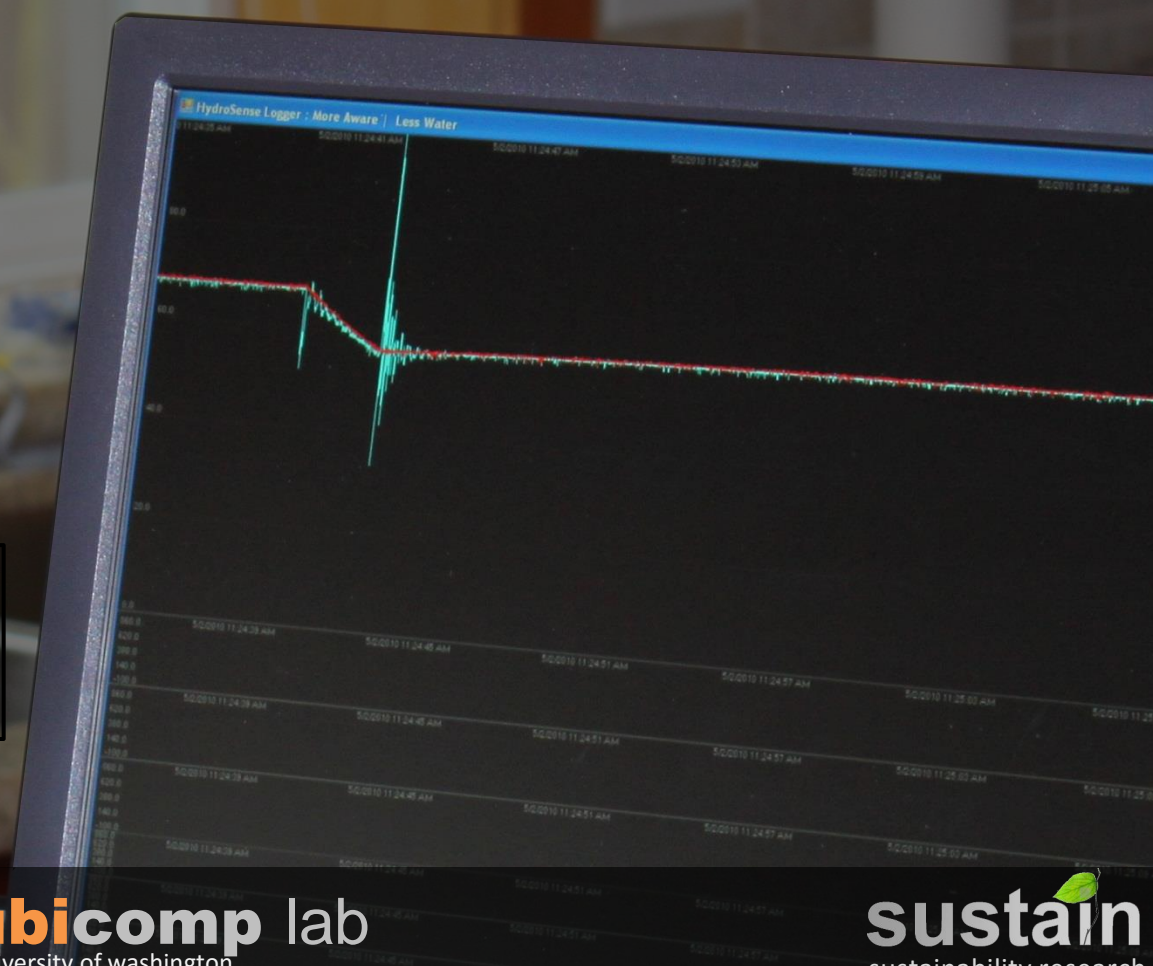


under pressure

transforming the way we think about water in the home

jon froehlich, eric larson, shwetak patel
twitter: @jonfroehlich
dorkbot seattle, oct 27, 2010



Movie Removed for Public Posting of Slides

sky soleil performing *under pressure* by queen & bowie







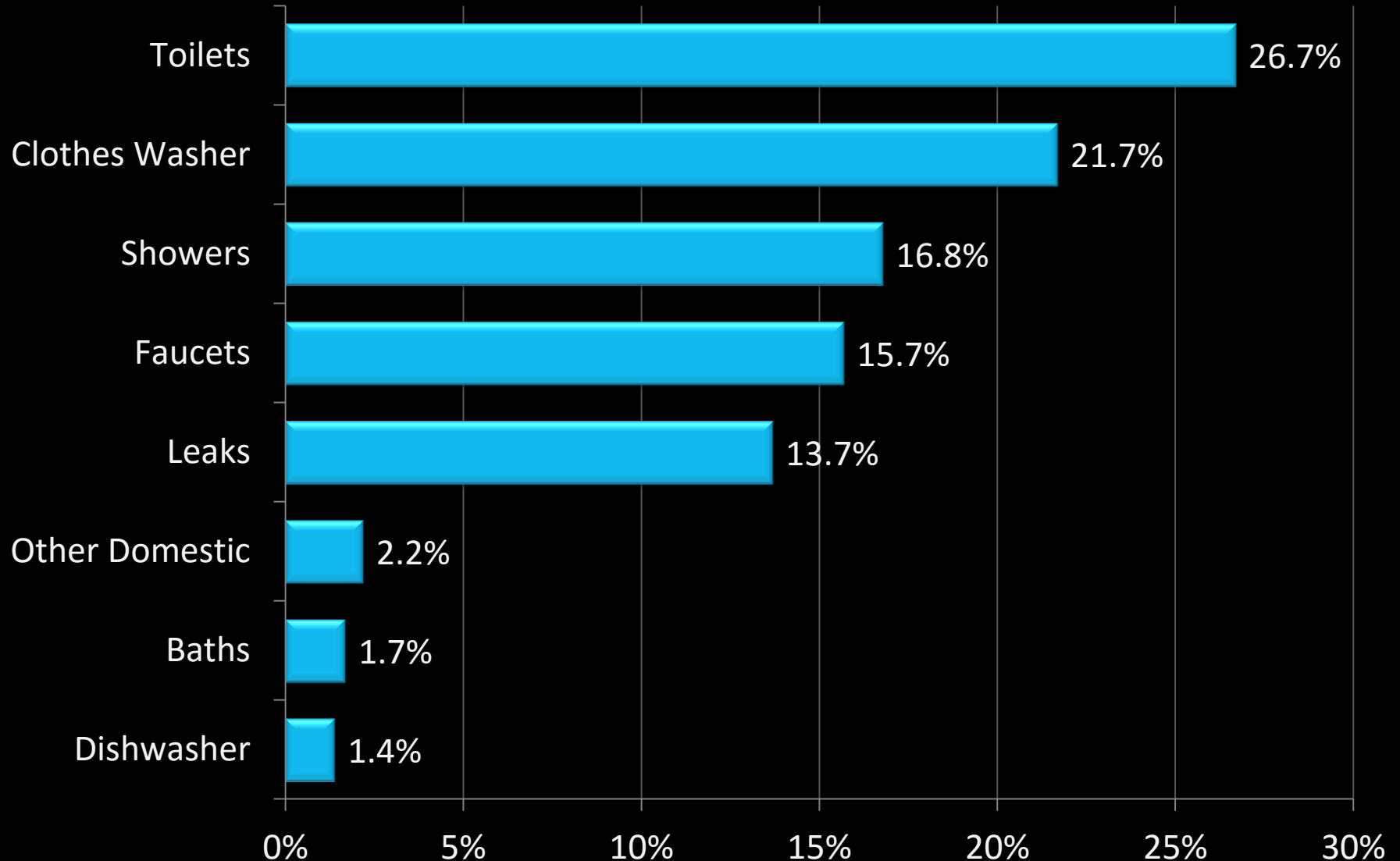
water pressure





what are the most **water** consuming
activities in your home?

top indoor water usage activities



one sensor tracks **water** usage
at every fixture

today's usage

refrigerator
0.3 gallons

dishwasher
6.5 gallons

kitchen sink
28 gallons



today's usage

shower
62.4 gallons

bath
6.5 gallons

toilet
78.4 gallons

bathroom sink 1
4.2 gallons

bathroom sink 2
0.8 gallons



today's usage: hot vs cold

shower
52.4 gallons

shower
10.4 gallons

bath
6.5 gallons

bath
0.0 gallons

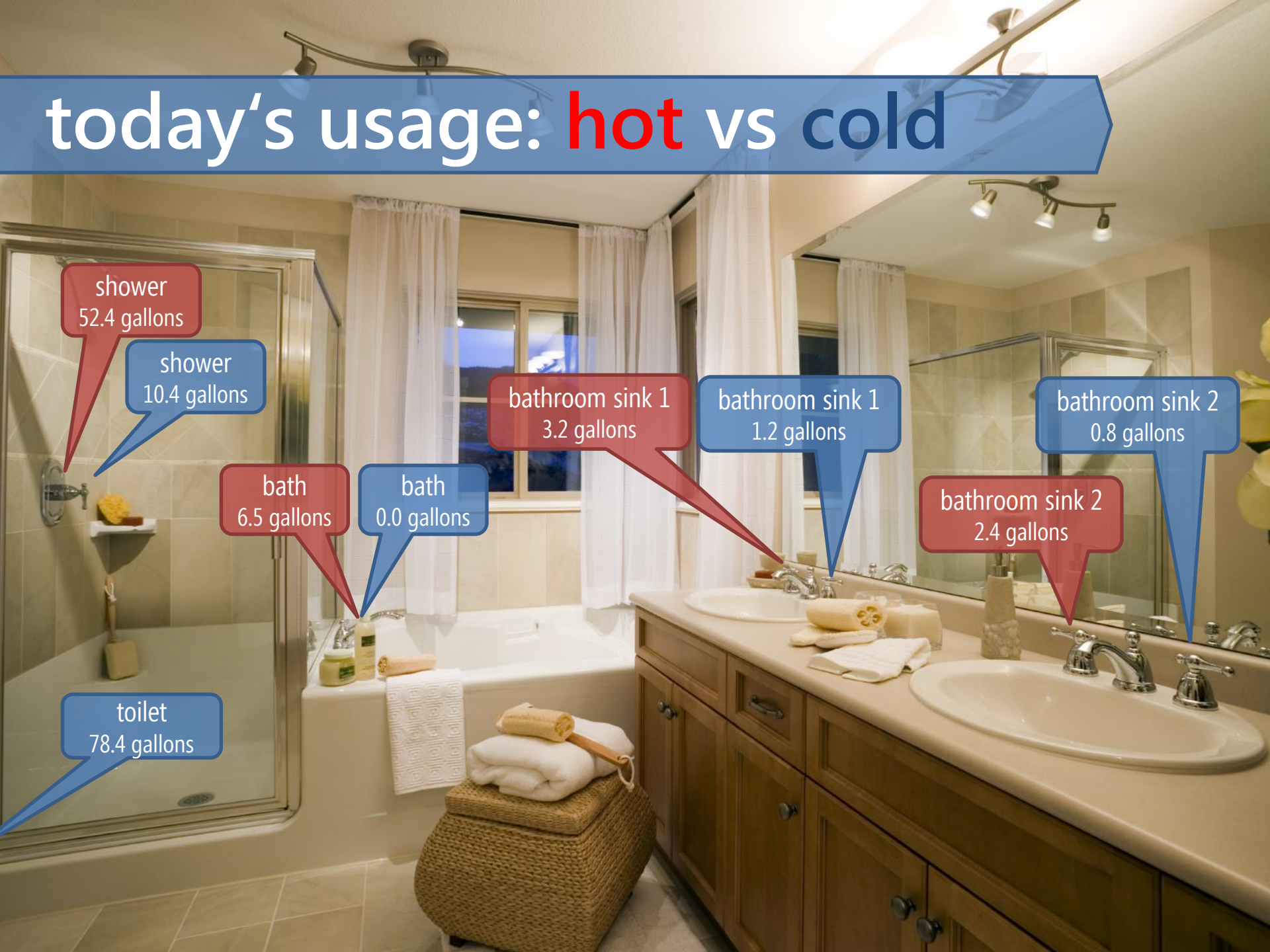
toilet
78.4 gallons

bathroom sink 1
3.2 gallons

bathroom sink 1
1.2 gallons

bathroom sink 2
0.8 gallons

bathroom sink 2
2.4 gallons



water meter



SAFEGWAY

SAVE MORE AT SAFEGWAY

GROCERY

SFWY PRTZLE STICK		1.50 B
RegPrice 1.79	CardSav .29	3.79 B
BLKBERY PRES		2.39 B
SFY CANOLA OIL		3.69 B
CEREAL PNT BUTTER		3.29 B
CHILI SAUCE SWT		
CHF-B PIZZA		
LK GRCL SCE		

REFRIG/FROZ

LUC CHEESE	Car	
RegPrice 6.79		
SPINACH ARTICHOKE	Ca	
RegPrice 3.79		
3S CRWN VEG RSTD	C	
RegPrice 3.79		
202.50 SFWY SEL MF		
RegPrice 7.58		
MARGARINE		

GEN MERCHANDISE

#SFY BENEHIST TAB		7.99 T
-------------------	--	--------

BAKED GOODS

LD COSMIC BROWNIES		1.29 B
DROWEAT RYE		3.14 B
CUSTARD PIE 9IN		4.99 B
RegPrice 5.99	CardSav 1.00	4.99 B
CHOC CREAM PIE		
RegPrice 5.99	CardSav 1.00	

**** TAX	6.26	BAL	144.25
VF MC XXXXXXXXX			144.25

CHANGE		.00
TOTAL SAVINGS	16.97	
NUMBER OF ITEMS =	35	

12/27/06 12:00 1877 02 0150 5145

SAFEGWAY


SAVE MORE AT SAFEGWAY

Month: April 2006

Total Food Units: 1527

Total Price:

\$527



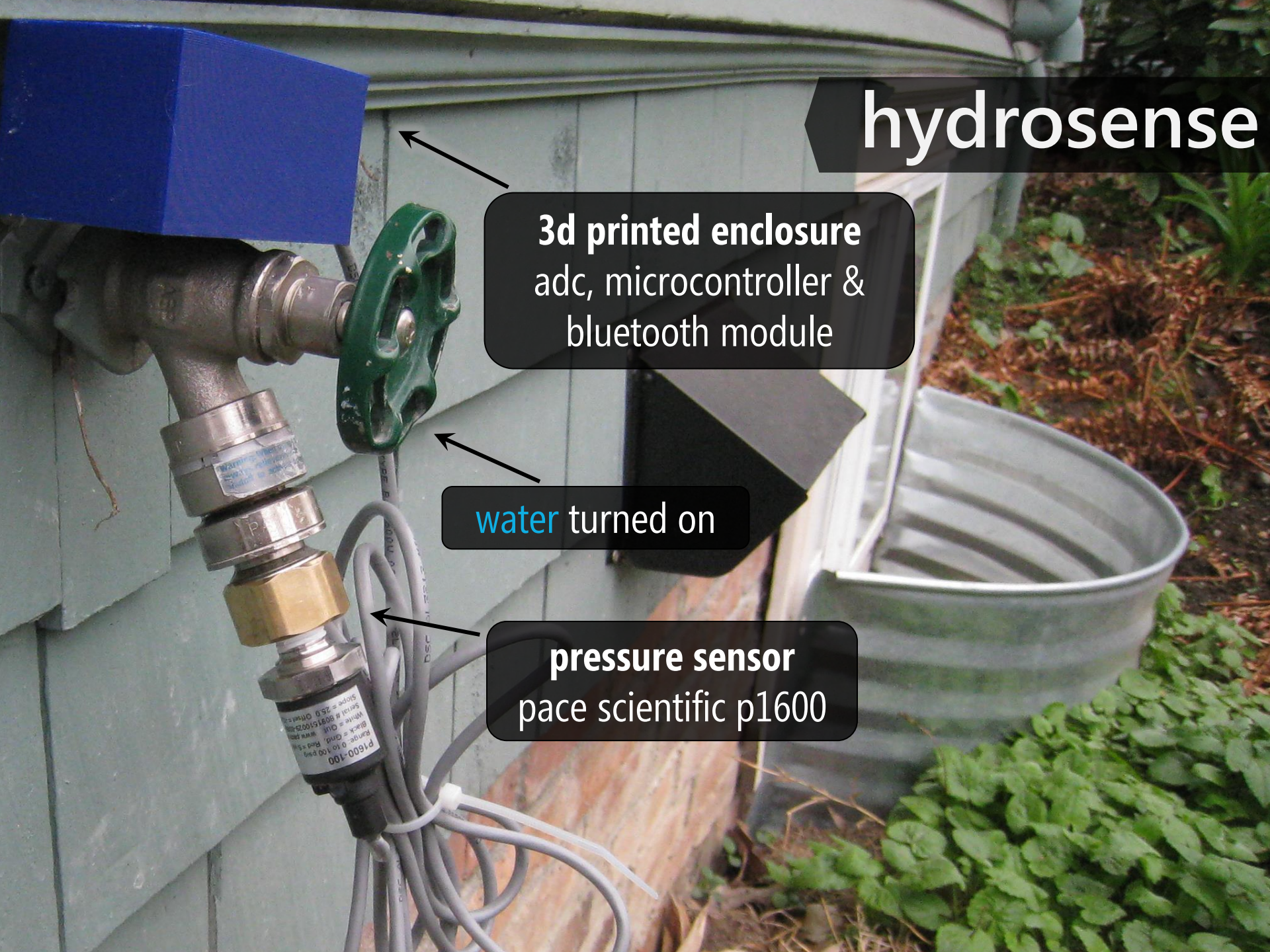
traditional inline
water meter

hydrosense

3d printed enclosure
adc, microcontroller &
bluetooth module

water turned on

pressure sensor
pace scientific p1600



brief plumbing tutorial



brief plumbing tutorial



brief plumbing tutorial





water tower

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



pressure regulator



incoming cold
water from
supply line



utility water
meter



pressure
regulator



plumbing layout

incoming cold
water from
supply line
→



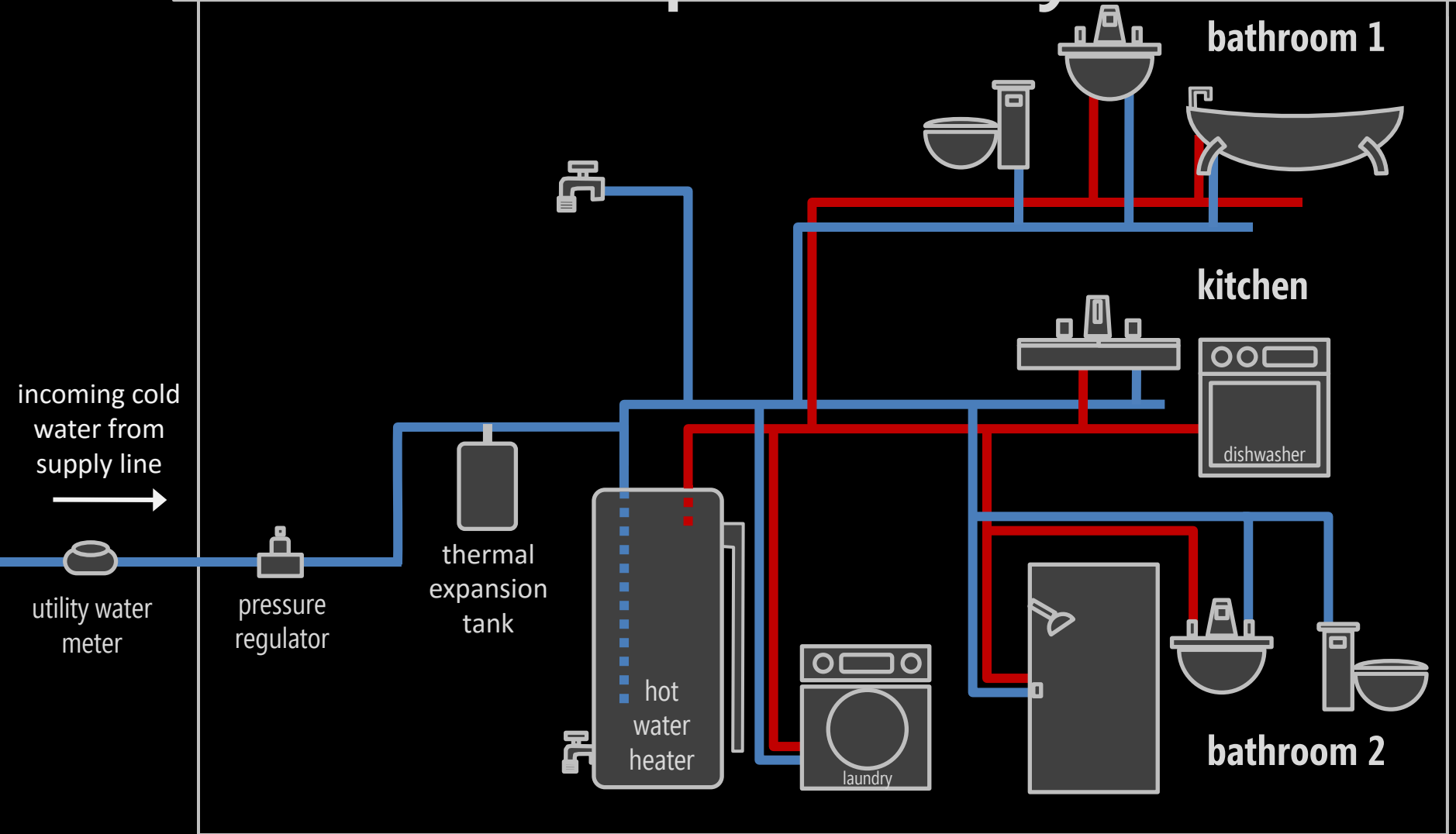
utility water
meter



pressure
regulator



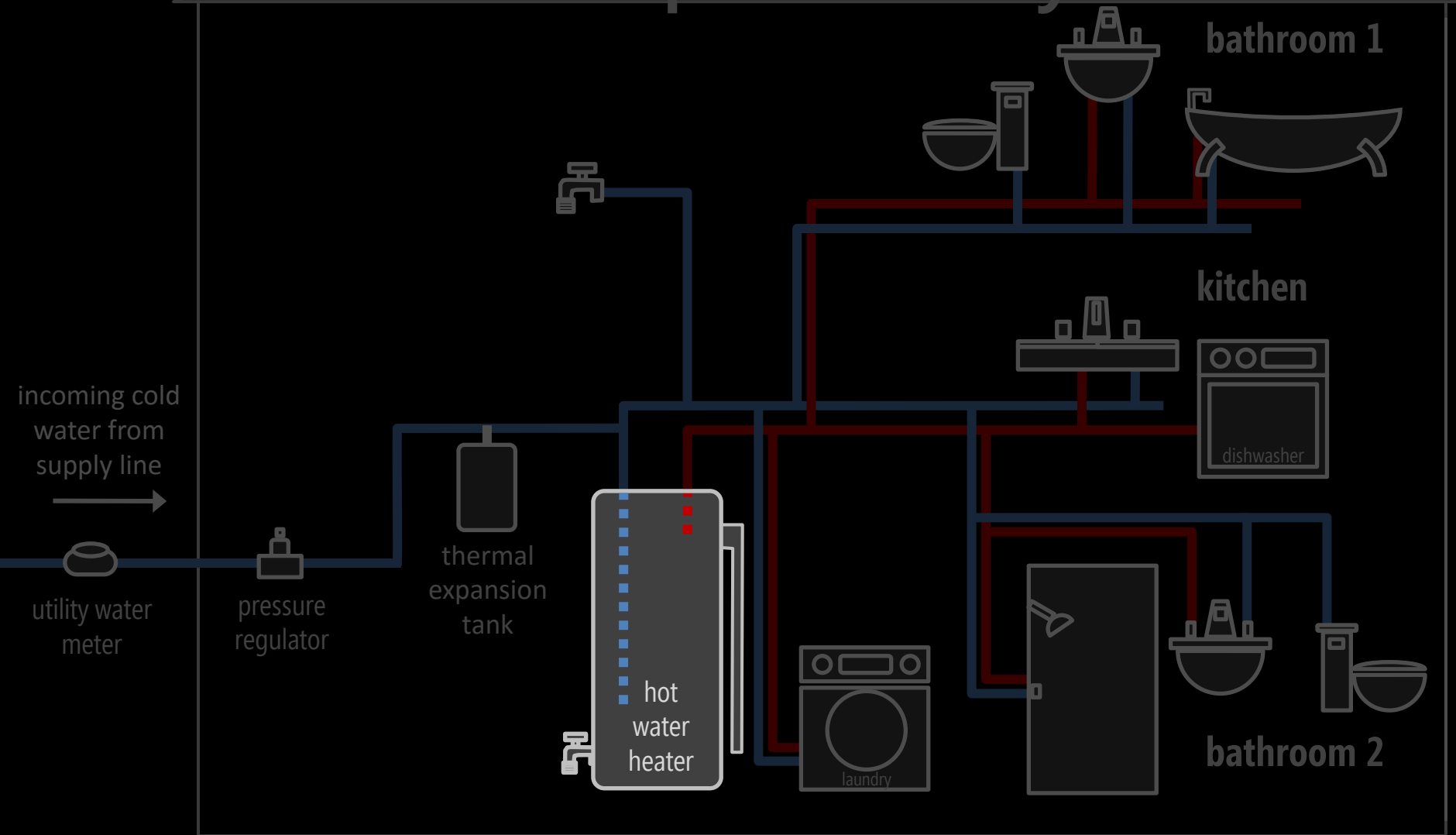
closed pressure system

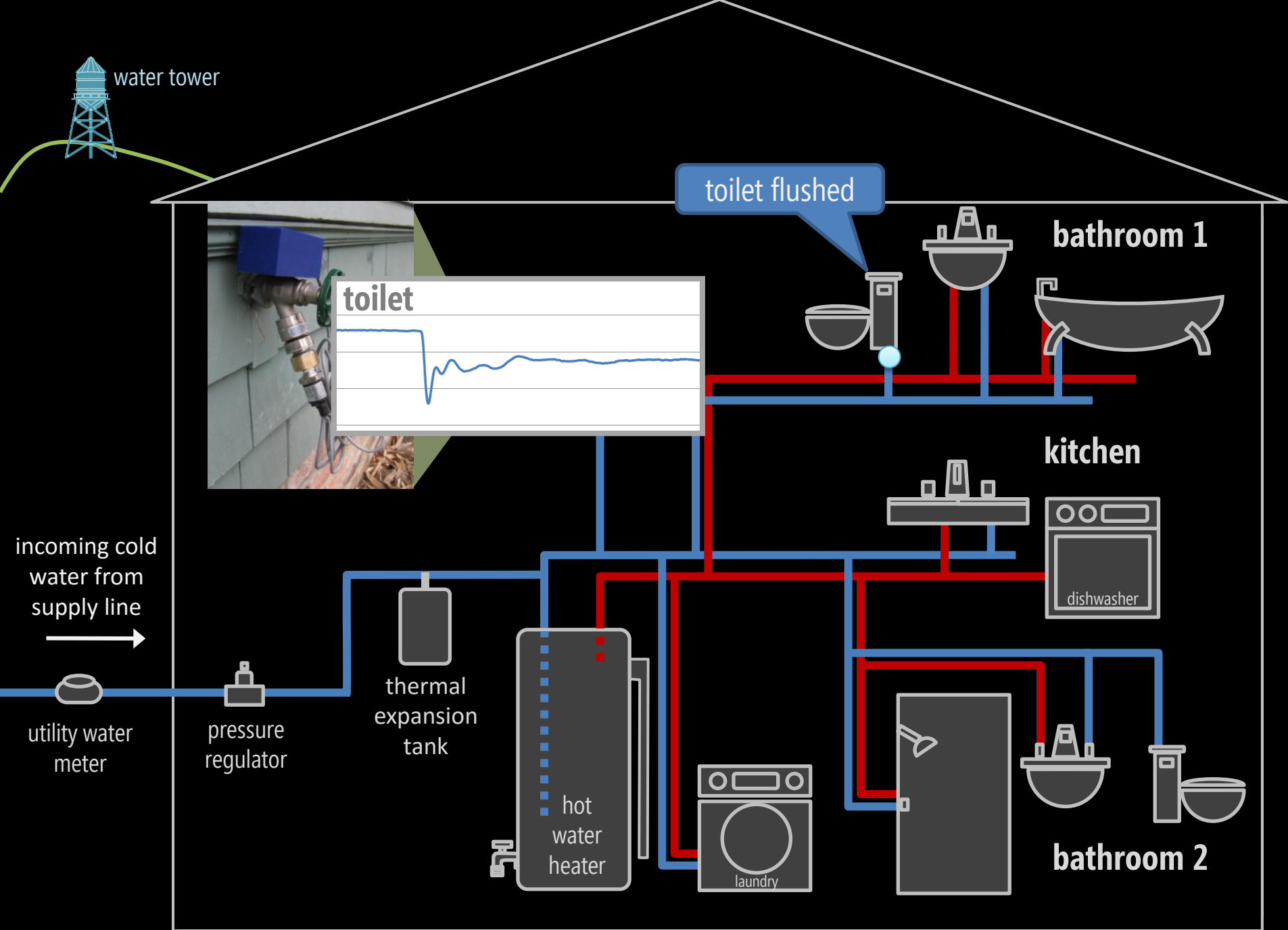




water tower

closed pressure system





water tower

toilet flushed

bathroom 1

toilet

kitchen

dishwasher

incoming cold water from supply line

utility water meter

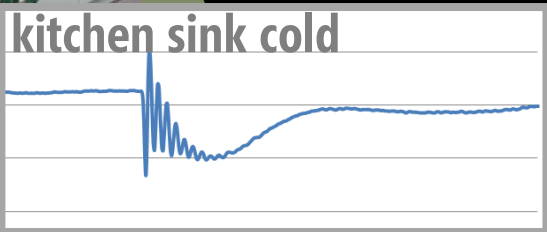
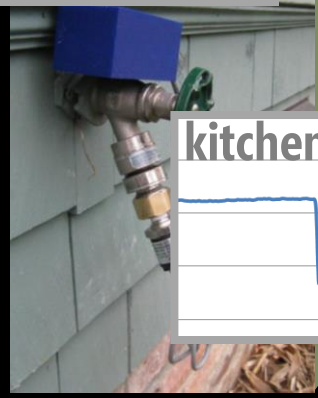
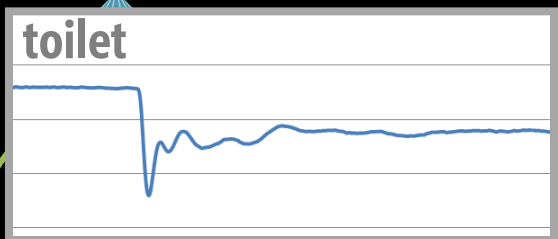
pressure regulator

thermal expansion tank

hot water heater

laundry

bathroom 2



kitchen sink cold open

incoming cold water from supply line



utility water meter

pressure regulator

thermal expansion tank

hot water heater

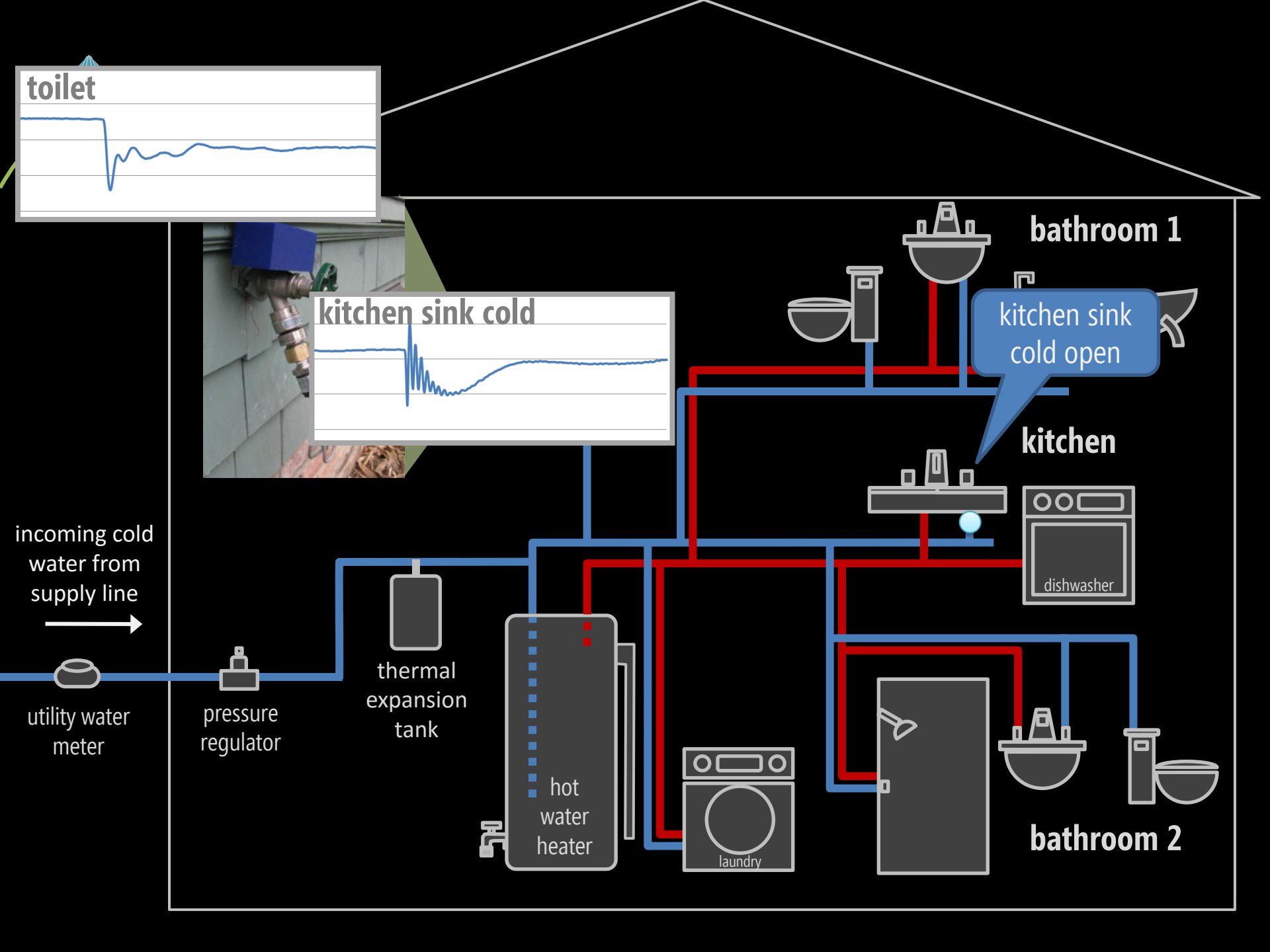
laundry

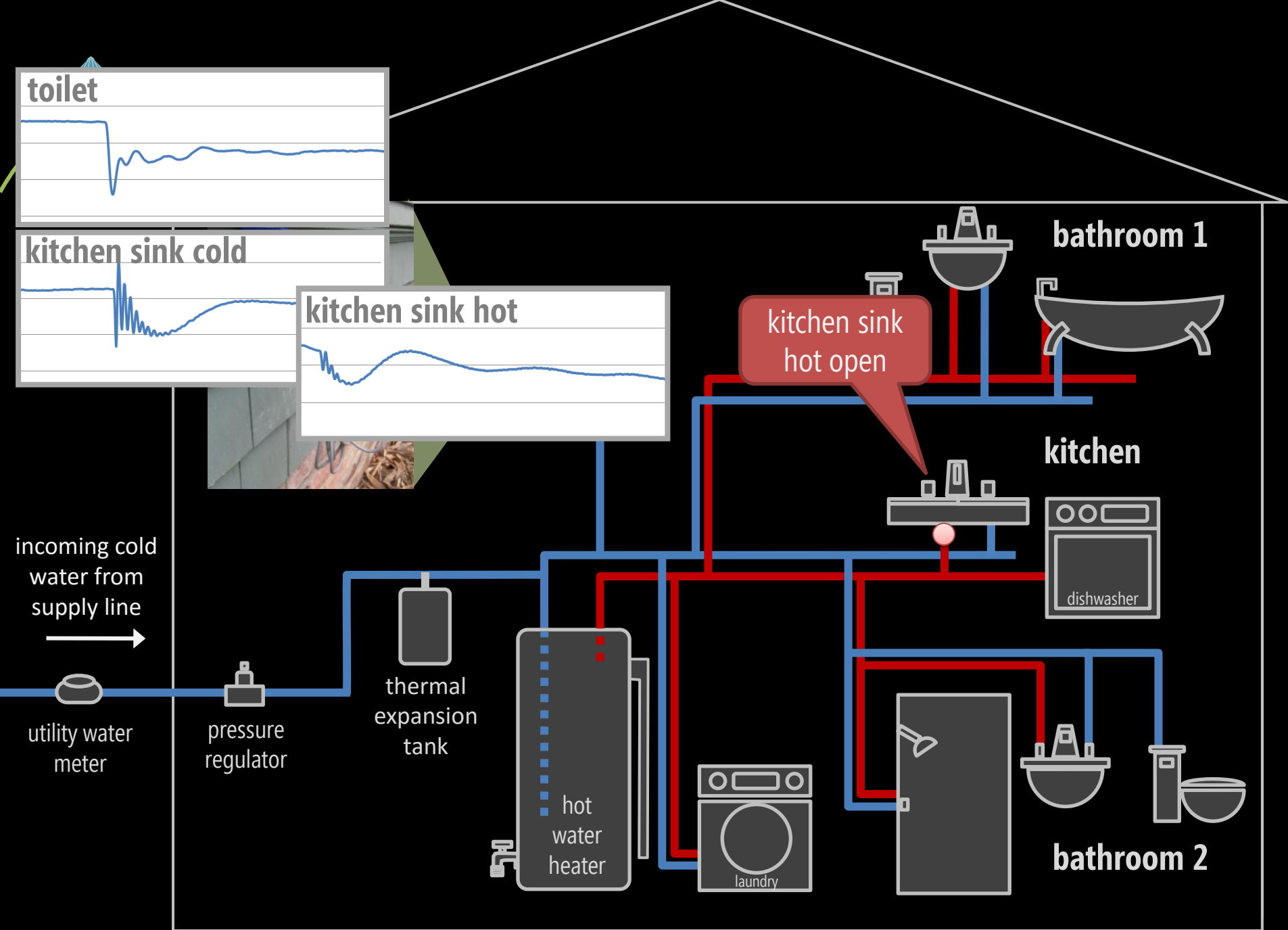
dishwasher

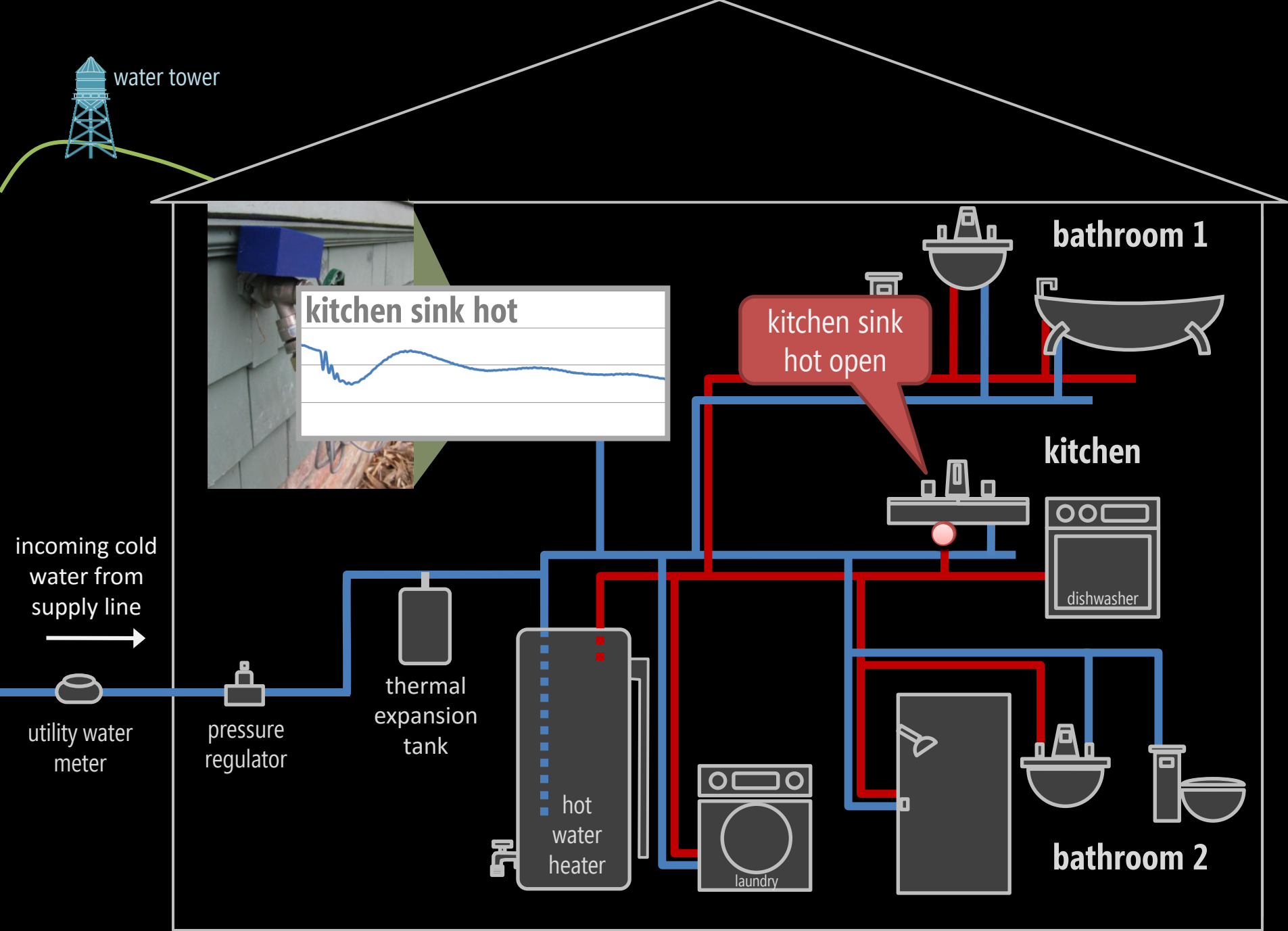
bathroom 2

bathroom 1

kitchen

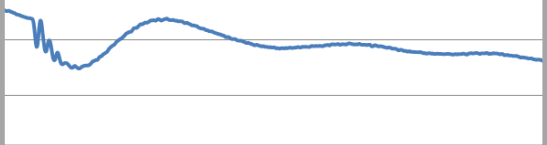






water tower

kitchen sink hot



kitchen sink hot open

bathroom 1

kitchen

dishwasher

incoming cold water from supply line

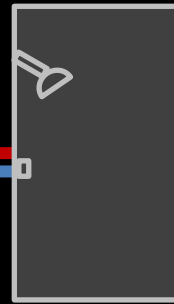
utility water meter

pressure regulator

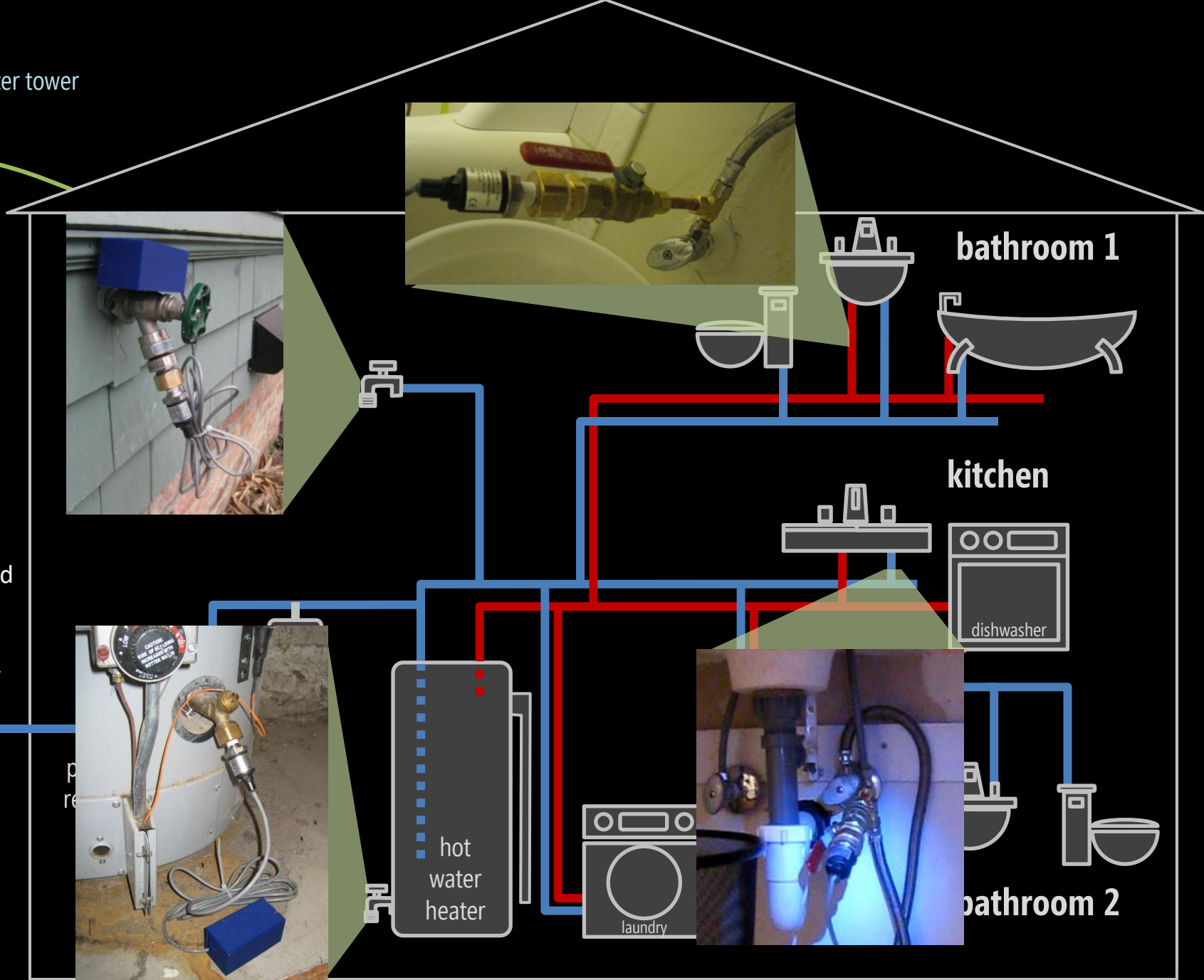
thermal expansion tank

hot water heater

laundry



bathroom 2



incoming cold water from supply line

utility water meter

bathroom 1

kitchen

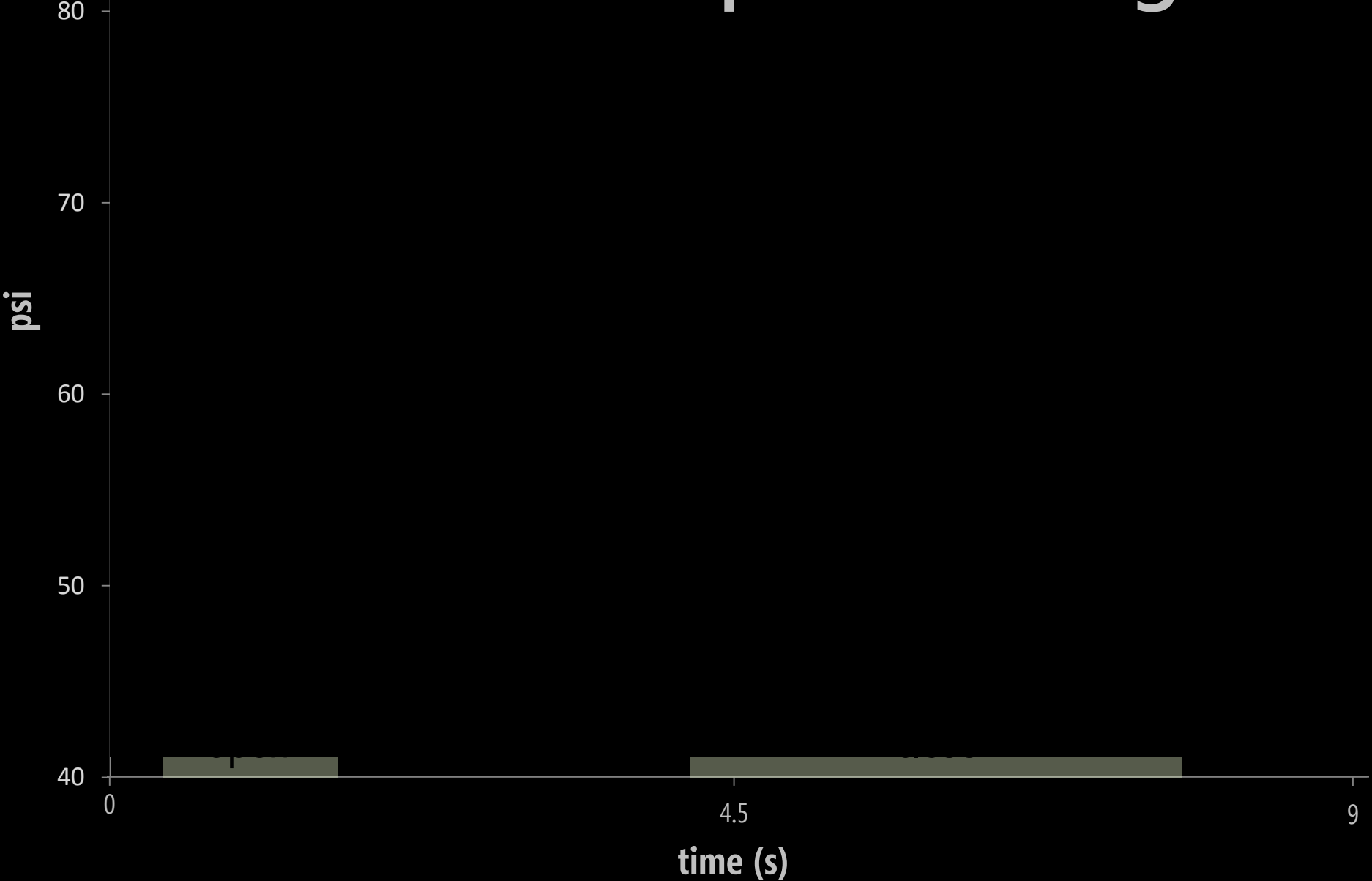
bathroom 2

hot water heater

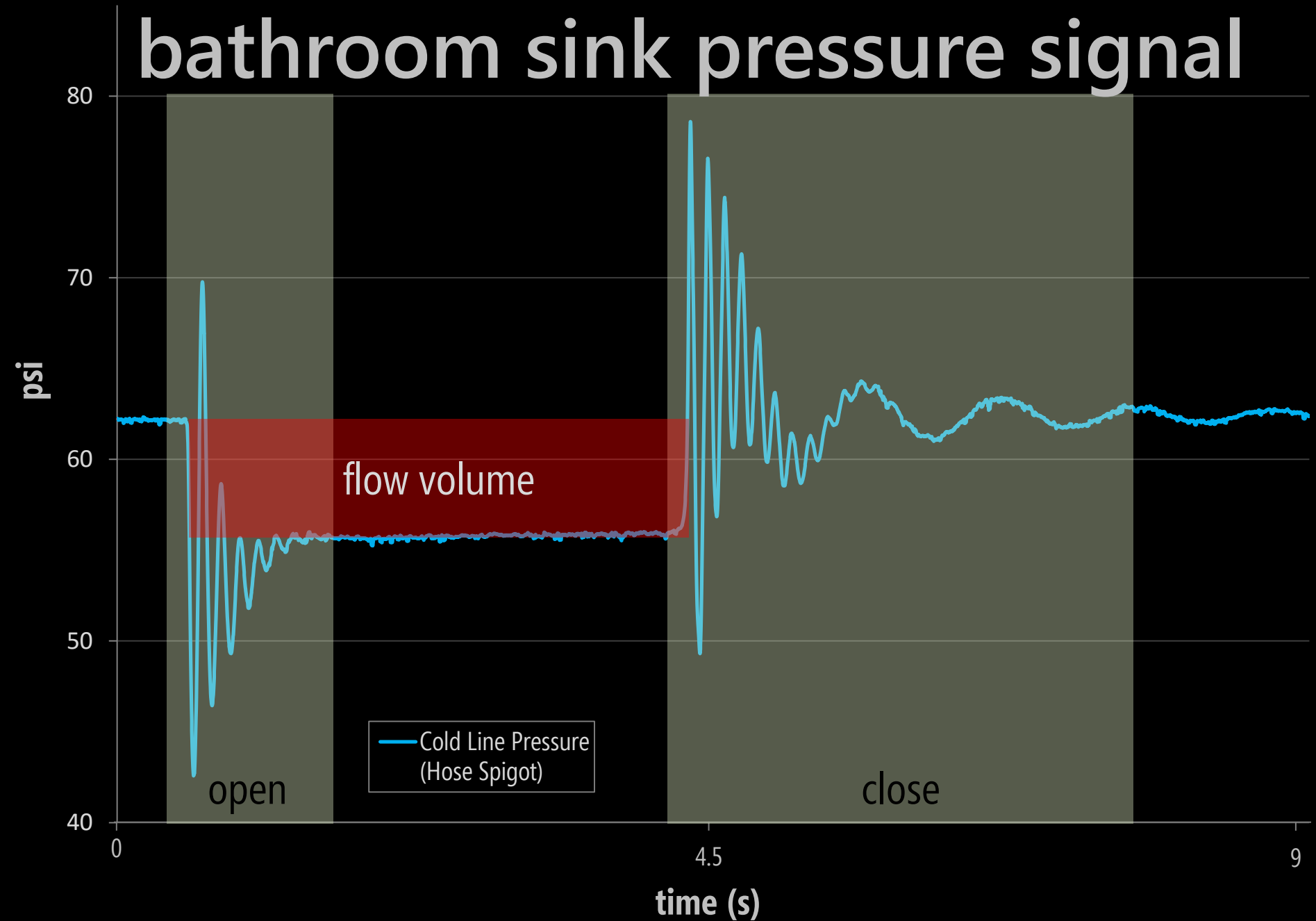
laundry

dishwasher

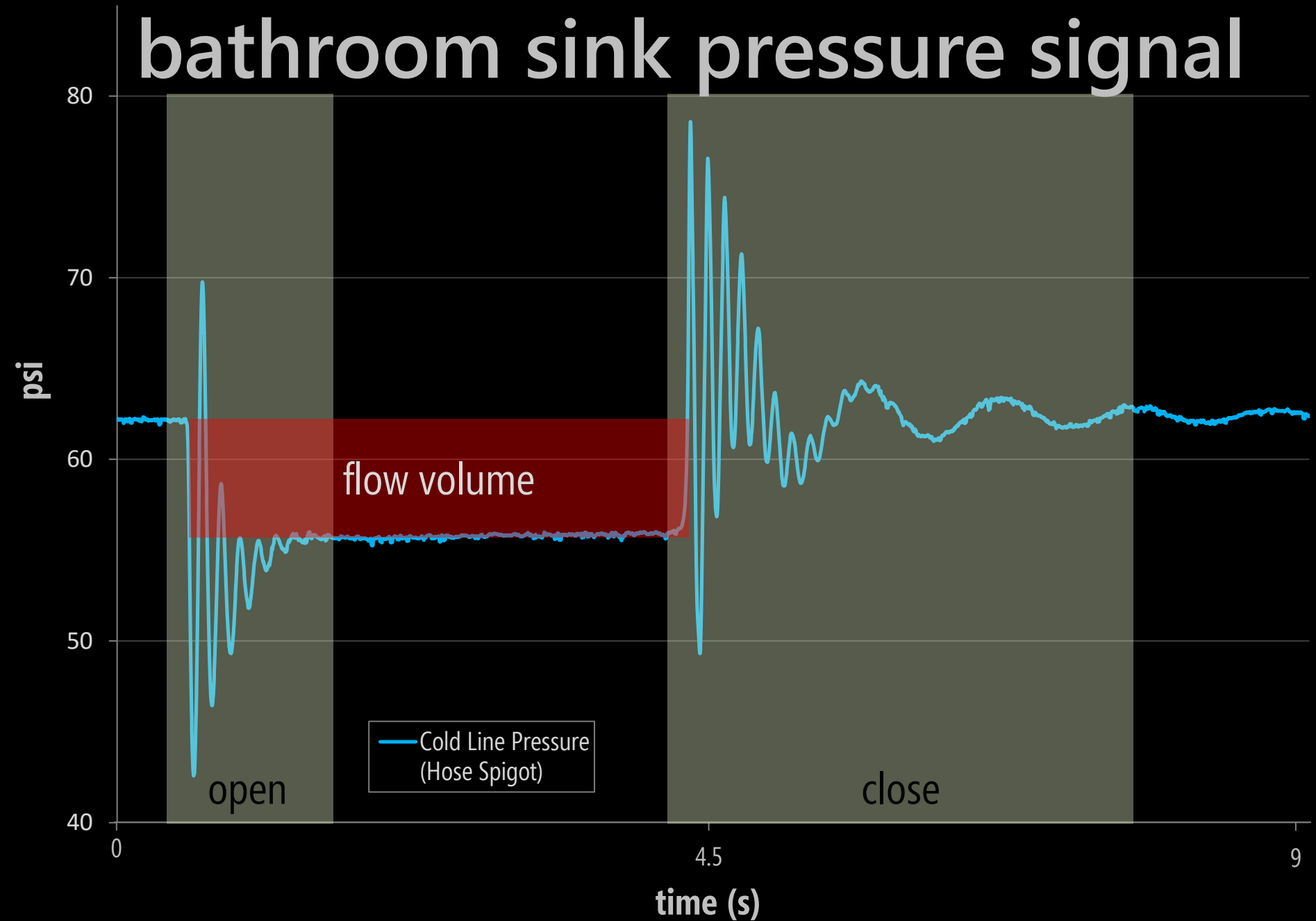
bathroom sink pressure signal



bathroom sink pressure signal



bathroom sink pressure signal



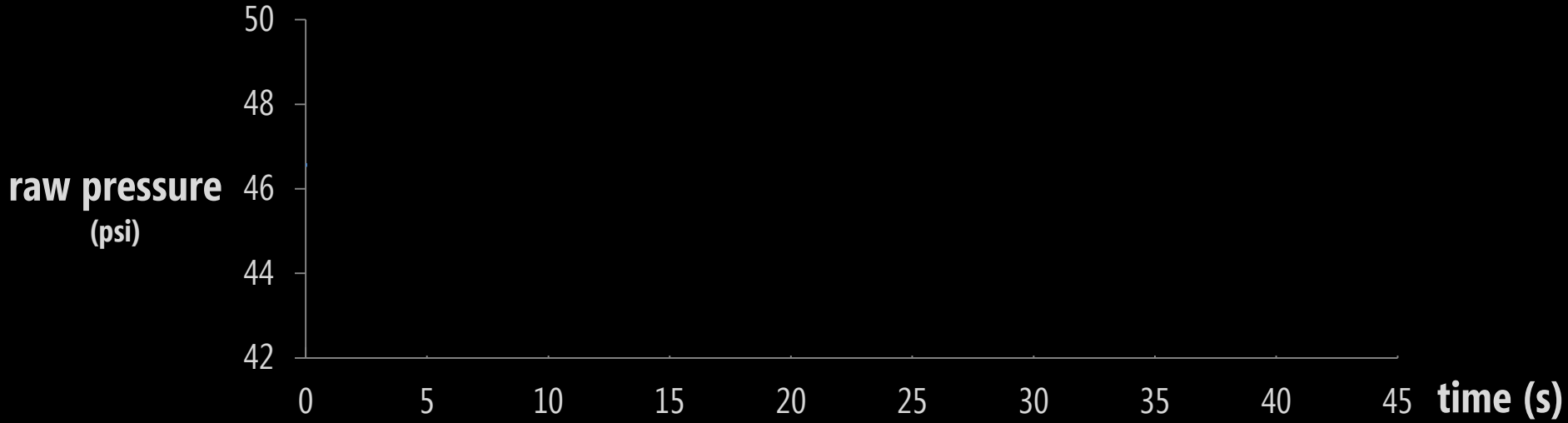
Movie Removed for Public Posting of Slides

how it works

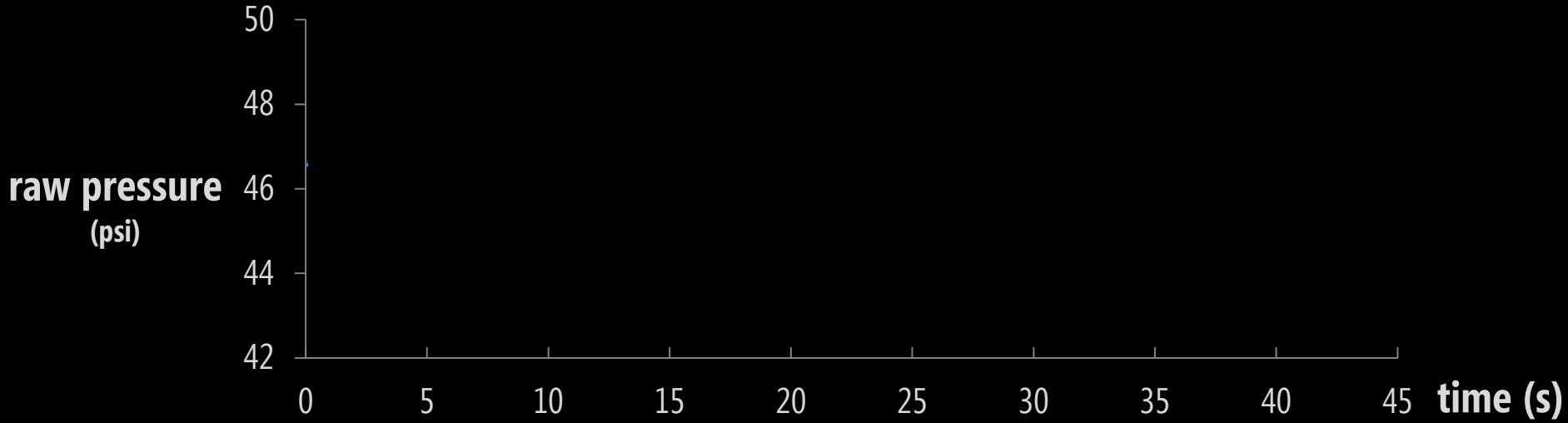


1. detect that a water event has occurred
2. classify event as "open" or "close"
3. determine source of event (e.g., toilet, shower).
4. provide flow estimate

event detection



event detection



smoothed pressure (psi)

48
46
44

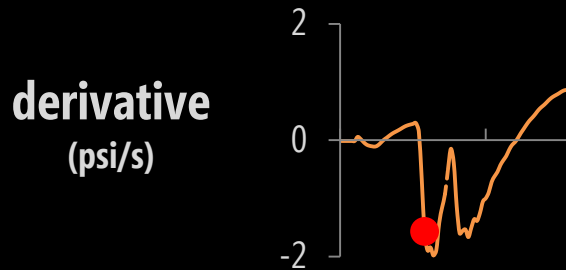
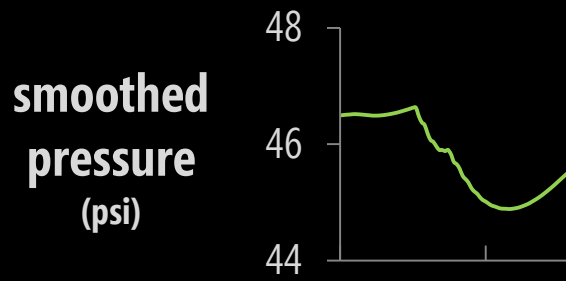
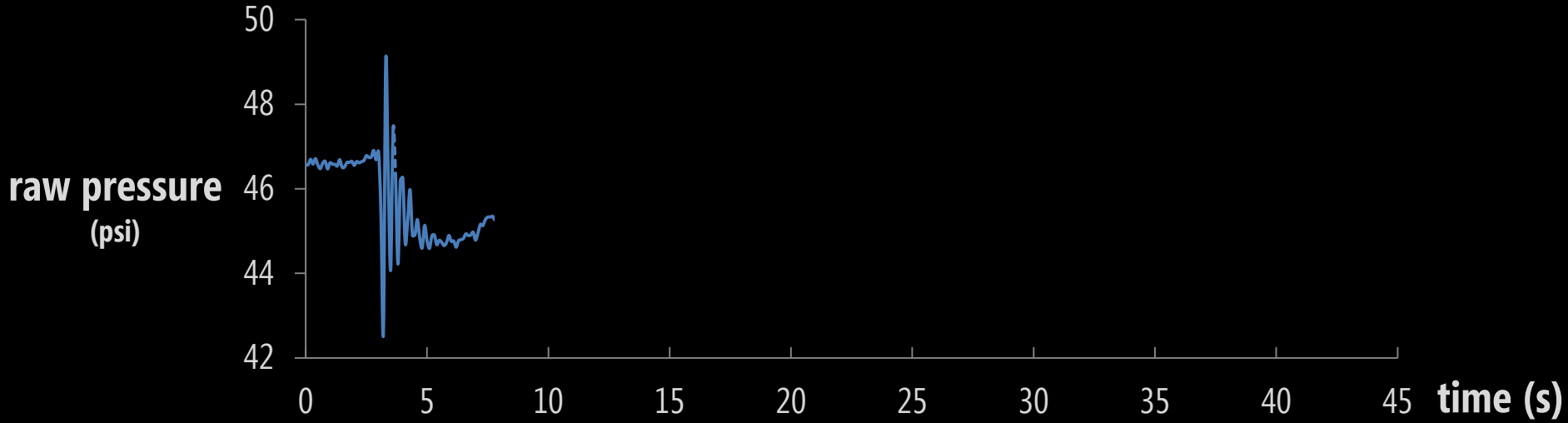
derivative (psi/s)

2
0
-2

critical change in pressure

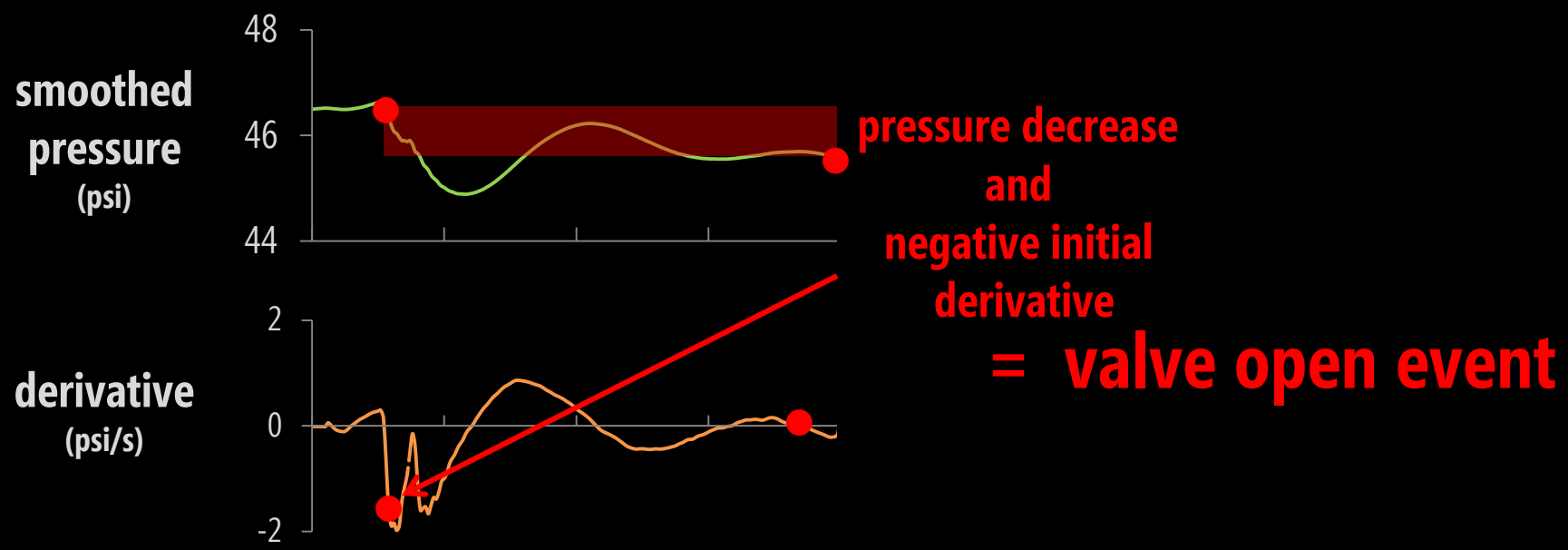
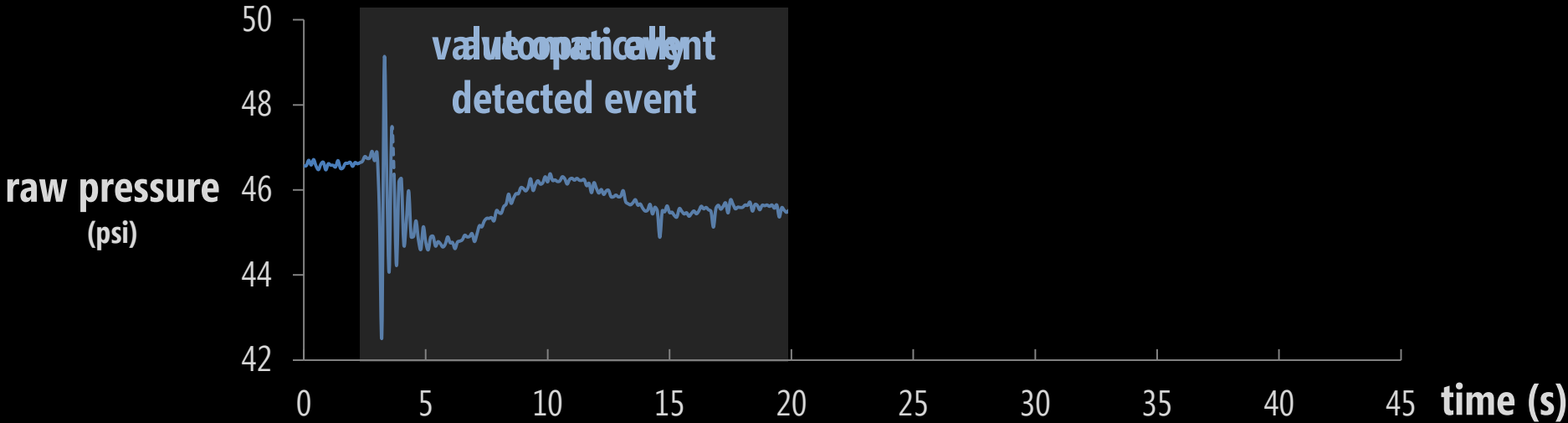


event detection



critical stabilization point

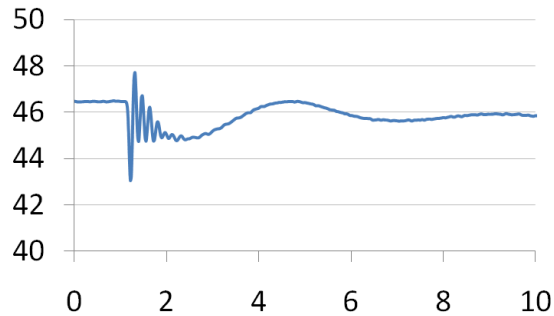
event detection



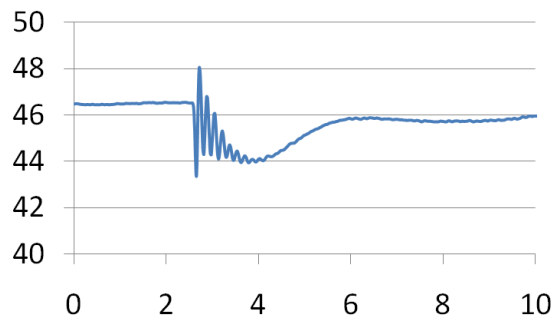
example open events

home 1

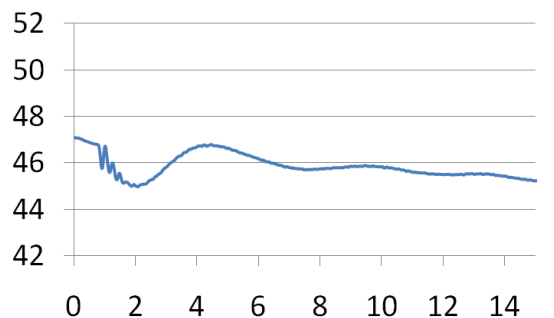
toilet



faucet



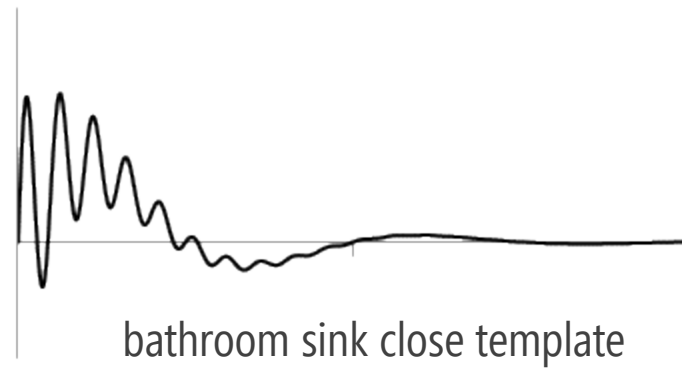
shower



signature dependent on:


- fixture type
- valve type
- valve location in home

matched filtering



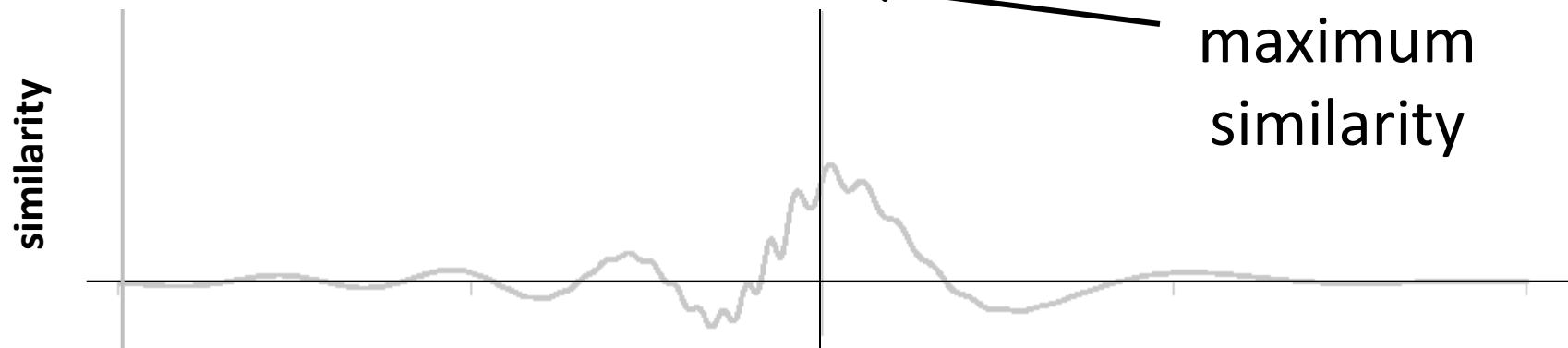
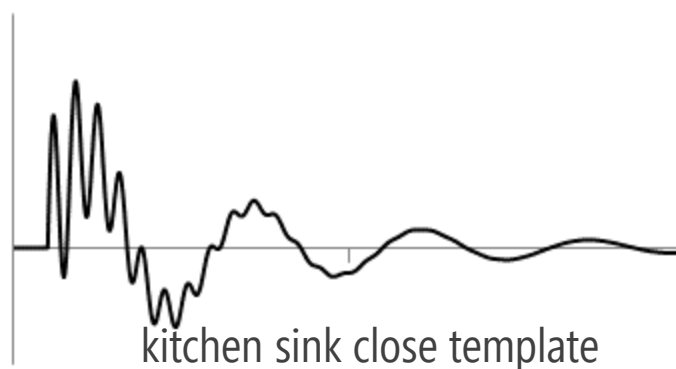
similarity

save
maximum
similarity



An arrow pointing from the text 'save maximum similarity' to the left, indicating the direction of the matched filtering process.

matched filtering



evaluation



home profiles

ten test locations

- 8 houses / 1 apt / 1 cabin
- avg size: 2,300 sq ft
- 1920s – 2000s

installation points

- 8 outdoor hose bibs
- 1 water heater
- 1 utility faucet



experimental protocol

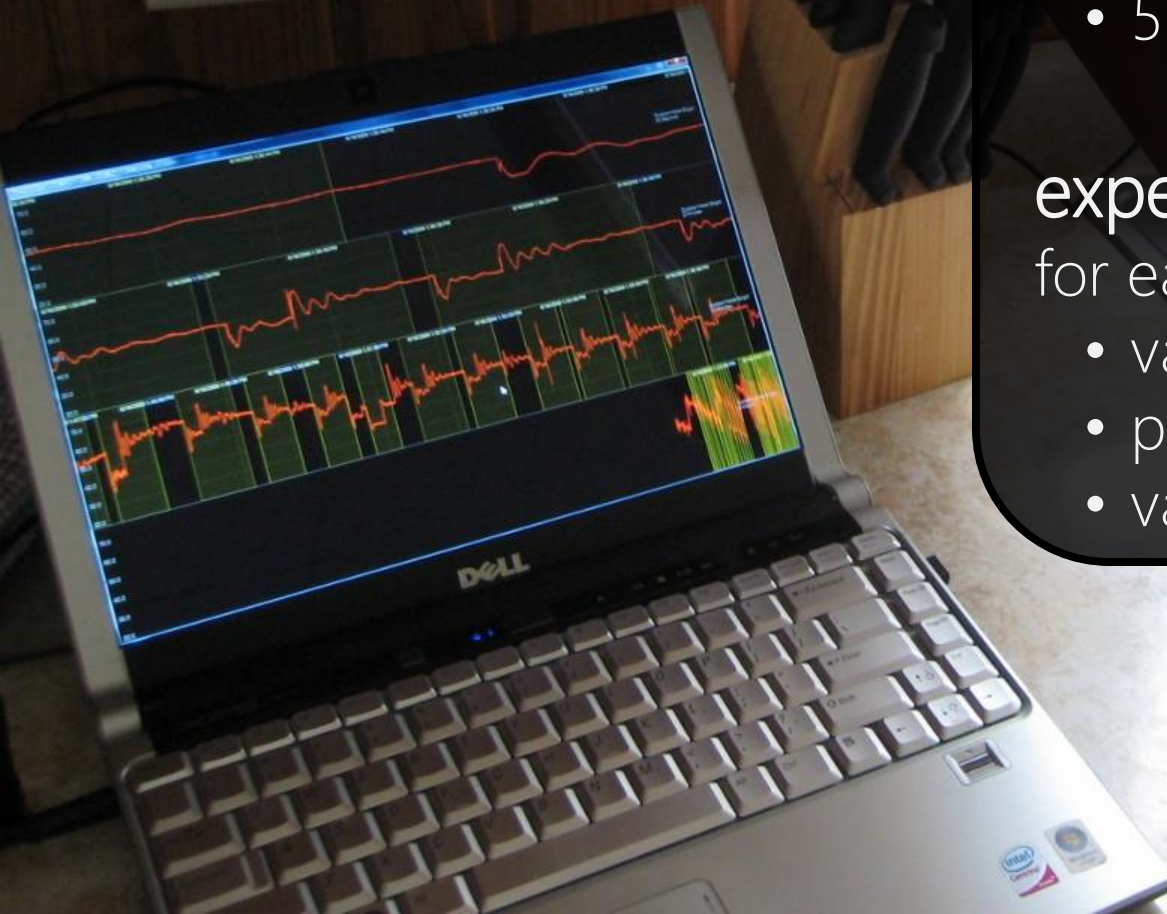
controlled experiments

- 2 researchers per site
- 5 trials per valve

experimental script

for each trial:

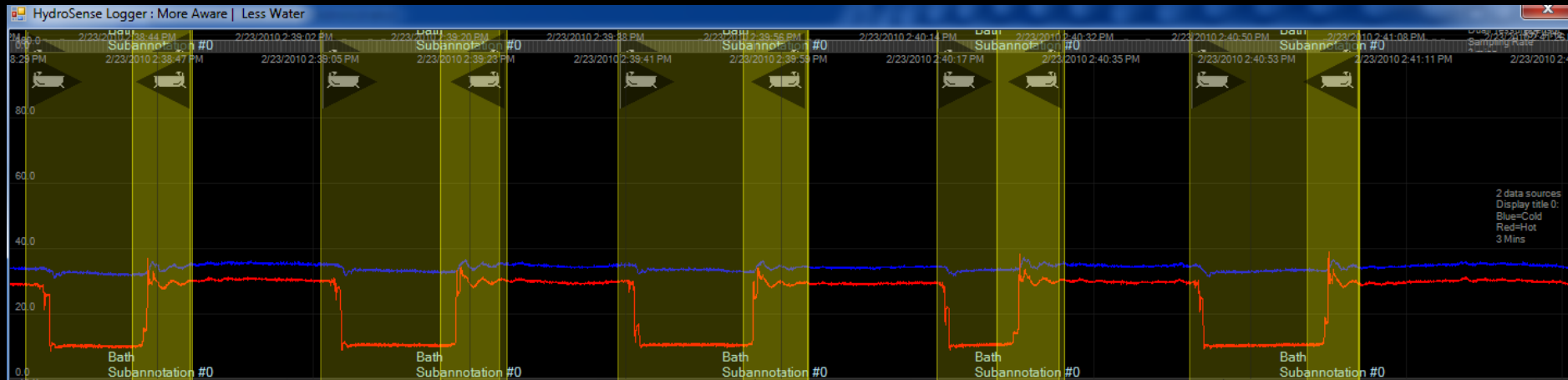
- valve opened full stop
- pause for ~5 seconds
- valve closed



example trial

Movie Removed for Public Posting of Slides

5 manually annotated bath trials

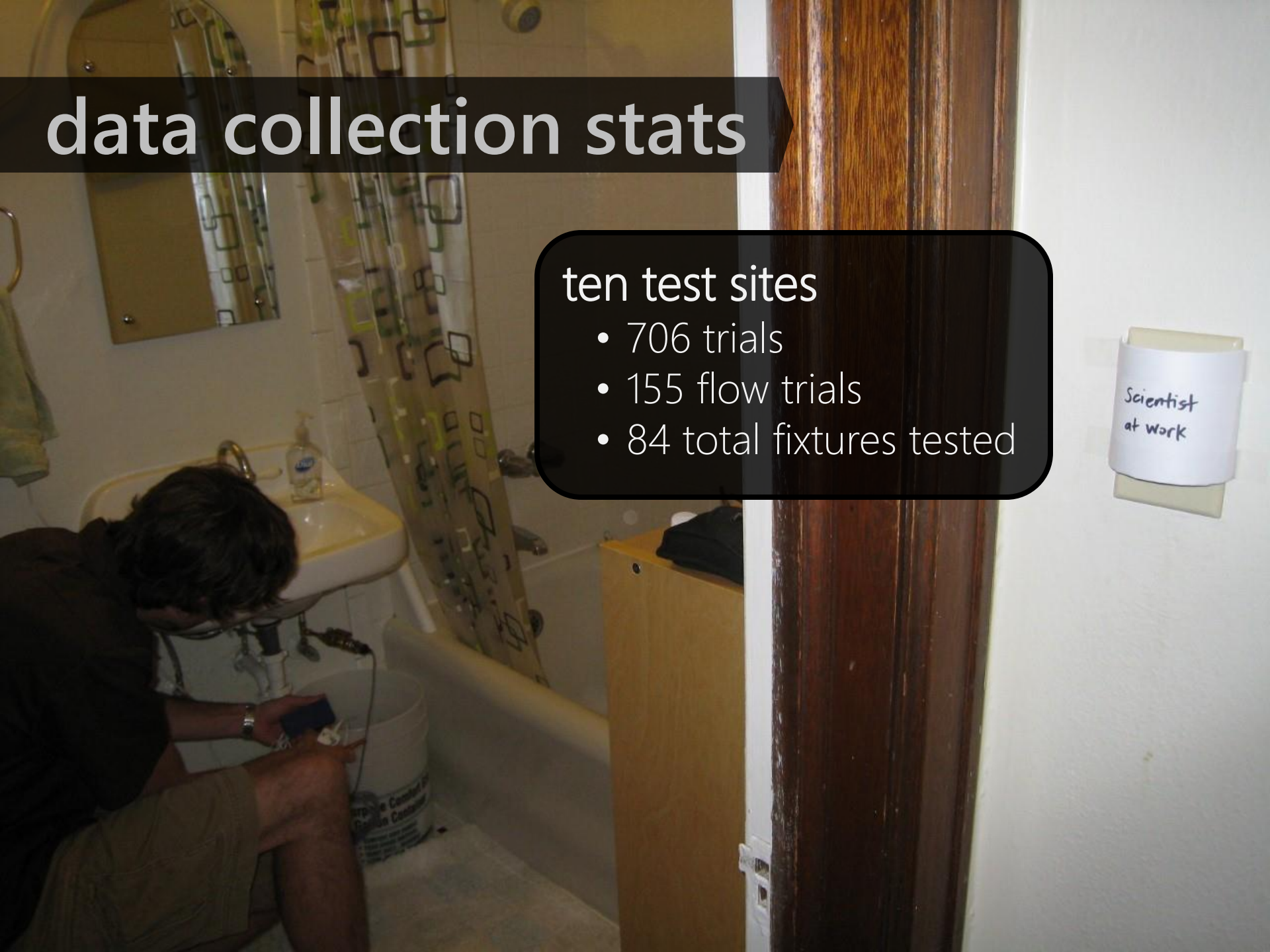


data collection stats

ten test sites

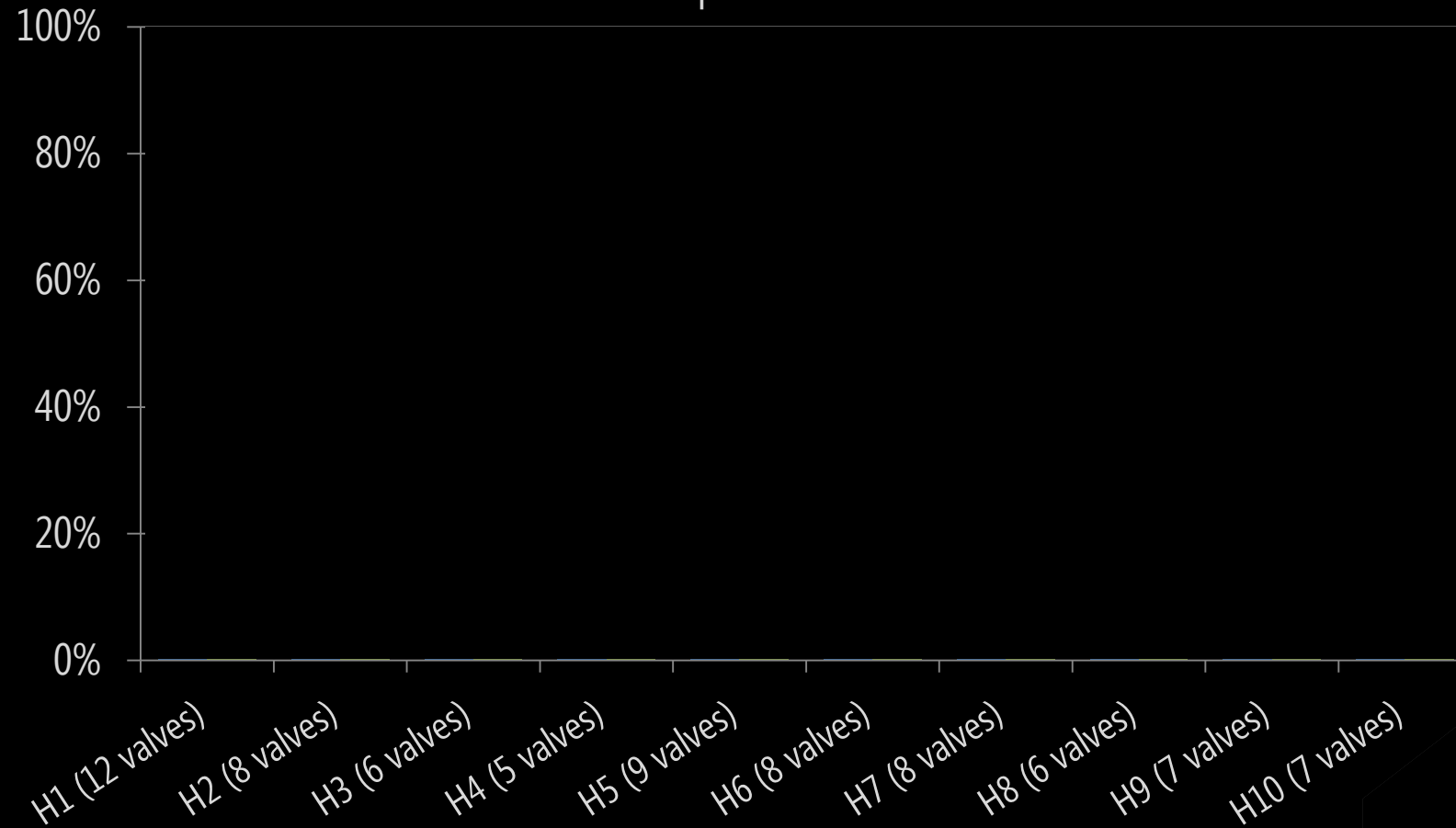
- 706 trials
- 155 flow trials
- 84 total fixtures tested

Scientist
at work

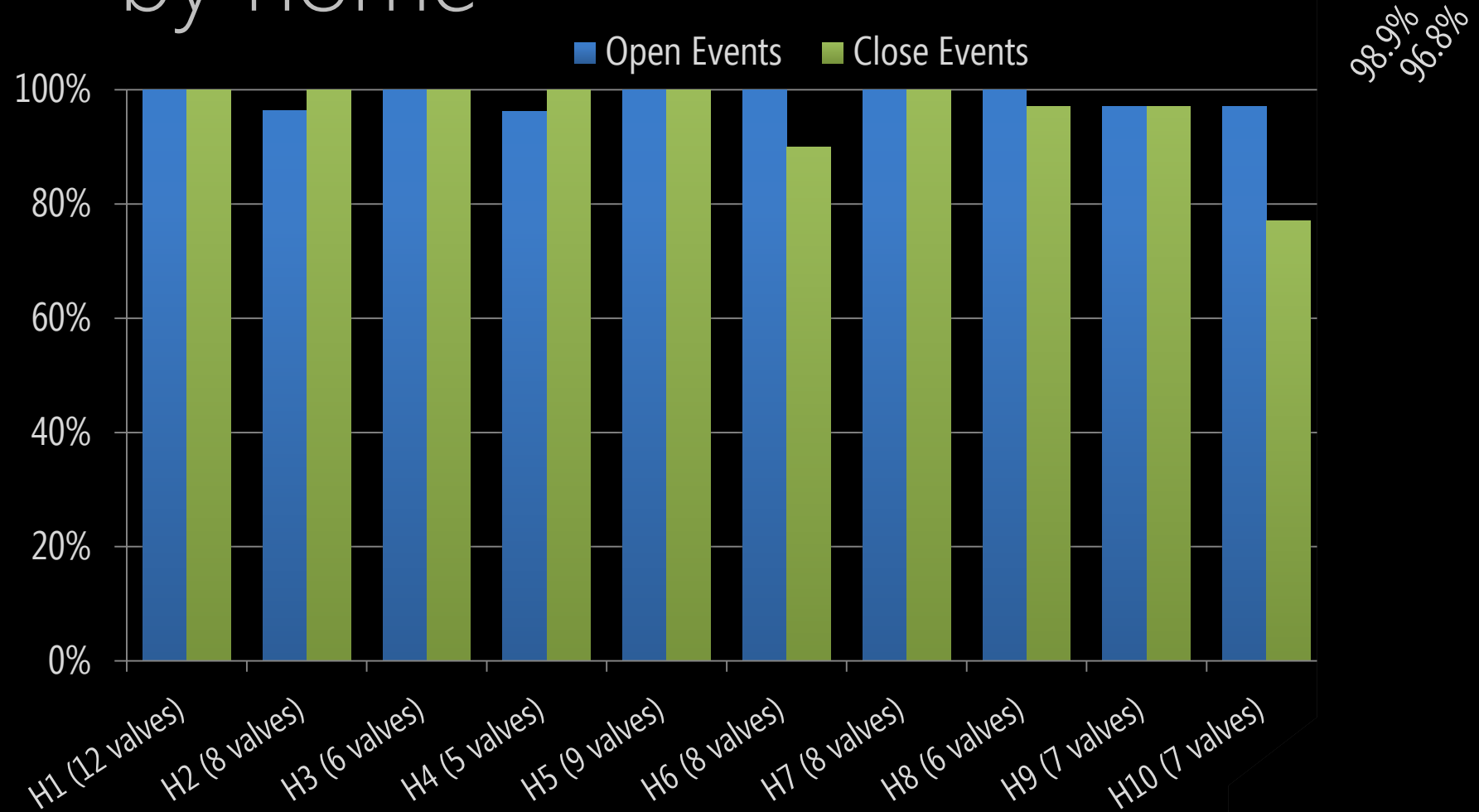


fixture classification results by home

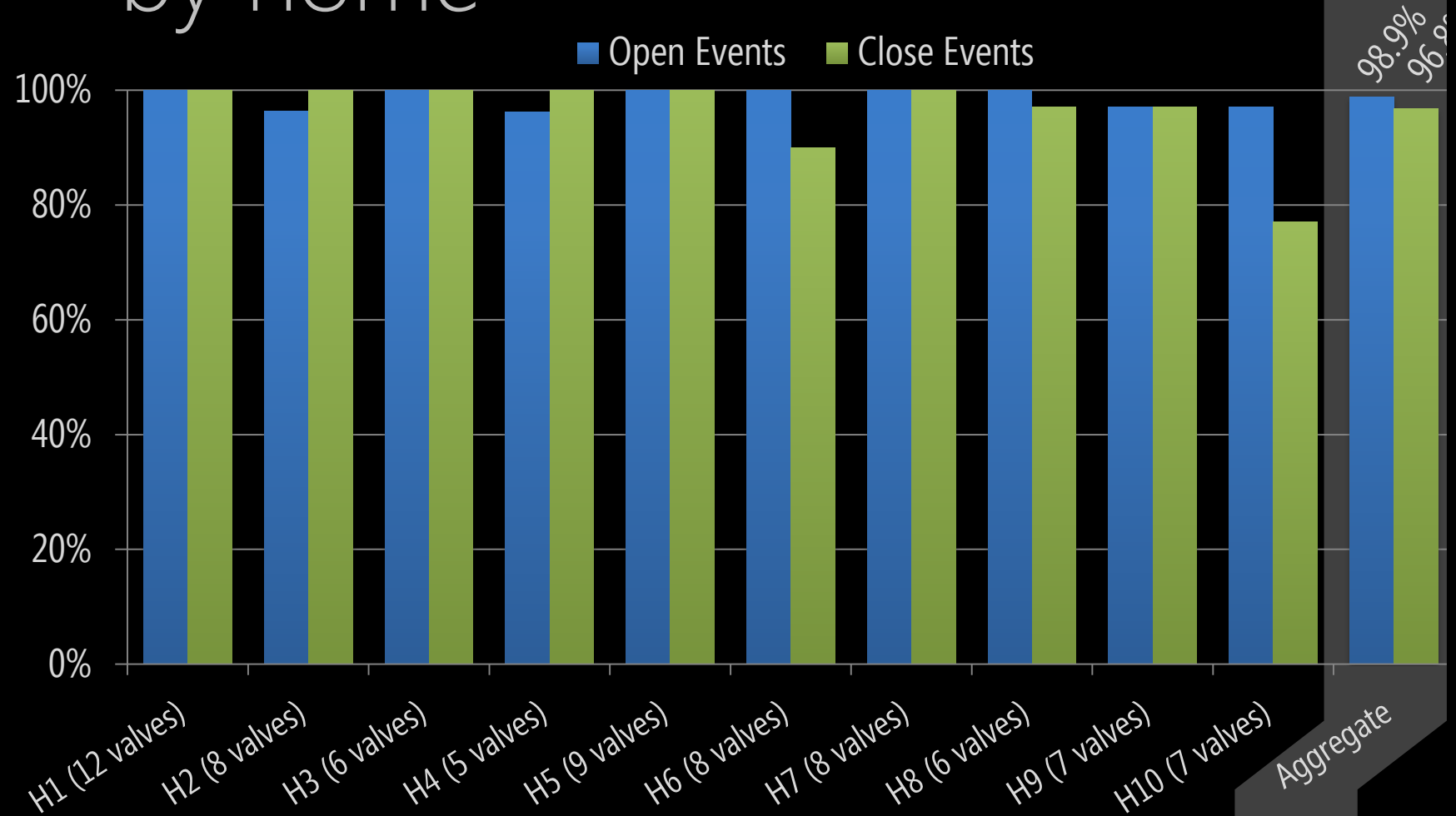
■ Open Events ■ Close Events



fixture classification results by home



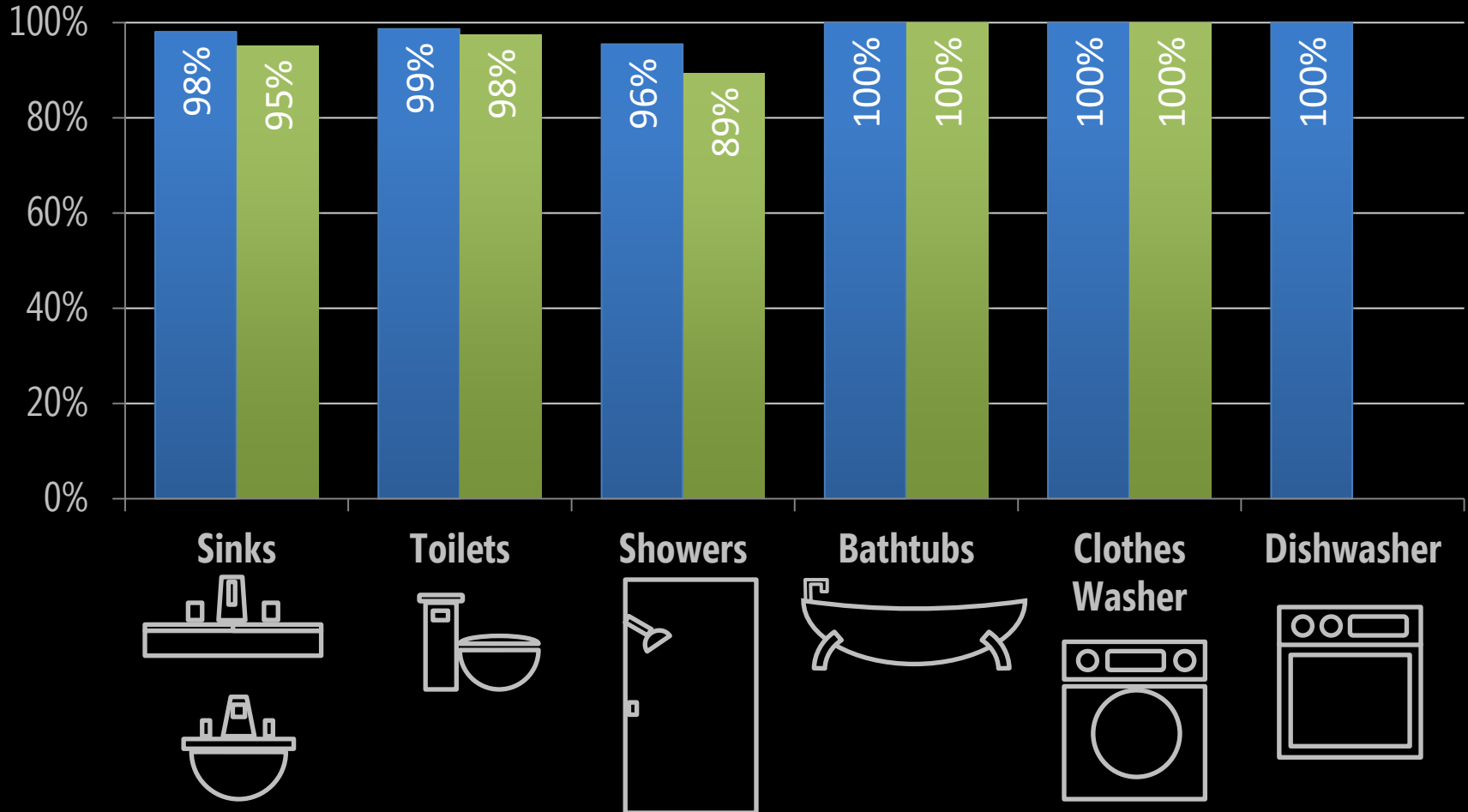
fixture classification results by home



fixture classification results

by fixture

■ Open Events ■ Close Events



first to show: pressure can be used to
dissaggragate water usage



but....

brushing teeth



A photograph of a man shaving in a bathroom. He is shirtless and has shaving cream on his face and chest. He is holding a razor to his cheek. In the foreground, the back of another person's shoulder and arm is visible, reaching towards the sink. The sink has a white mug, a toothbrush, and other toiletries on it. A large mirror is on the wall behind the sink, reflecting a window. The word "shaving" is written in white text on a dark grey arrow-shaped background pointing to the right.

shaving

bathing



paw washing





compound events

incoming cold water from supply line



utility water meter

pressure regulator

thermal expansion tank

hot water heater

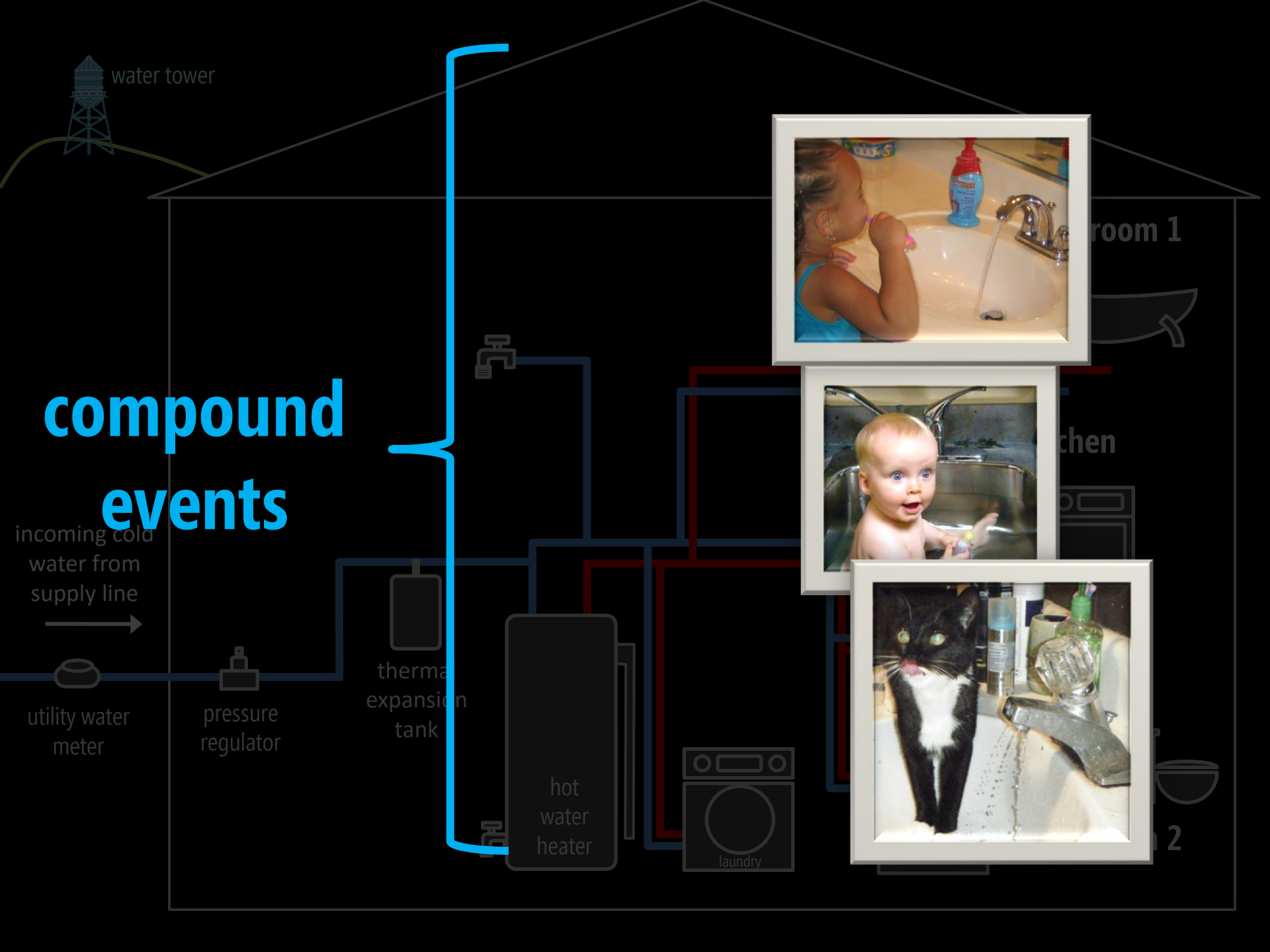
laundry



room 1

chen

2



how can we study naturalistic
uses of **water**?

Movie Removed for Public Posting of Slides

FAIL

**how can we collect
“ground truth labels”?**

our failed attempts



wireless buttons



how many times will
the **hot** and **cold** water
valves be opened and
closed while washing
these dishes?

Movie Removed for Public Posting of Slides

tracks the number of times
hot and **cold** are turned on/off

Movie Removed for Public Posting of Slides

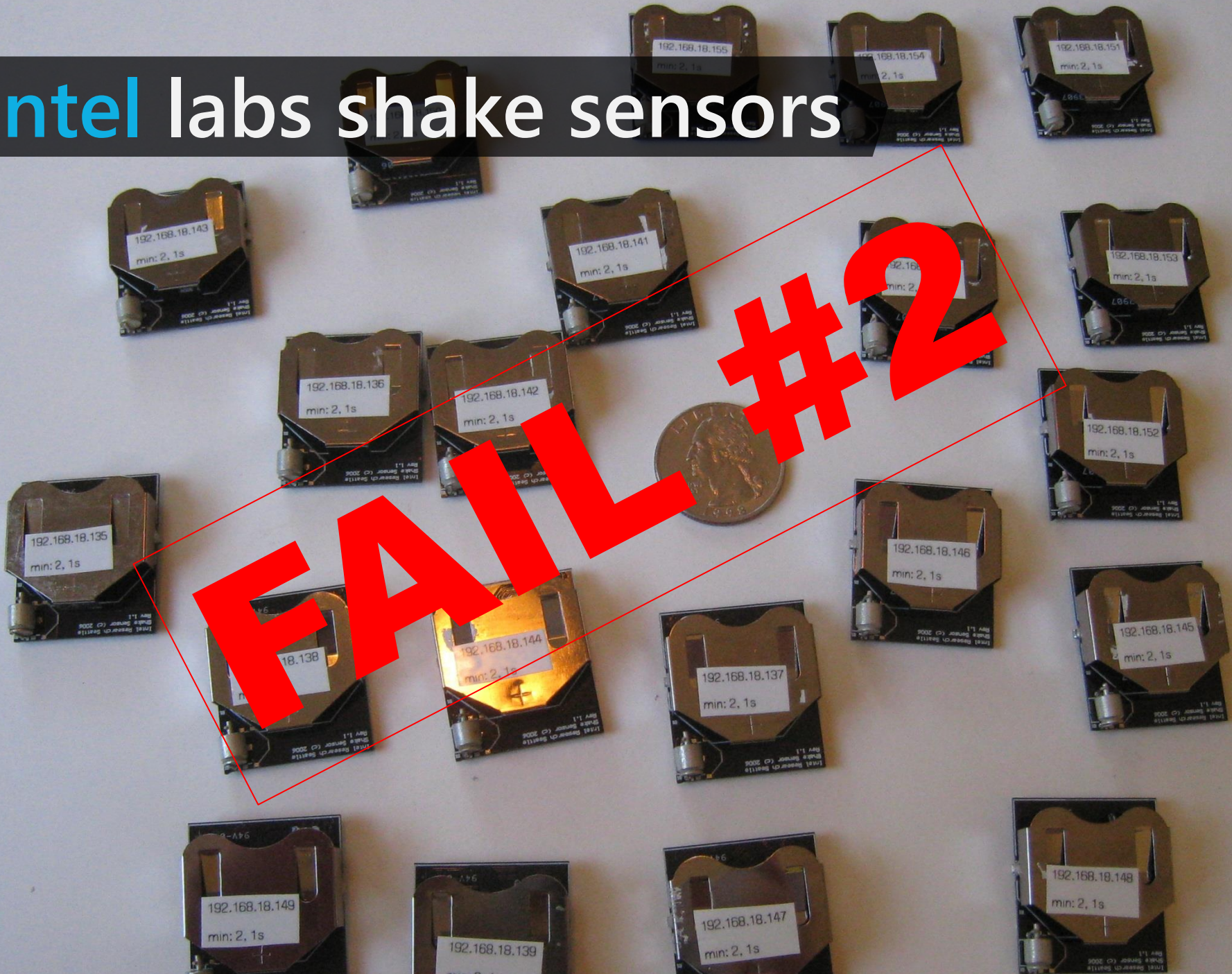
wireless buttons

FAIL #1

A photograph of a bathroom sink with a chrome faucet and handles. A large red 'FAIL #1' stamp is overlaid on the image. In the background, a mirror reflects the sink and a black wireless button is mounted on the wall.

intel labs shake sensors

FAIL #2



nike+ ipod piezo

Movie Removed for Public Posting of Slides

FAIL #3

thermistor

Movie Removed for Public Posting of Slides

FAIL #888

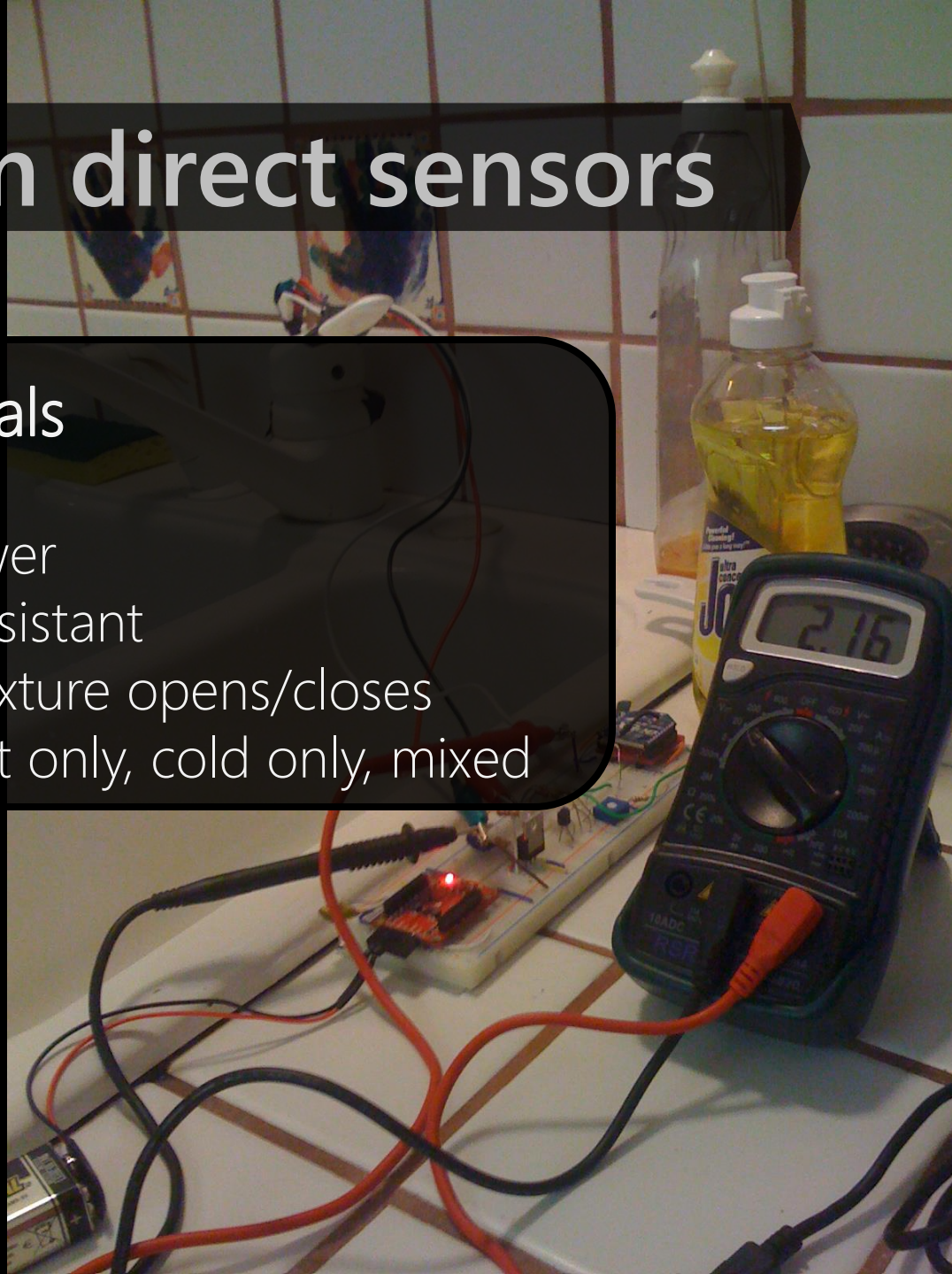
our solution



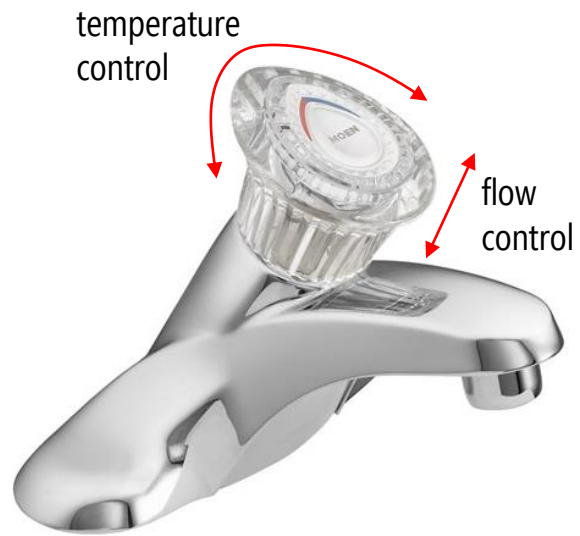
custom direct sensors

design goals

- wireless
- low-power
- water resistant
- detect fixture opens/closes
- track hot only, cold only, mixed



challenge: fixture diversity

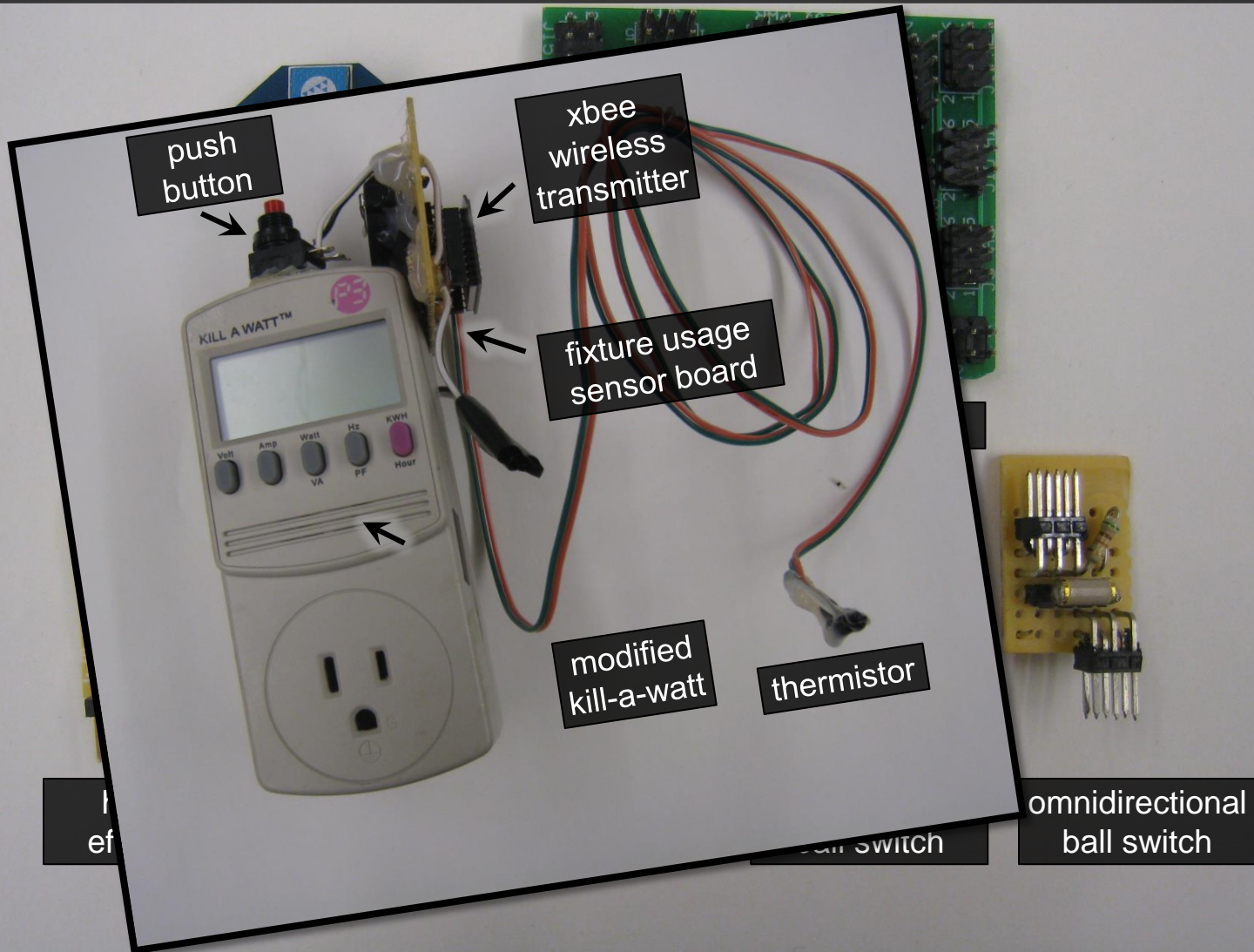


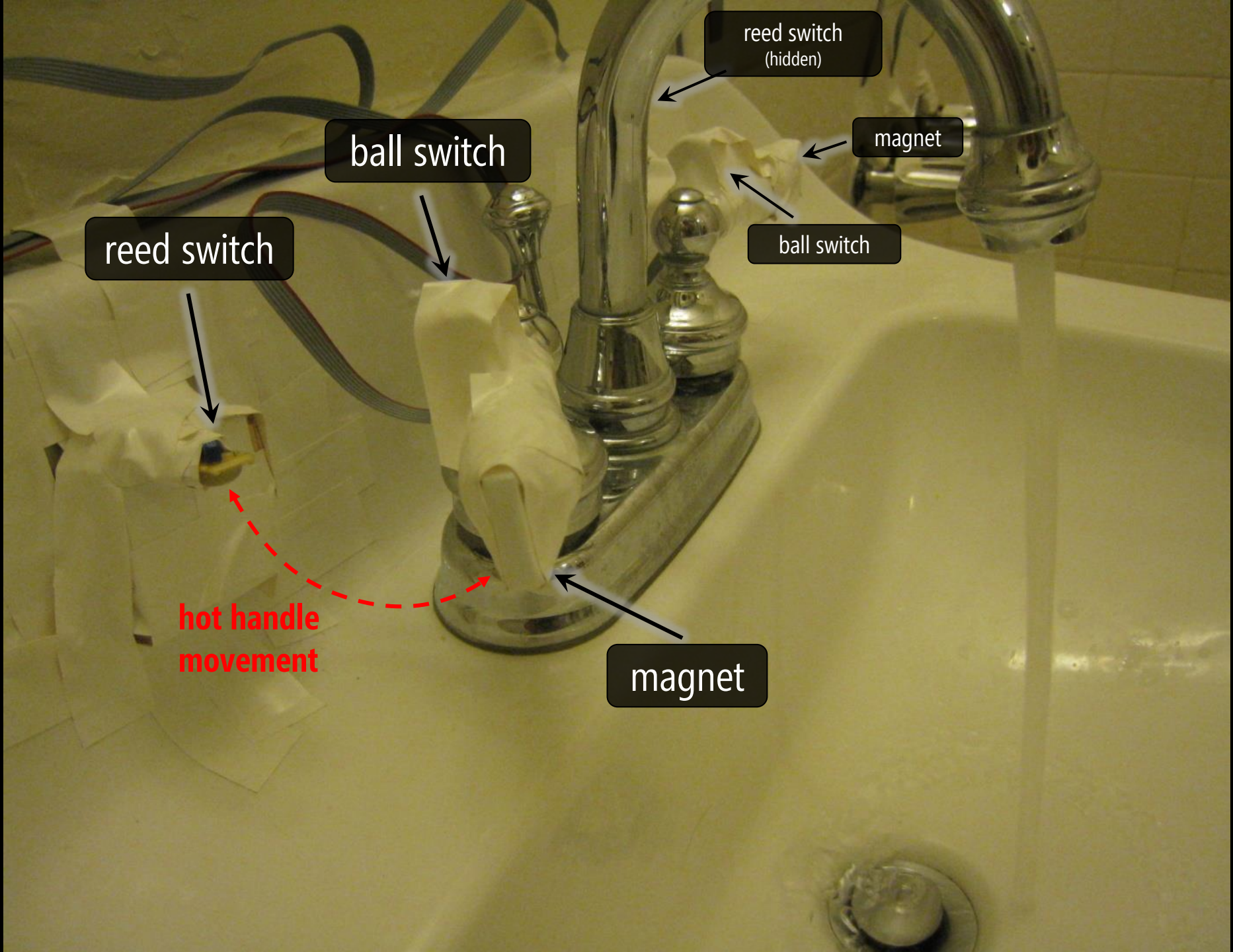
single handle faucet



dual handle faucet

custom ground truth data collection system





reed switch
(hidden)

ball switch

magnet

reed switch

ball switch

hot handle
movement

magnet



parent sensor board

accelerometer & ball switch



magnet & ball
switch

reed switch
(cold handle)

reed switch
(hot handle)

magnet &
ball switch



reed
switch

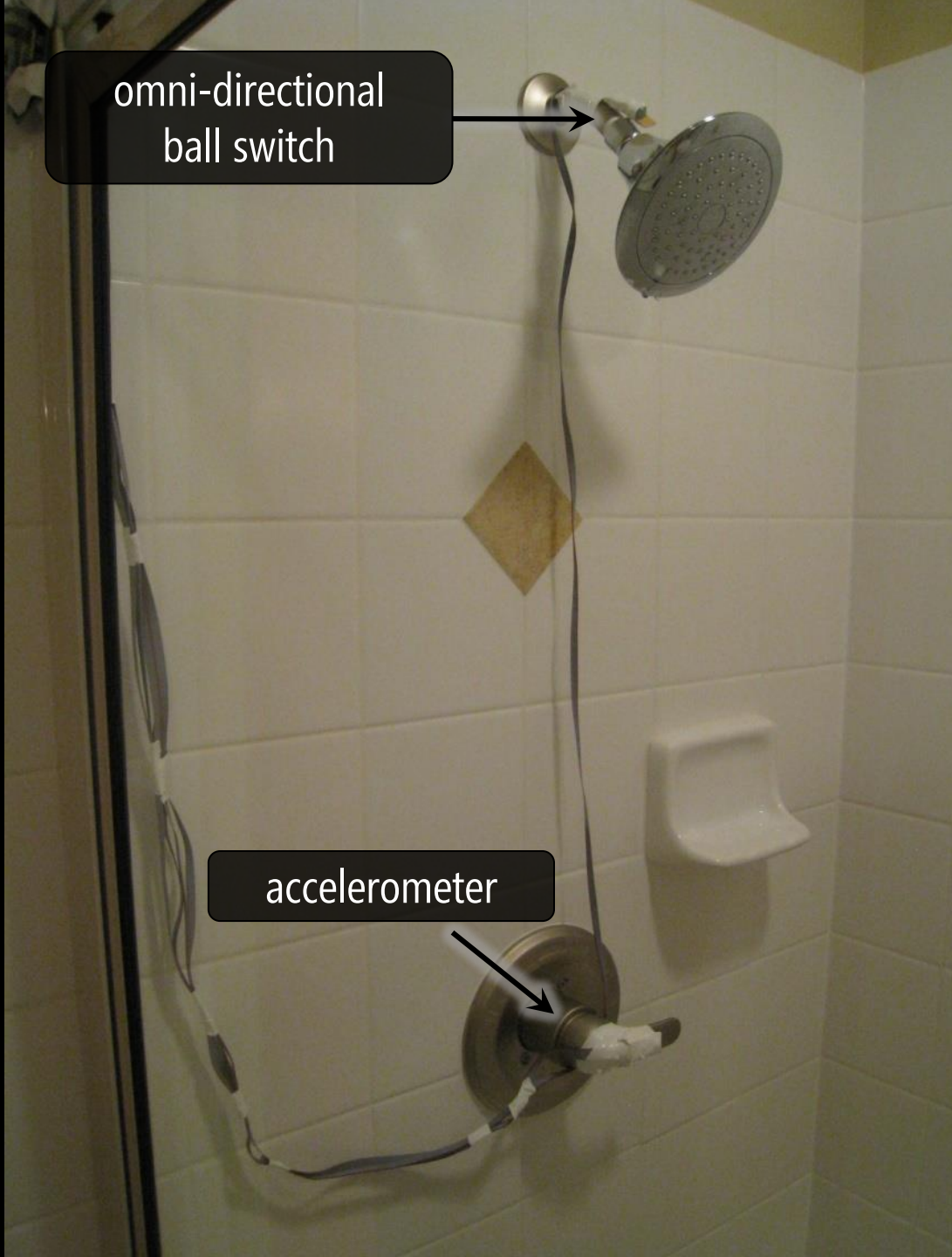
magnet

omni-directional
ball switch

omni-directional
ball switch



accelerometer



reed switch
(hot handle)

reed switch
(tub/shower diverter)

reed switch
(cold handle)

magnet

magnet

magnet



parent sensor board

xbee wireless transmitter

modified kill-a-watt

thermistor cable for drain pipe (in red)

washing machine plug (connects to kill-a-watt outlet)



WASH/SPIN SPEED

GENTLE SLOW
NORMAL SLOW
NORMAL FAST

TEMPERATURE

WARM COLD
HOT COLD
COLD COLD
WARM WARM

EXTRA RINSE

OFF SET

PULL KNOR TO START-PUSH TO PAUSE
COTTONS REGULAR
LIGHT SOIL
MEDIUM HEAVY
POWER WASH
PERMANENT PRESS
DELICATES
20 MIN AUTO SOAK
EXTRA RINSE
99% OFF

9 Cycle 3 Speed Combinations
Heavy Duty Super Capacity

how did we do the installations?

Movie Removed for Public Posting of Slides

ground truth sensors example

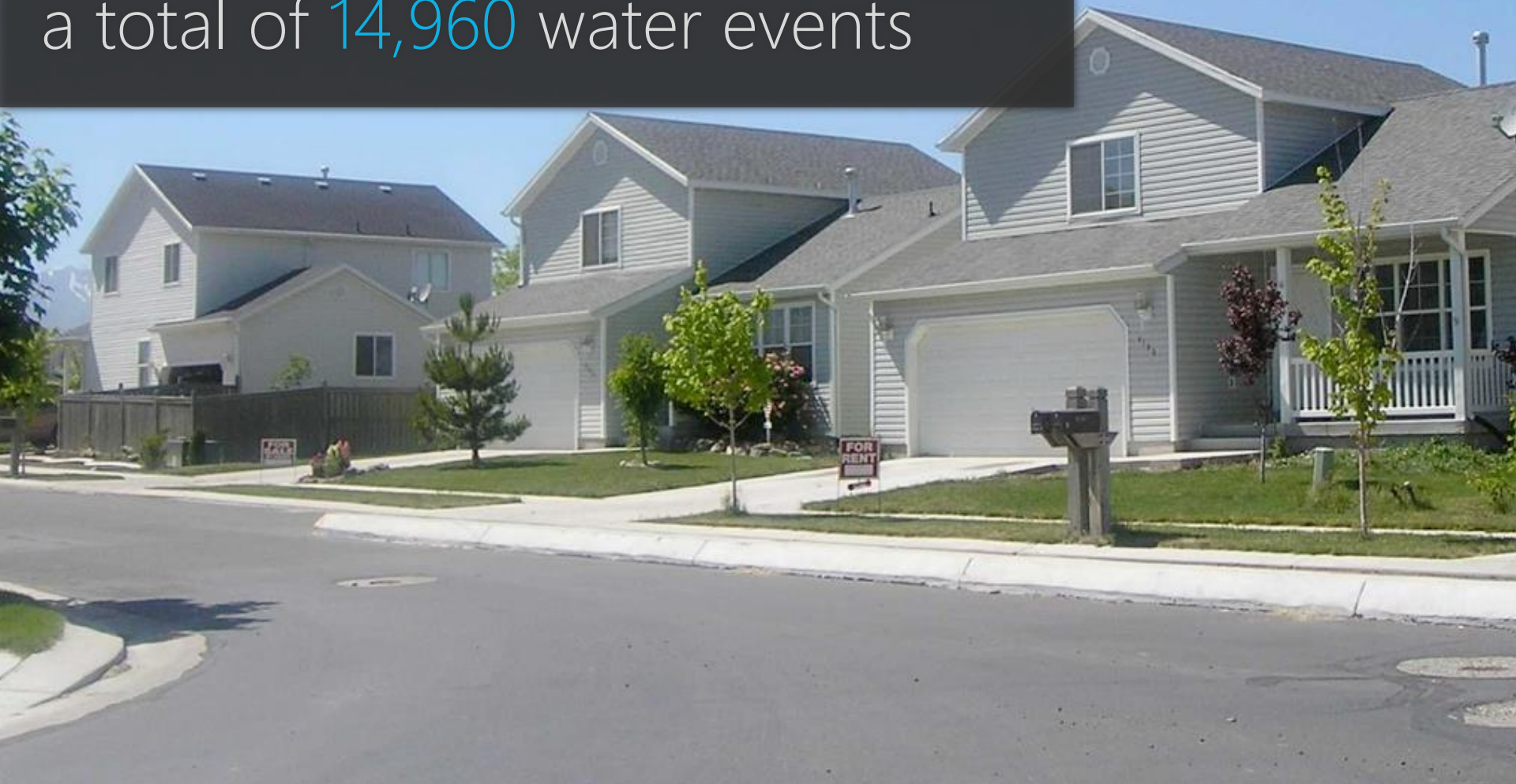
Movie Removed for Public Posting of Slides

five week deployment

2 apartments & 3 houses

103 water valves

a total of 14,960 water events





compound events

incoming cold water from supply line



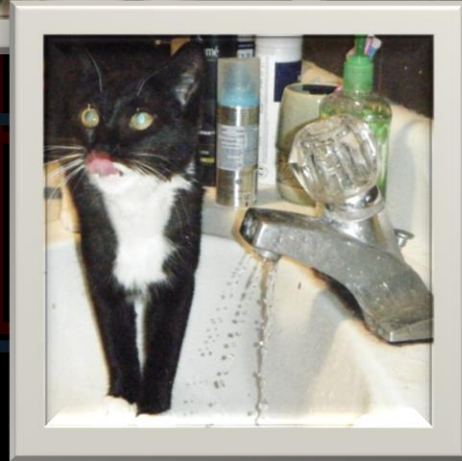
utility water meter

pressure regulator

thermal expansion tank

hot water heater

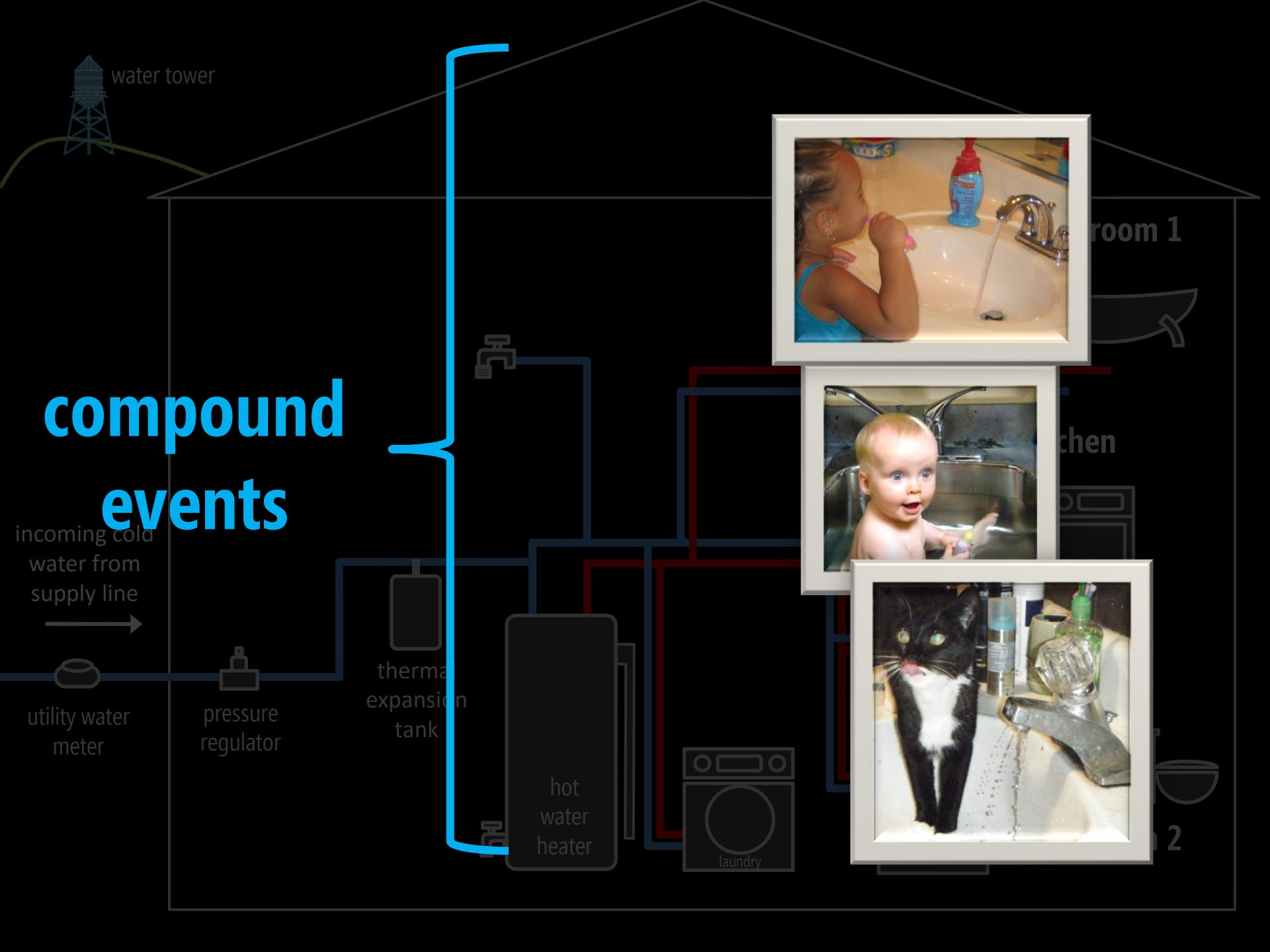
laundry



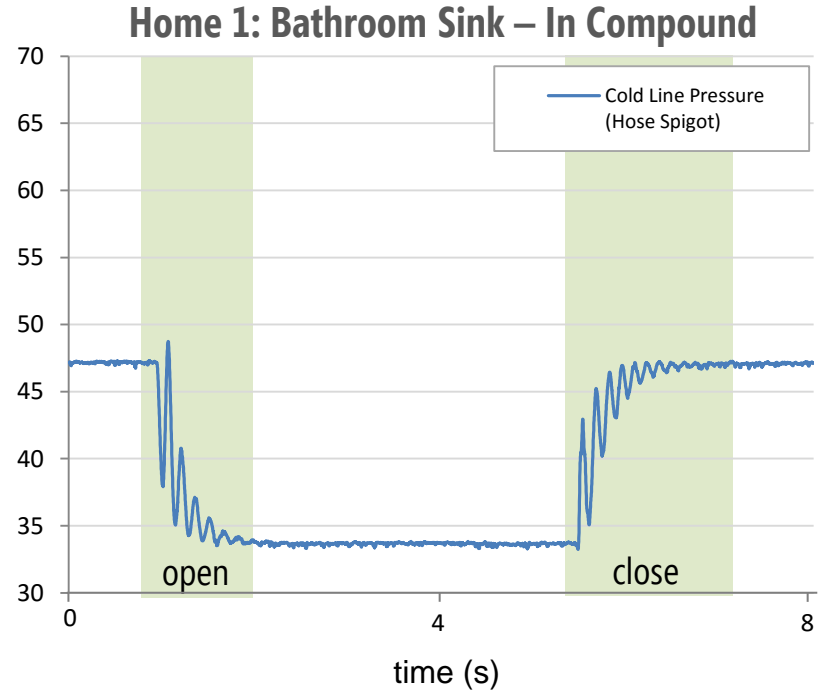
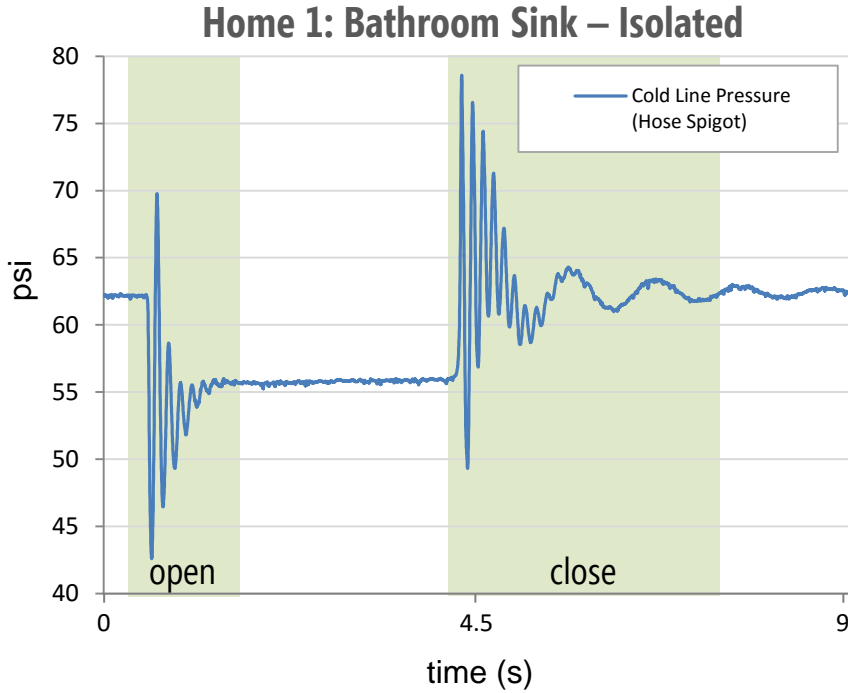
room 1

chen

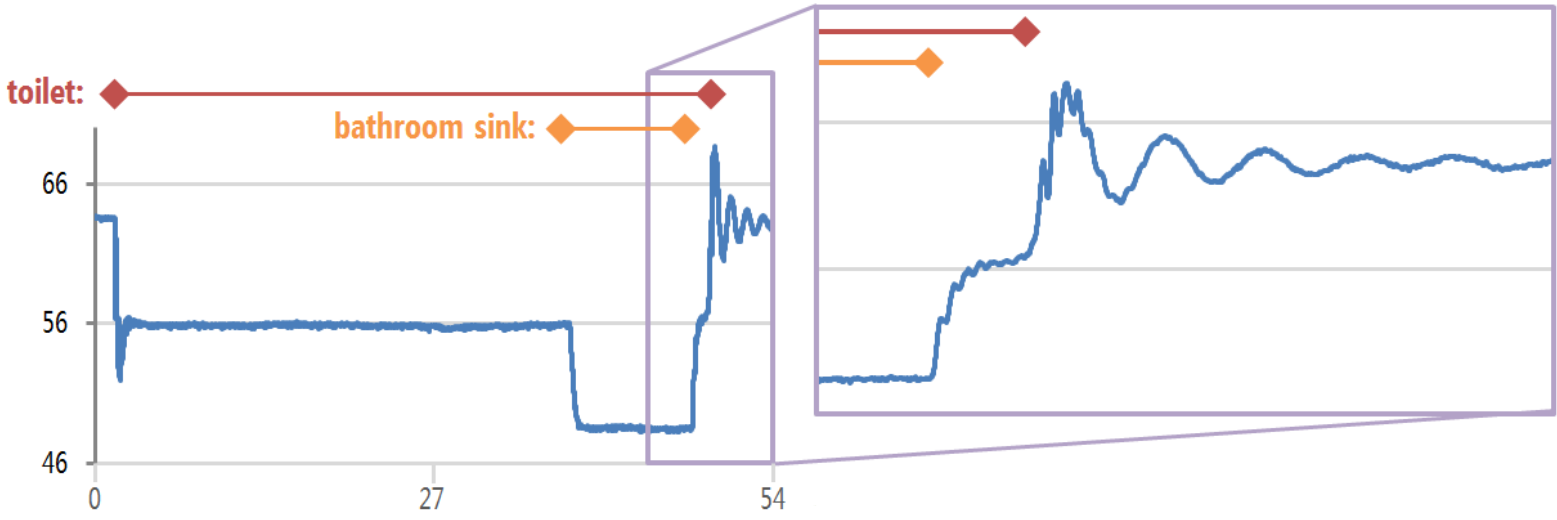
2



compound event effect



collisions



22%

of all **water** events were either
compound or collisions

five week deployment

2 apartments & 3 houses

103 water valves

a total of 14,960 water events

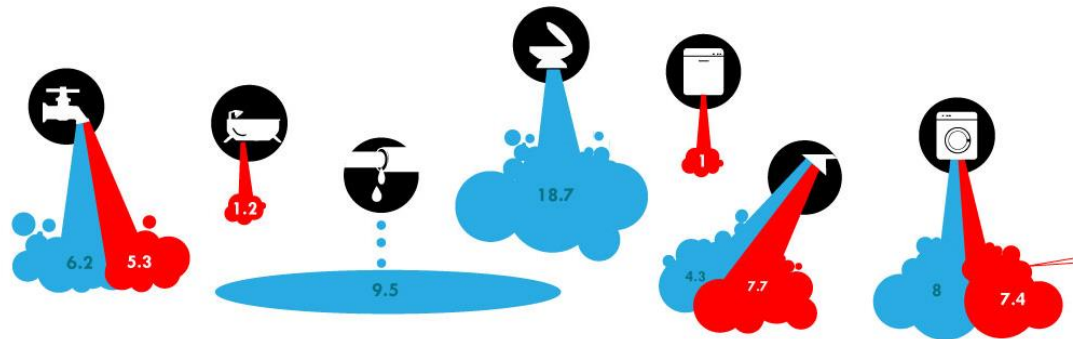
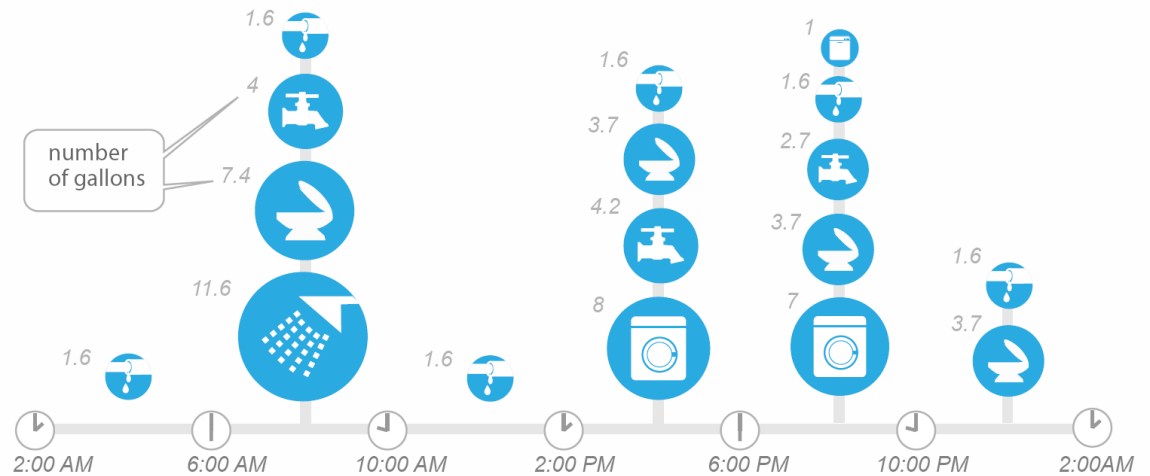
75.5% valve

89.5% fixture

95.9% fixture category

real-time water feedback

TODAY'S water usage (in gallons)



thank you!

jonfroehlich@gmail.com
twitter @jonfroehlich

<http://ubicomplab.cs.washington.edu>
<http://dub.washington.edu/>

students



Jon Froehlich



Eric Larson



Tim Campbell



Elliot Saba

faculty



Shwetak Patel



James Fogarty



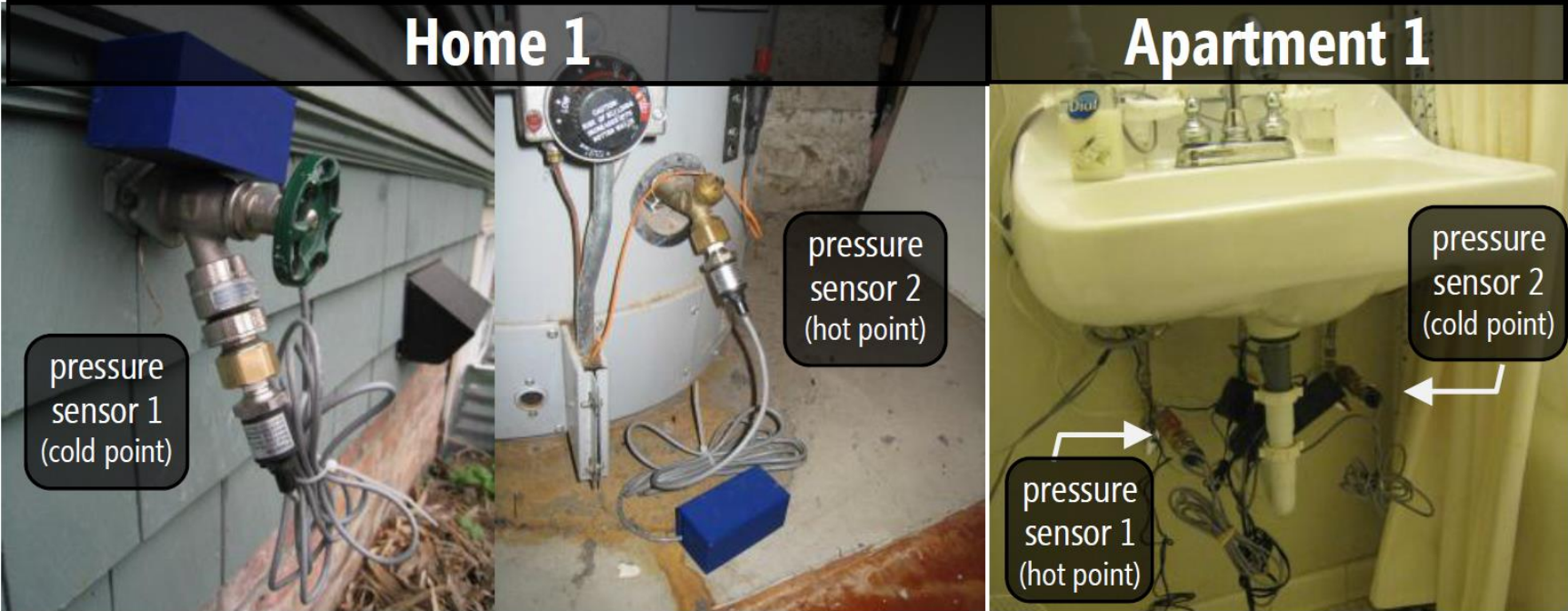
James Landay

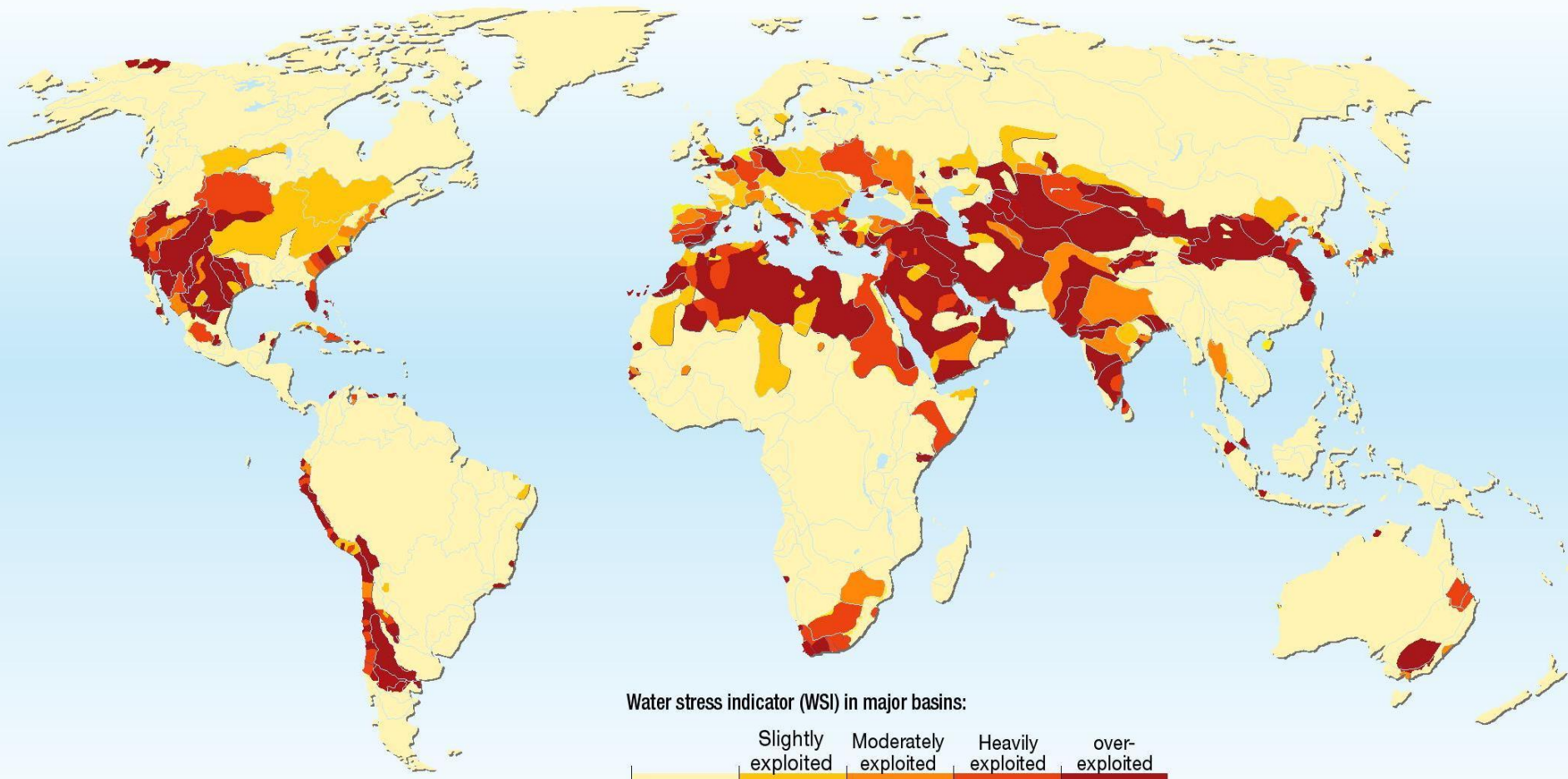


Les Atlas

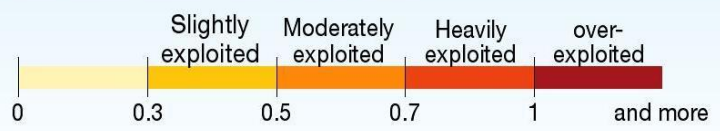


two pressure sensors per home





Water stress indicator (WSI) in major basins:



Sources: Smakhtin, Revenga and Döll, 2004.

barcelona, spain




lake mead, nevada



feedback improves performance

low-level

high-level

Name Deak REVIEW 13  **All Star!** Test

Home Remedies *stop

How (1) am I going to (2) stop my hiccups? Eat a sugar cube. I (3) can't get rid of my sore throat. Drink (4) strong tea with a (5) piece of lemon and some honey. People to whom you (6) talk think differently as to (7) whether these (8) really work. Of (9) course, some home remedies (10) probably work (11) fine for (12) common problems, but for serious illnesses, a doctor (13) usually gives the best advice. Survey your friends and (14) family for (15) their home remedies that have (16) shown good results (17) through the years. Compile these get-well (18) ideas into a (19) class book, (20) complete with illustrations.

Skill Test

Write the word with the ing suffix.
begin beginning drop droppings mail mailing

Write the word without the suffix.
skipped skip spelling spell sunny sun

Turn your paper over and write the rule.

130 LEVEL FOUR May be reproduced for students within your classroom. All rights reserved. SPELLING SOURCEBOOK Series © 2002 Egger Publishing, Inc. 888-WE-SPELL

Osceola County Rural Schools

MONTHLY REPORT OF

Flossie Peterson a Member of

the first Grade, District No. 8 Feb.

Evart Township

191.3. and 191

	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	Average
Times tardy	0	1	3	3	1	1	0				
Days absent	6	1	4	2	5	3	4				
Department	95	93	93	92	90	91	92				
Reading	96	94	94	94	93	94	94				
Spelling	94	93	93	93	93	94	94				
Writing	90	90	91	91	94	95	92				
Numbers	93	93	95	95	95	93	93				
Language	98	96	97	96	96	96	96				
Arithmetic											

Becker, J. of Applied Psychology 1978

toyota prius

Consumption

-50Wh Regenerated

OUTSIDE TEMP 61 °F



Energy

Average

60.5 MPG

204 miles

Reset

6:22

H
M

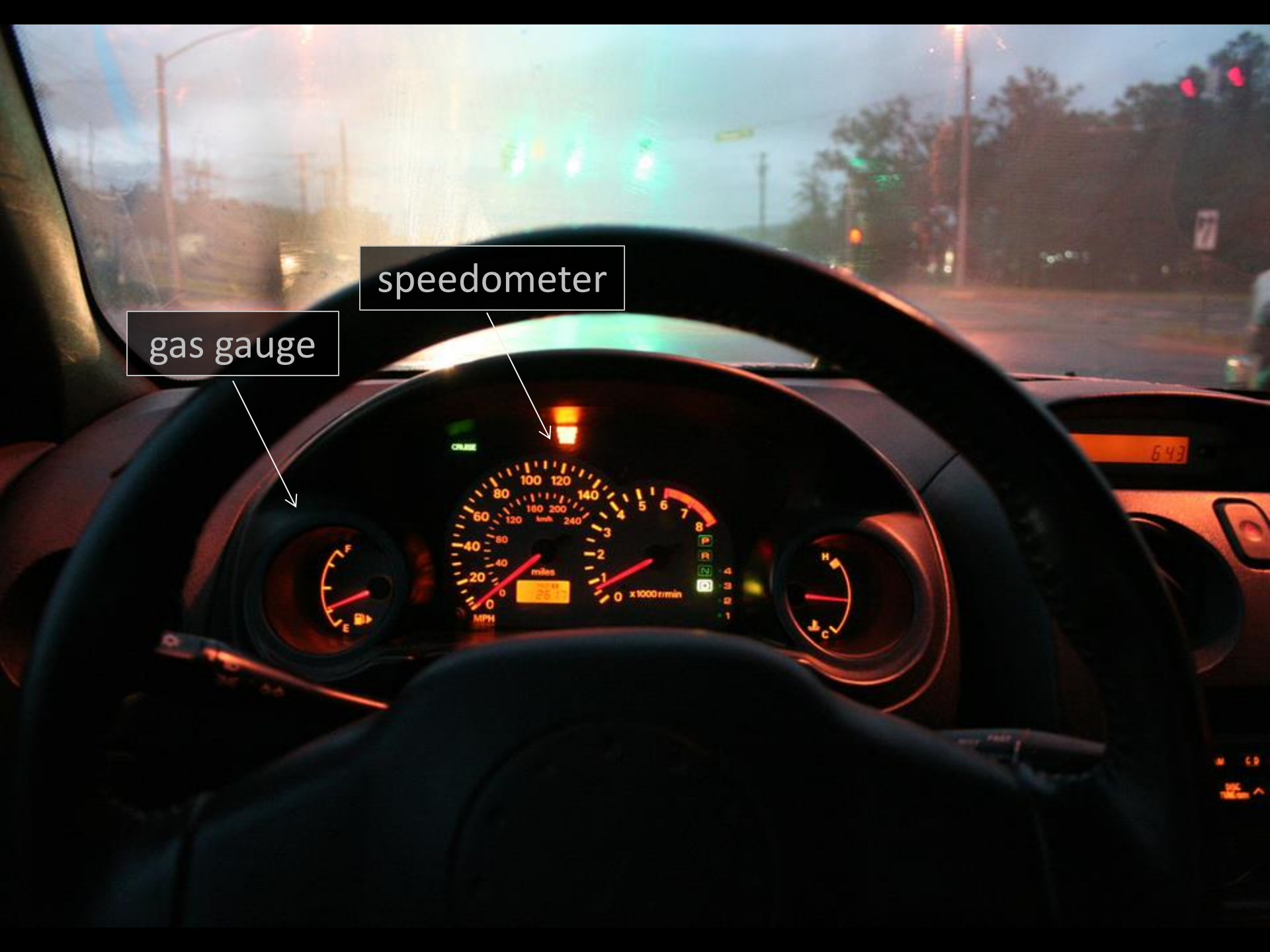


ODO
TRIP

km/h
MPH

gas gauge

speedometer





CRUISE



P
R
N
D



643

4 6.9
EPC
100.0km ^

**vehicle
activated
speed
signs**



speed cameras



**vehicle
activated
speed
signs**

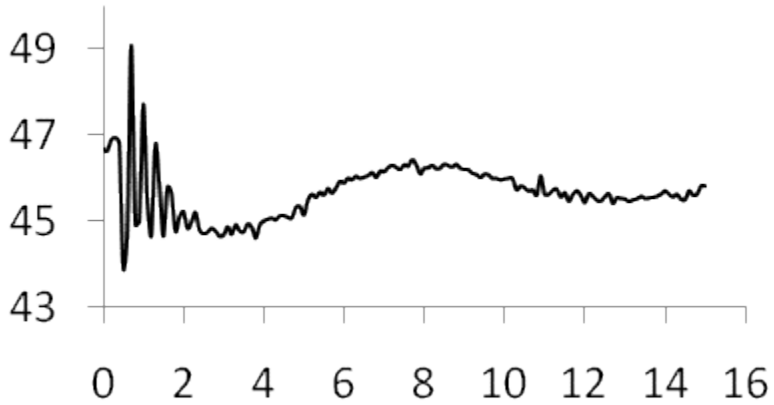


vas signs

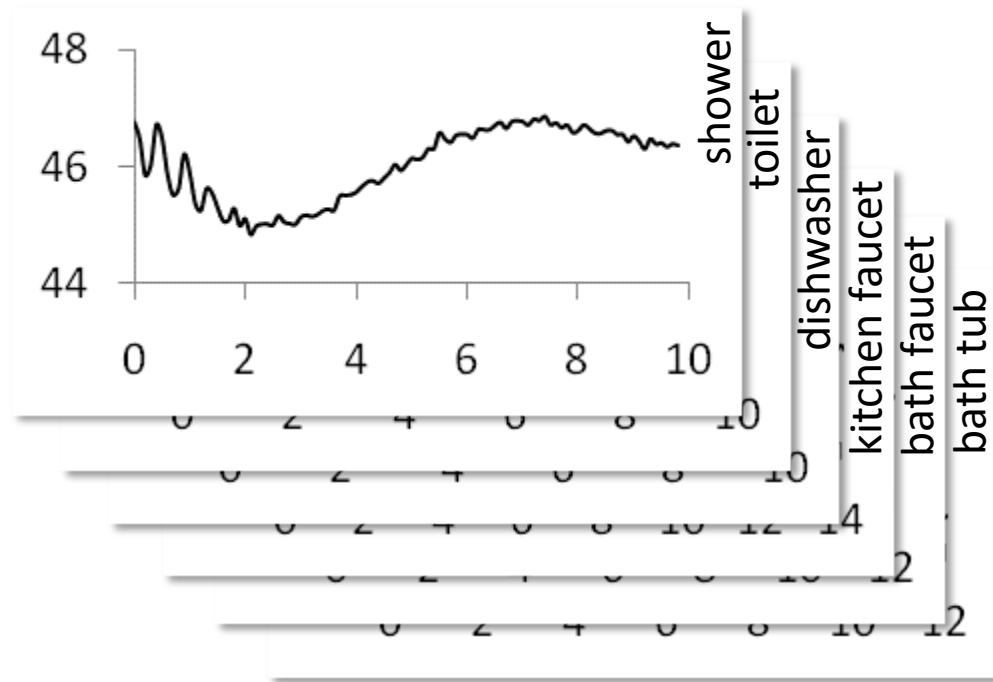
A light blue rectangular sign is mounted on a black post. On the left side of the sign, there is a black rectangular digital display showing the number '46' in bright orange LED lights. Above the display are two small rectangular cutouts and a circular hole. To the right of the display, the text 'DAYS IN HOSPITAL BED' is printed in white, bold, sans-serif capital letters. Further to the right, there is a white rectangular box containing the text 'SPEED LIMIT' in small black letters above the large number '25' in black. Below this box, the text 'SLOWER IS BETTER' is printed in white, bold, sans-serif capital letters. At the bottom right of the sign, the text 'ELM GROVE POLICE' is printed in white, sans-serif capital letters. The sign is set against a background of green trees and a paved road.

fixture classification

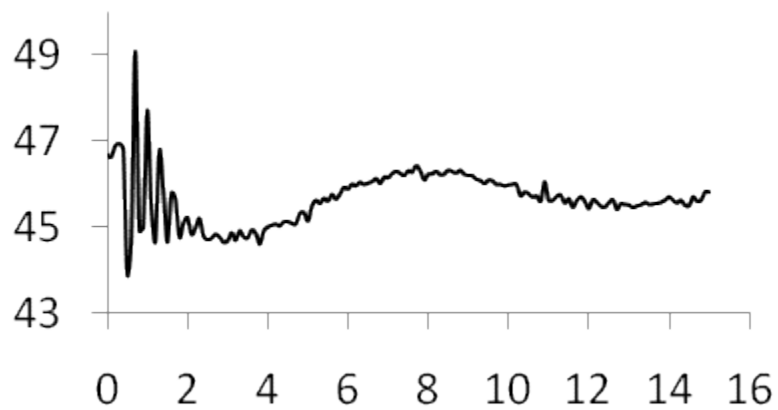
unclassified open event



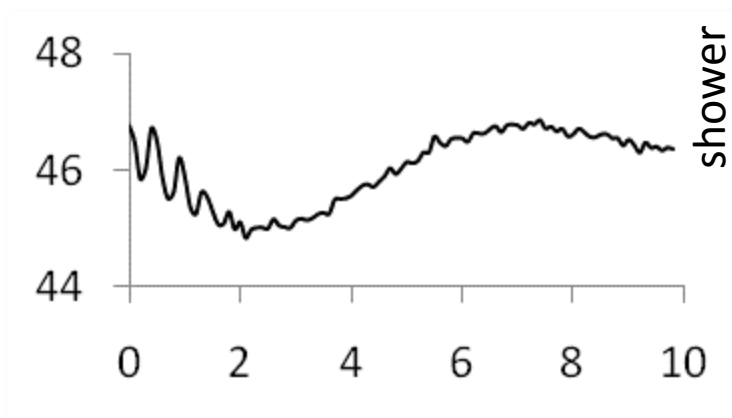
open event library



unclassified open event



open event library



toilet

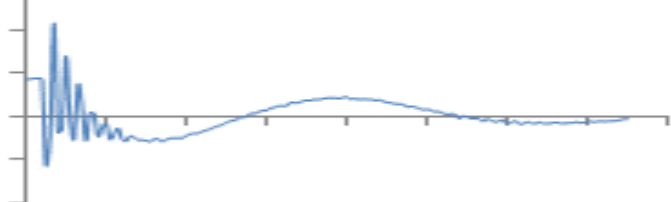
dishwasher

kitchen faucet

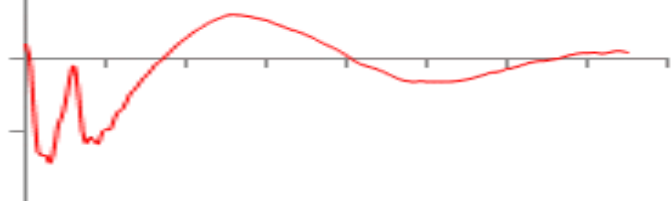
bath faucet

bath tub

detrended_{unclassified}



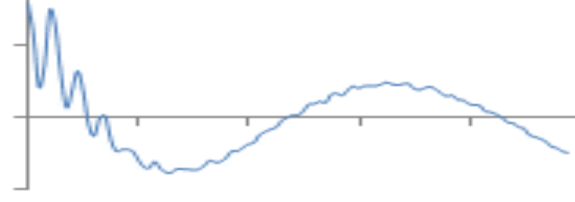
derivative_{unclassified}



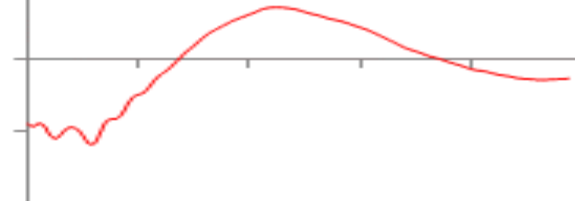
cepstrum_{unclassified}



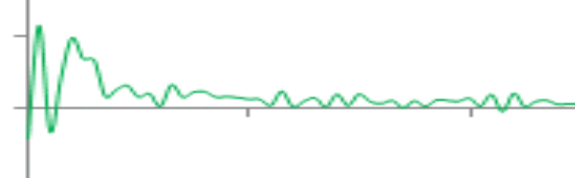
detrended_{shower}



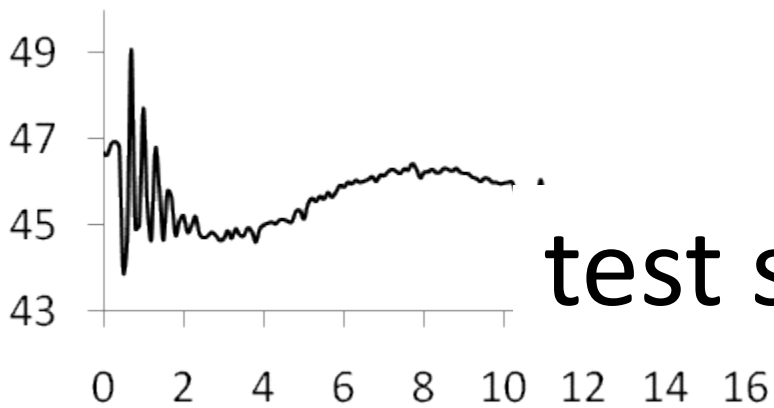
derivative_{shower}



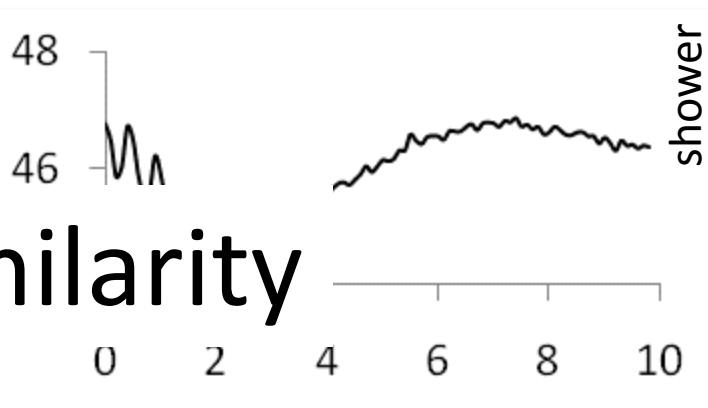
cepstrum_{shower}



unclassified open event



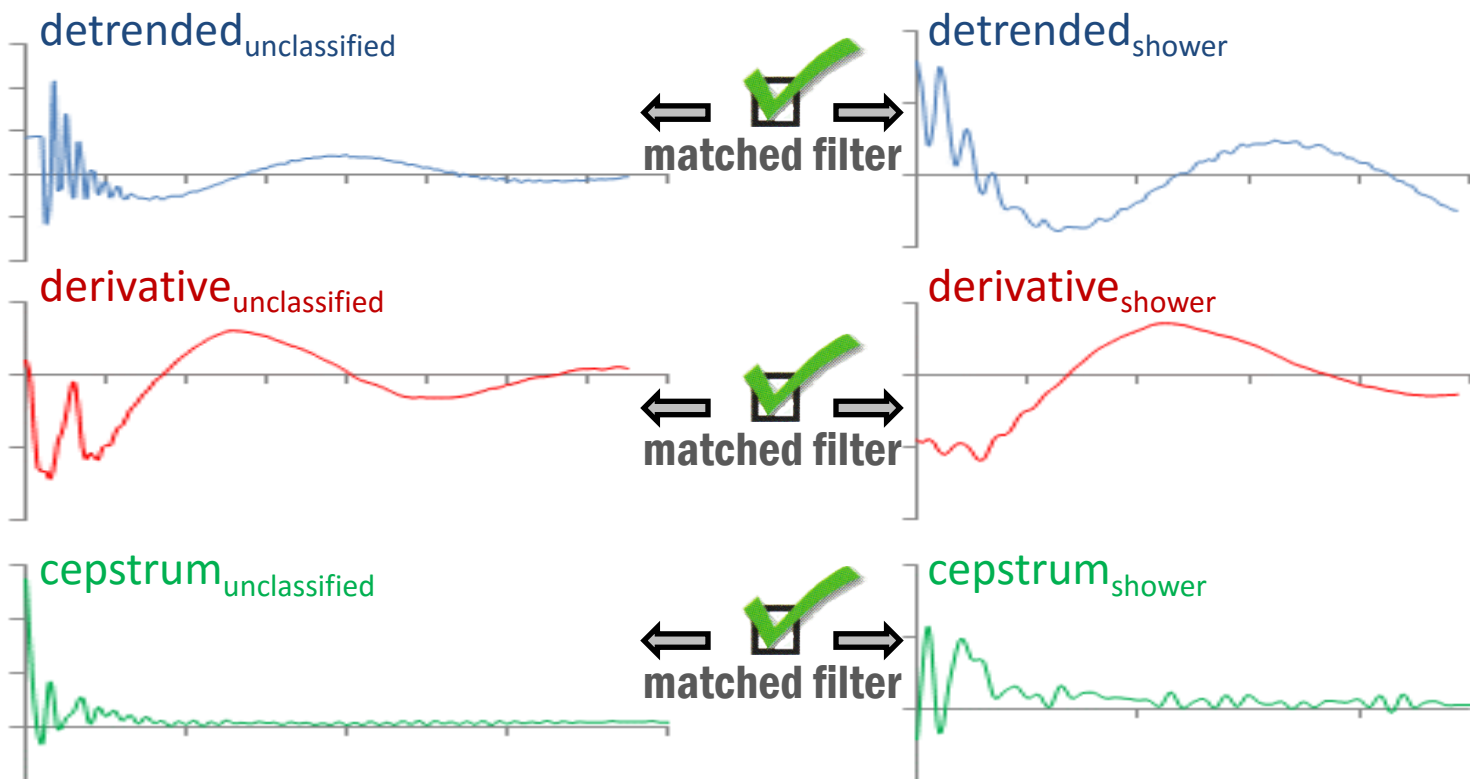
open event library



test similarity

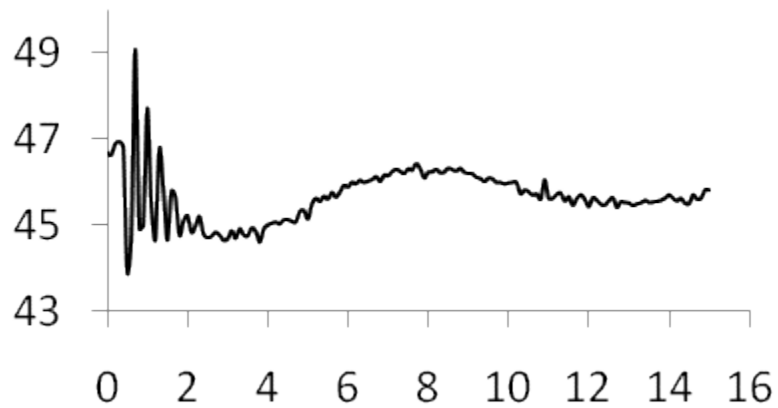


- toilet
- dishwasher
- kitchen faucet
- bath faucet
- bath tub

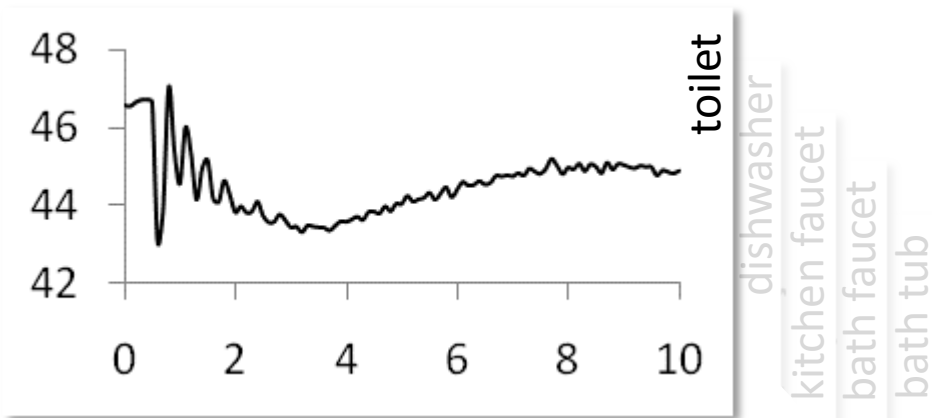


possible events

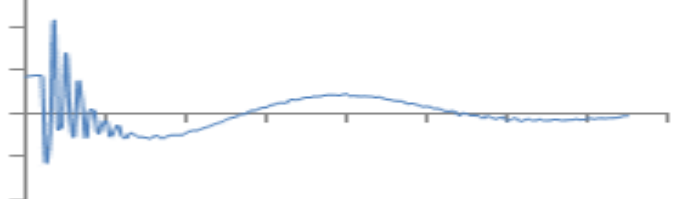
unclassified open event



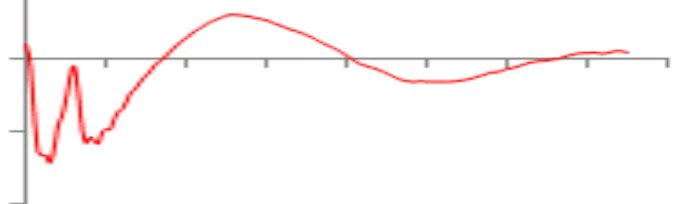
open event library



detrended_{unclassified}



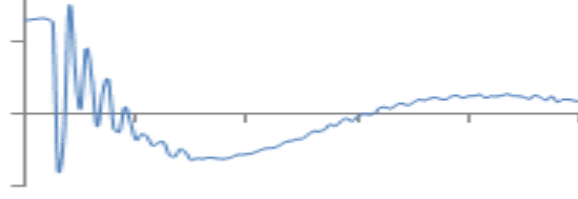
derivative_{unclassified}



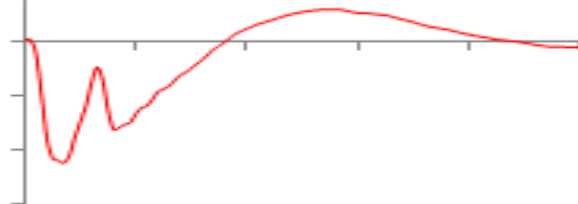
cepstrum_{unclassified}



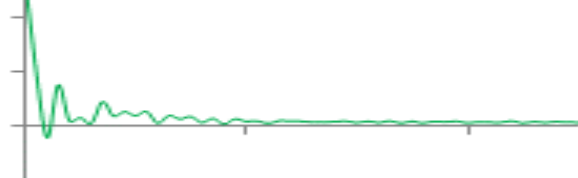
detrended_{toilet}



derivative_{toilet}

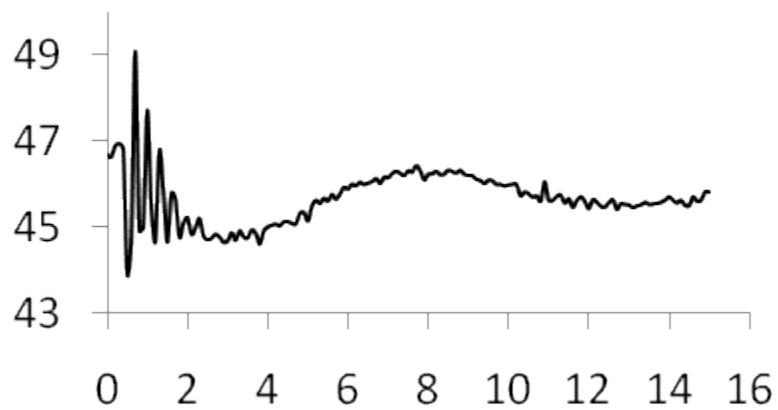


cepstrum_{toilet}

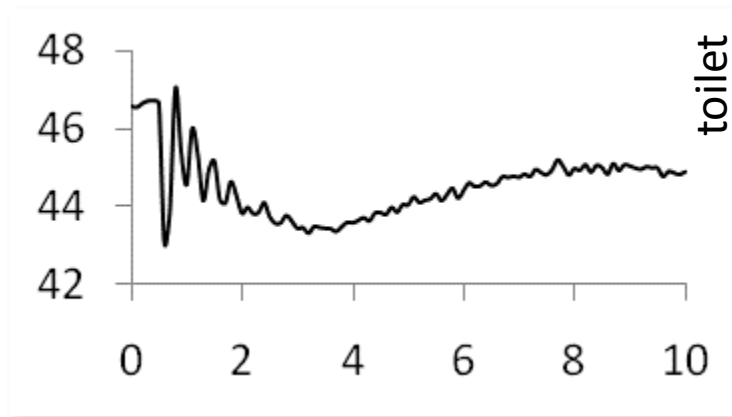


possible events

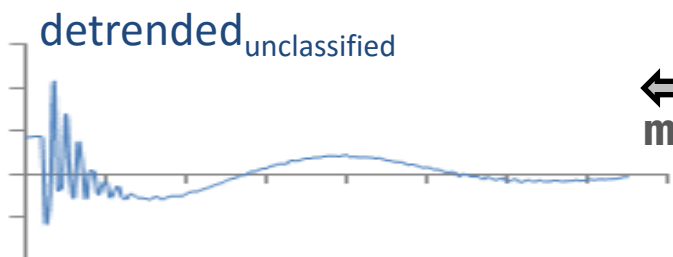
unclassified open event



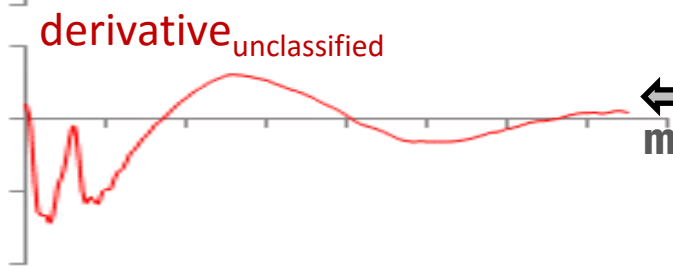
open event library



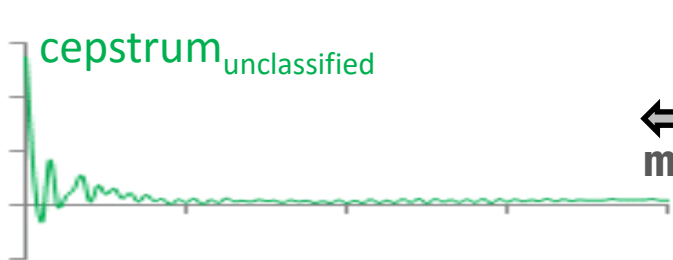
- dishwasher
- kitchen faucet
- bath faucet
- bath tub



matched filter



matched filter

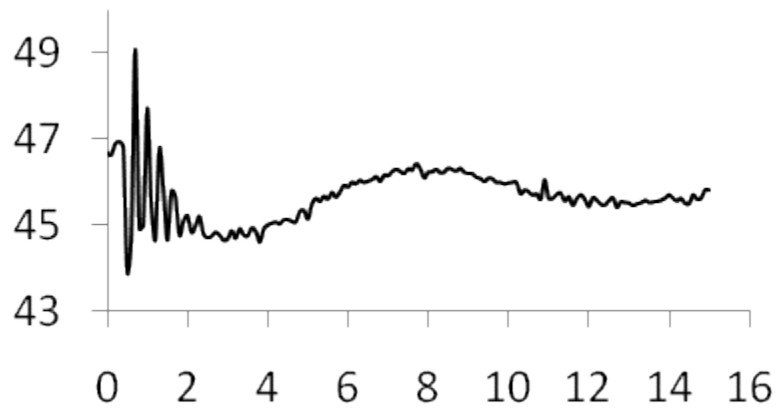


matched filter

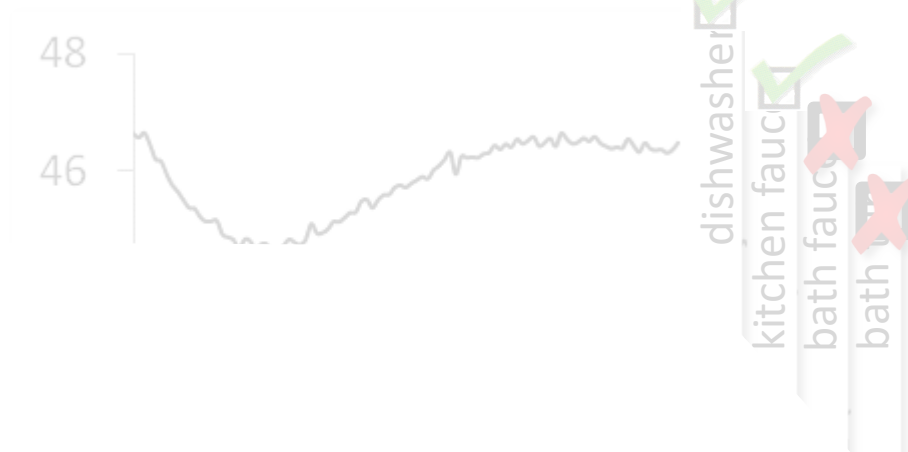


possible events

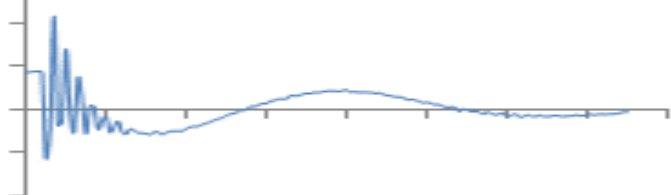
unclassified open event



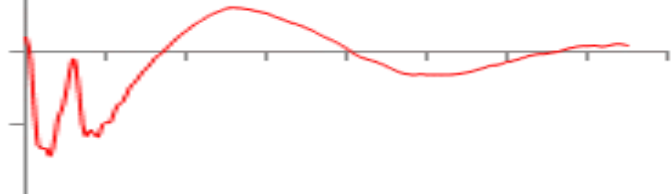
open event library



detrended_{unclassified}



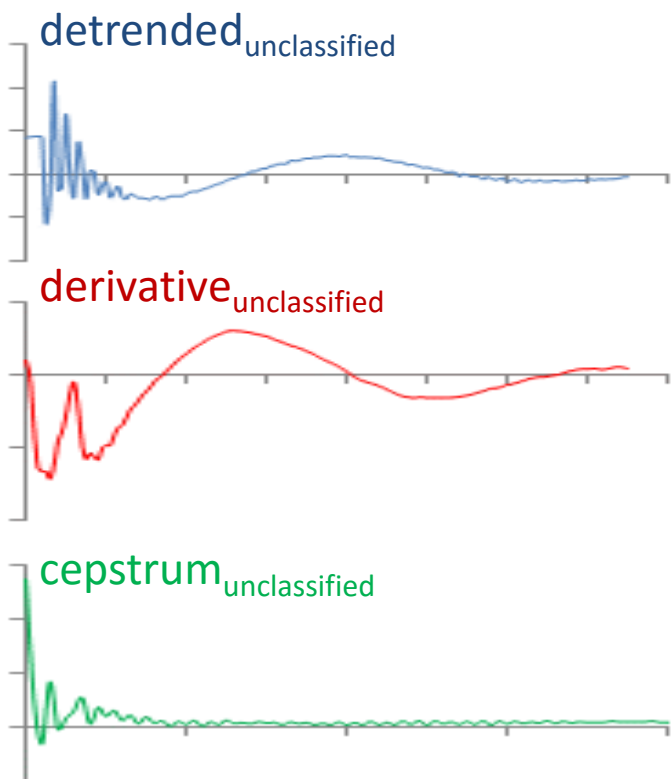
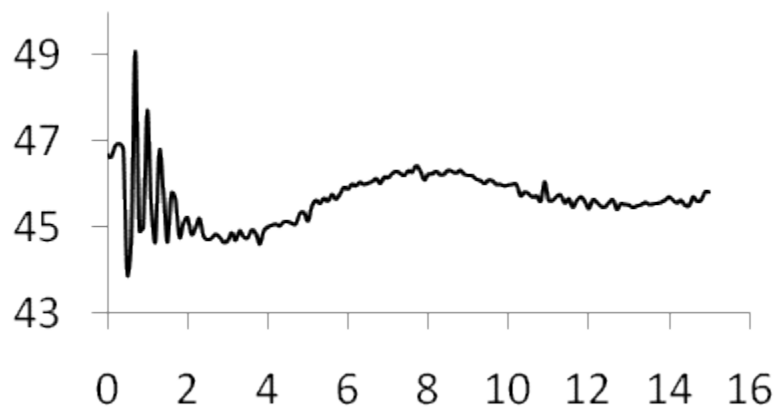
derivative_{unclassified}



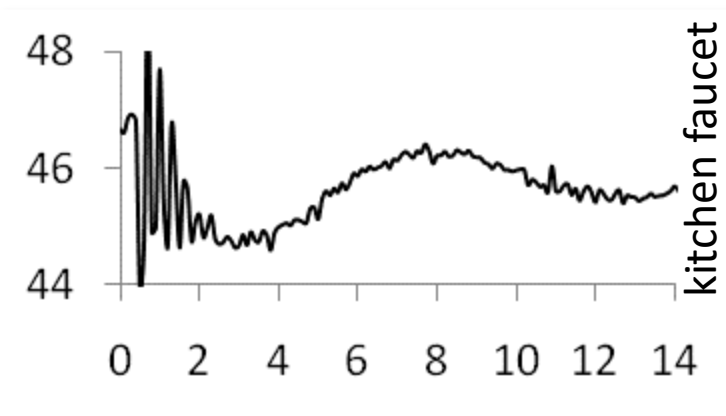
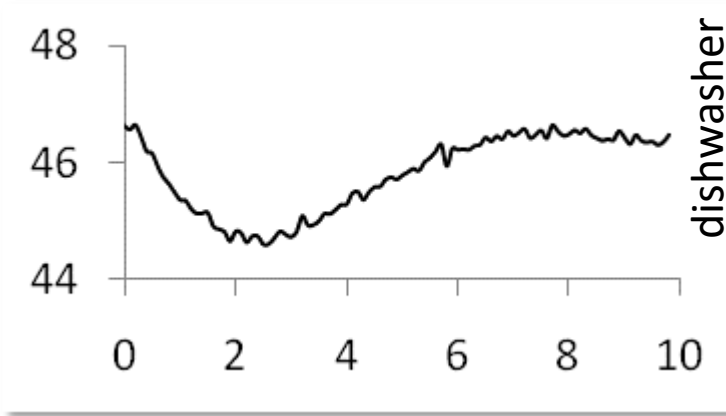
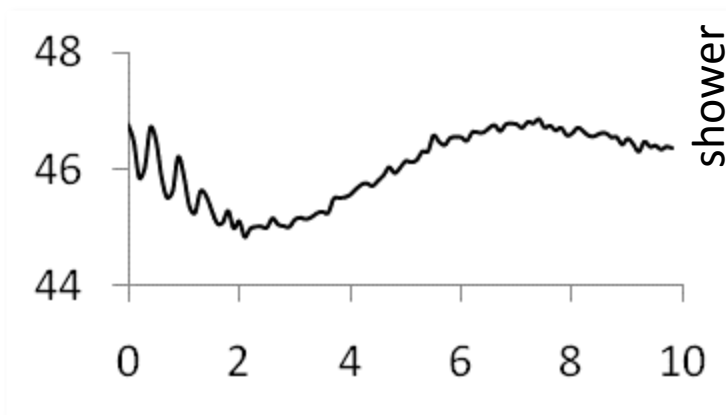
cepstrum_{unclassified}



unclassified open event

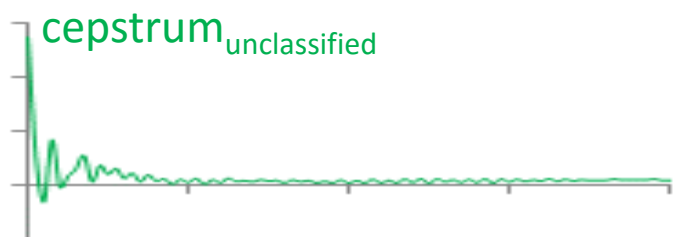
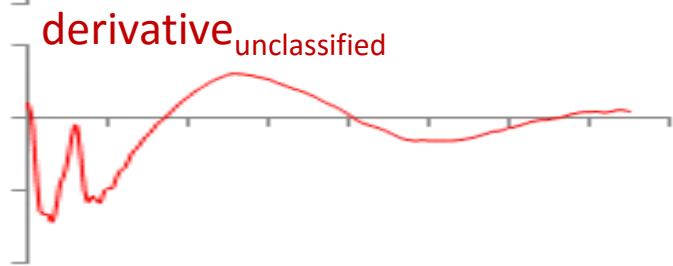
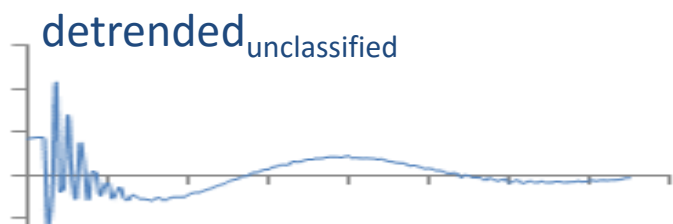
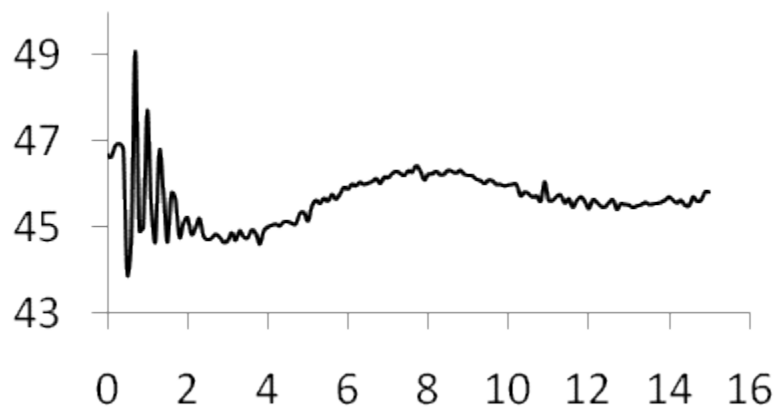


open event library

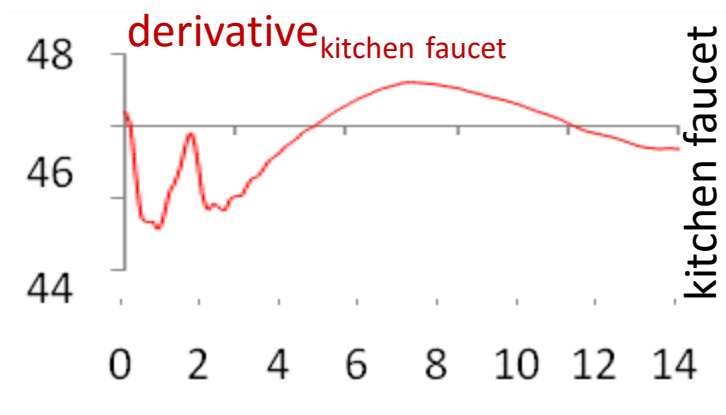
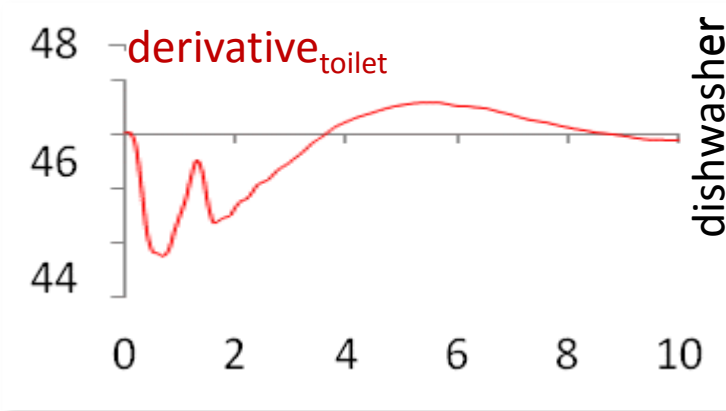
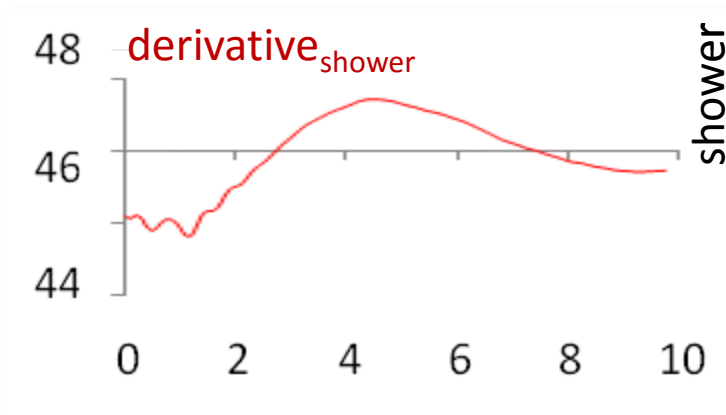


possible events

unclassified open event

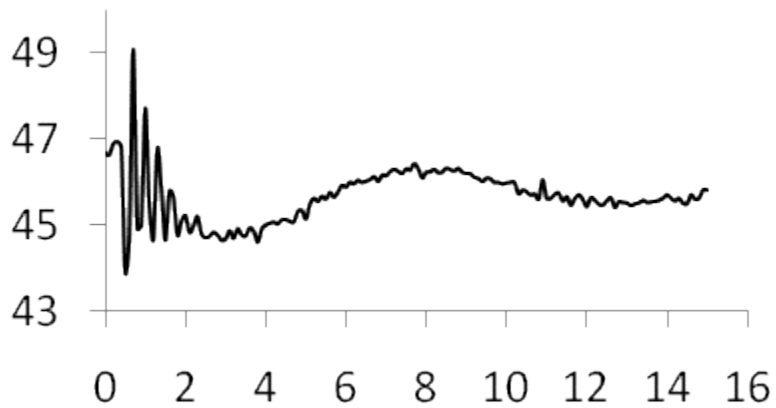


open event library

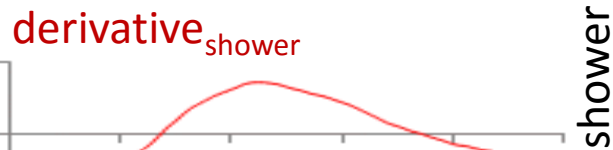


possible events

unclassified open event



open event library



nearest neighbor match

