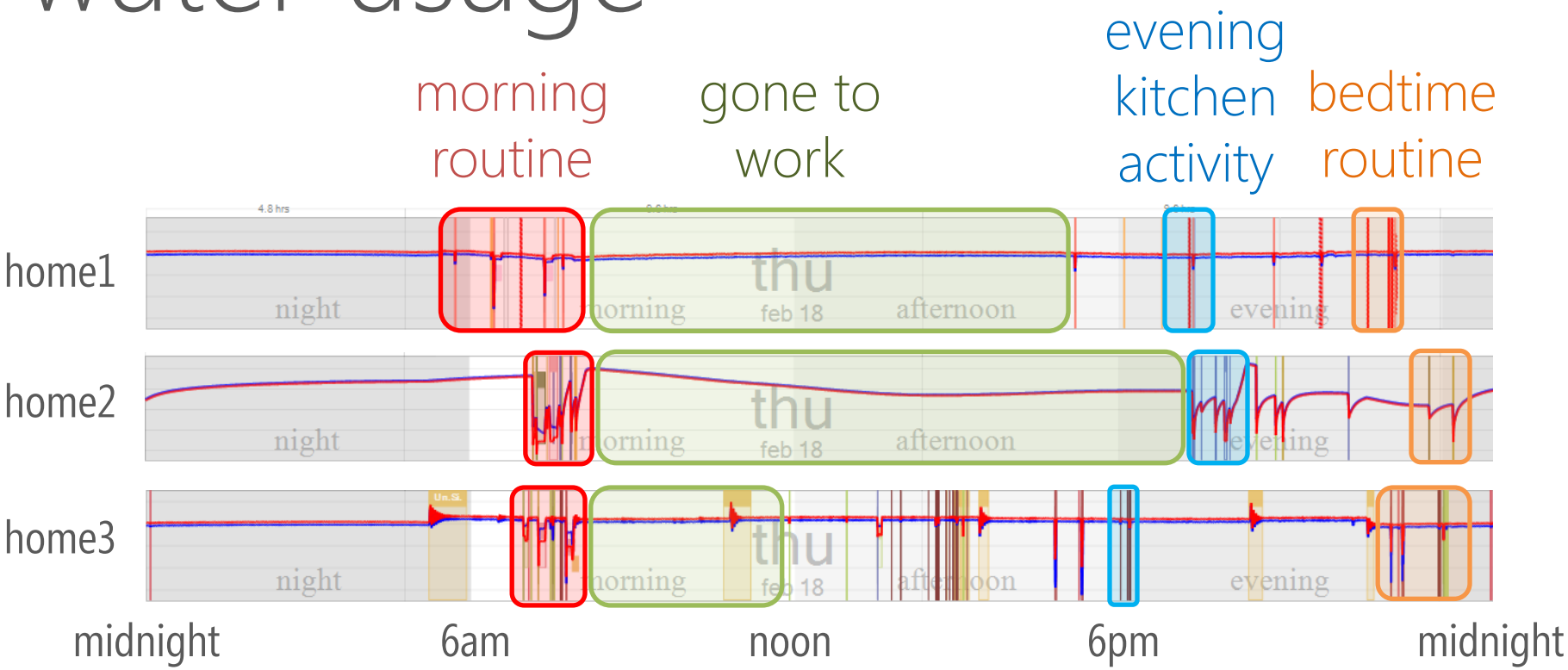
accessible when needed


hydrosense algorithms
1. minimal training set
2. cross-home training
3. unsupervised learning


epa estimates that
1 trillion gallons of
water are lost due
to leaks in homes
every year


can hydrosense be used to detect certain leaks?

behavioral patterns of water usage



how predictable are home water usage patterns?

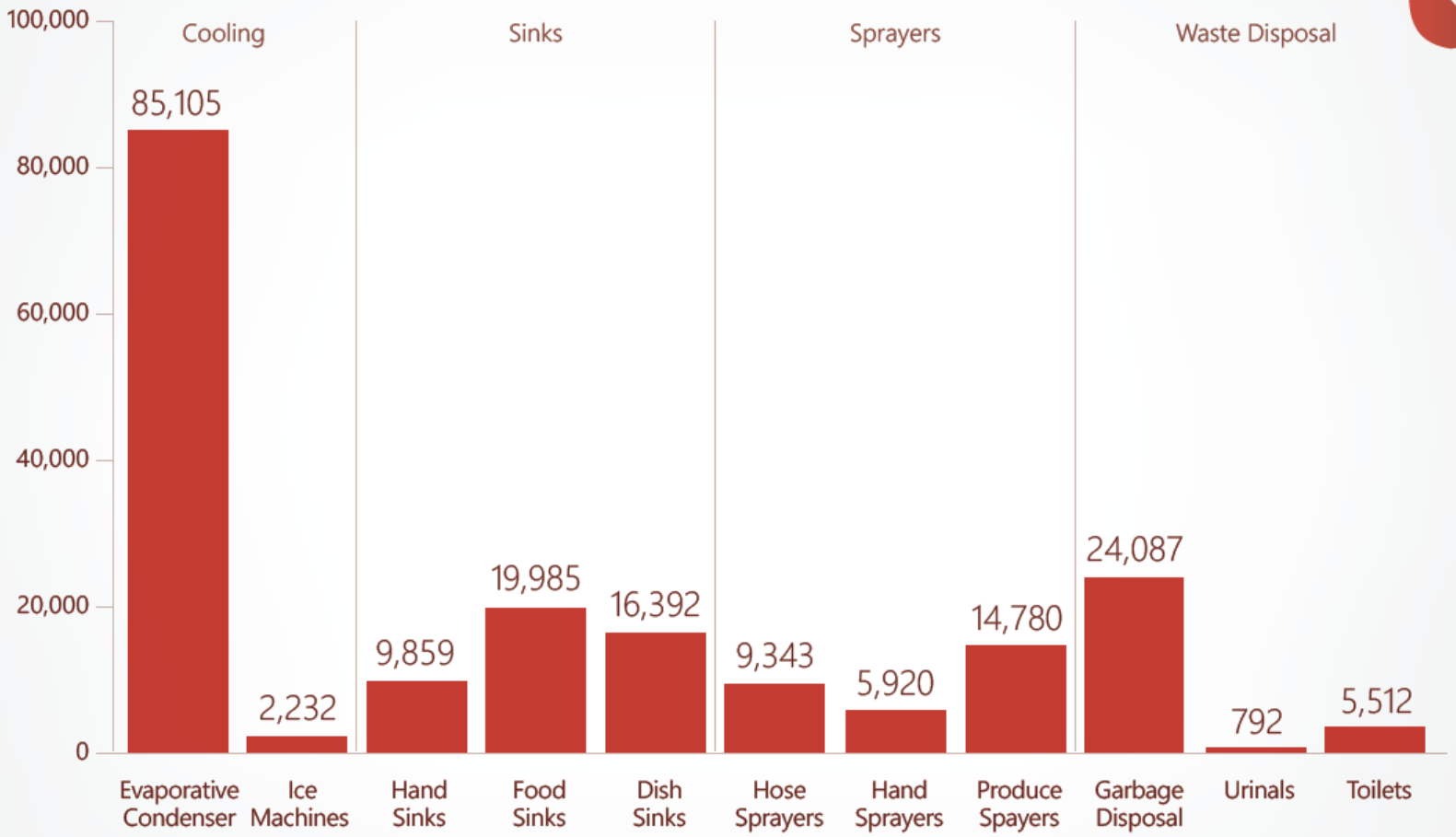

how can
hydrosense be
used to support
aging in place
applications?

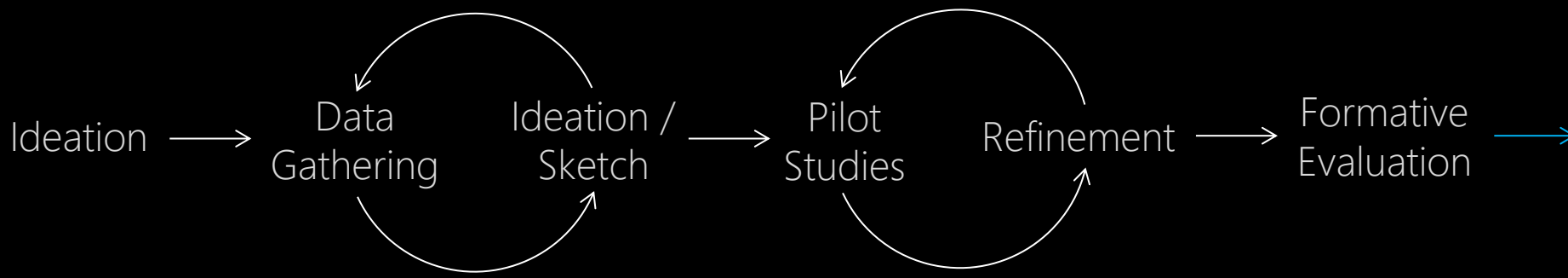
Today's Water Usage in Gallons

Individual Fixture View

This Month's Water Usage in Gallons

Individual Fixture View




Ideation
Data Gathering
Ideation / Sketch
Pilot Studies
Refinement
Formative Evaluation

Closing Thought

Eco-feedback displays do not just visualize consumption, they document household activities

acknowledgements

professors

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Mazhengmin Bai, Pre-Eng, UW
Fabia Fu, Pre-Eng, UW
Elliot Saba, EE, UW

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hydrosense

HydroSense: Infrastructure-Mediated Single-Point Sensing of Whole-Home Water Activity
Jon Froehlich, Eric Larson, Tim Campbell, Conor Haggerty, James Fogarty, Shwetak N. Patel, *Proc. of Ubicomp 2009*

Disaggregated Water Sensing From a Single, Pressure-Based Sensor: An Extended Analysis of HydroSense Using Staged Experiments
Eric Larson, Jon Froehlich, Tim Campbell, Conor Haggerty, Les Atlas, James Fogarty, Shwetak N. Patel, *Journal of Pervasive and Mobile Computing (PMC) 2010*

WATTr: A Method for Self-Powered Wireless Sensing of Water Activity in the Home
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A Longitudinal Study of Pressure Sensing to Infer Real-World Water Usage Events in the Home
Jon Froehlich, Eric Larson, Elliot Saba, Tim Campbell, Les Atlas, James Fogarty, Shwetak Patel, *Proc. of Pervasive 2011*

reflect$_2$O

The Design and Evaluation of Prototype Eco-Feedback Displays for Fixture-Level Water Usage Data
Jon Froehlich, Leah Findlater, Marilyn Ostergren, Solai Ramanathan, Josh Peterson, Inness Wragg, Eric Larson, Fabia Fu, Mazhengmin Bai, Shwetak Patel, James Landay, *Proc. of CHI 2012*

Sensing and Feedback of Everyday Activities to Promote Environmental Behaviors
Jon Froehlich, *UW Doctoral Dissertation 2011*

other eco-feedback publications

The Design of Eco-Feedback Technology
Jon Froehlich, Leah Findlater, James Landay. *Proc. of CHI 2010*

UbiGreen: Investigating a Mobile Tool for Tracking and Supporting Green Transportation Habits
Jon Froehlich, Tawanna Dillahunt, Predrag Klasnja, Jennifer Mankoff, Sunny Consolvo, Beverly Harrison, James A. Landay, *Proc. of CHI 2009*

Disaggregated End-Use Energy Sensing for the Smart Grid
Jon Froehlich, Eric Larson, Sidhant Gupta, Gabe Cohn, Matthew S. Reynolds, Shwetak N. Patel. *IEEE Pervasive Computing 2011*

GasSense: Appliance-Level, Single-Point Sensing of Gas Activity in the Home
Gabe Cohn, Sidhant Gupta, Jon Froehlich, Eric Larson, Shwetak Patel, *Proc. of Pervasive 2010*

Questions?

@jonfroehlich