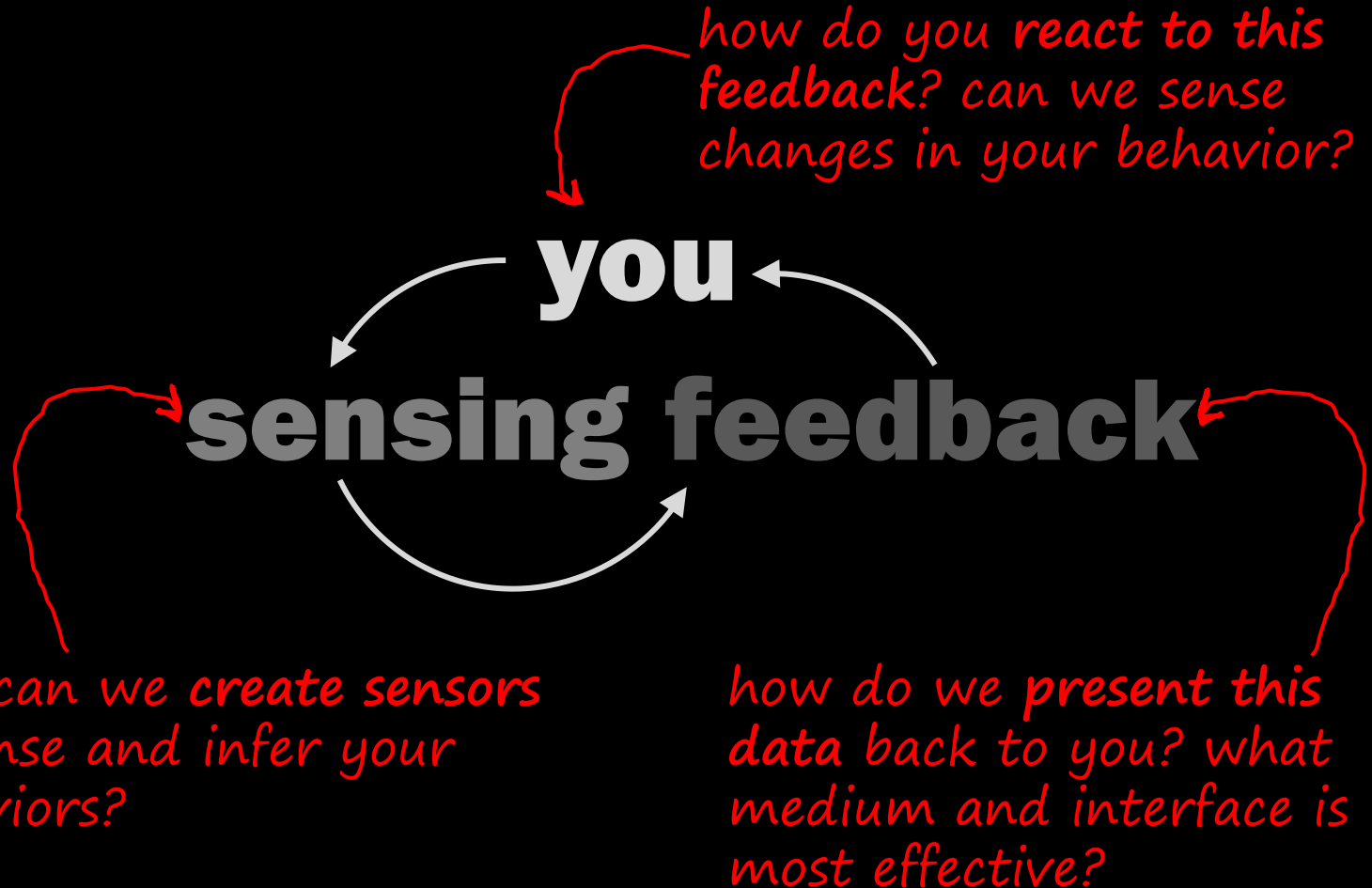
closing the gap between **action** & **effect**

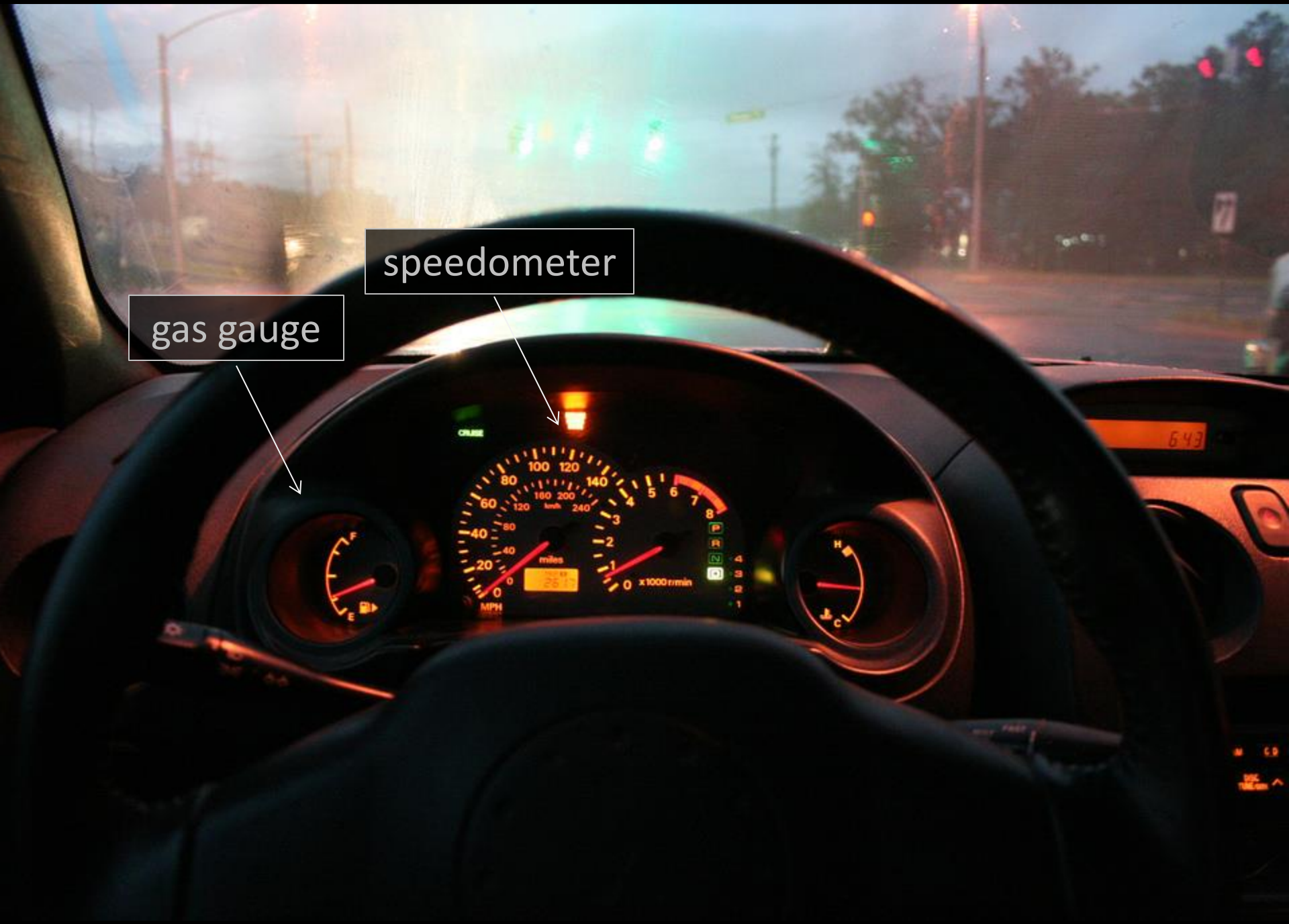
using computers to sense and feedback resource consumption information in the home

jfroehli@uw.edu
phd candidate in computer science
university of washington
oct 27, 2010


how do you react to this feedback? can we sense changes in your behavior?
you
sensing feedback
how can we create sensors to sense and infer your behaviors?
how do we present this data back to you? what medium and interface is most effective?

how much energy does a load of laundry use in the dryer?

toyota prius


speedometer
gas gauge

CRUISE
643
0 1 2 3 4 5 6 7 8
x1000 r/min
P R N D
4 3 2 1
H
C

vehicle activated speed signs

speed cameras

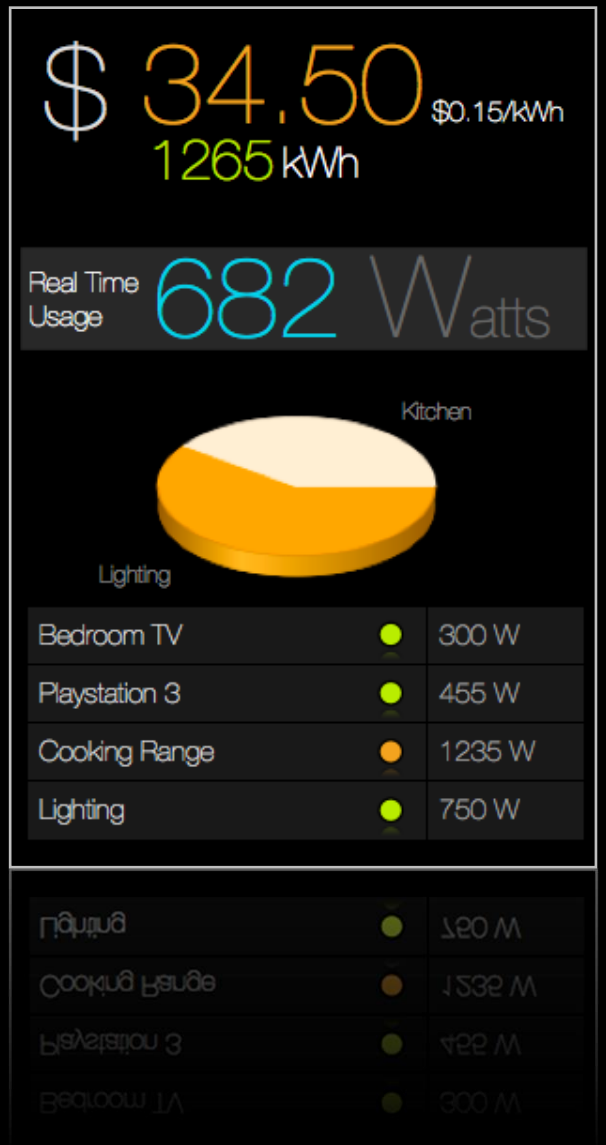
vehicle activated speed signs

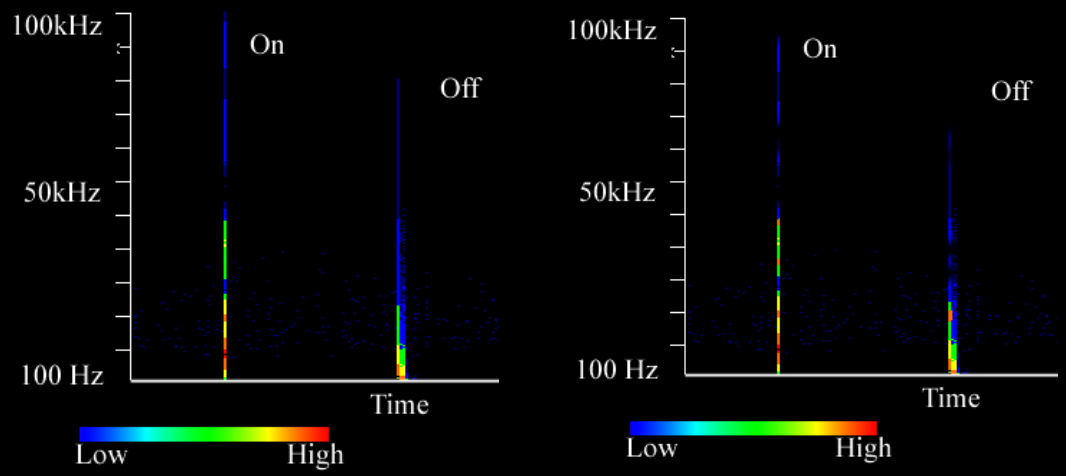
vas signs

46
DAYS IN
HOSPITAL
BED
SPEED
LIMIT
25
SLOWER
IS BETTER
ELM GROVE POLICE

SAFEWAY
SAVE MORE AT SAFEWAY
GROCERY
1.50 B
SFWY PRTZLE STICK
RegPrice 1.79 CardSav .29
3.79 B
BLKBERY PRES
2.39 B
SFY CANOLA OIL
3.69 B
CEREAL PNT BUTTER
CHILI SAUCE SWT
CHF-B PIZZA
LK GRLC SCE
REFRIG/FROZ
LUC CHEESE
RegPrice 6.79
SPINACH ARTICHOKE
RegPrice 3.79
3S CRWN VEG RSTD
RegPrice 3.79
2@2.50 SFWY SEL M
RegPrice 7.58
MARGARINE
GEN MERCHANDISE
7.99 T
#SFY BENEHIST TAB
BAKED GOODS
1.29 B
LD COSMIC BROWNIES
3.14 B
OROWEAT RYE
4.99 B
CUSTARD PIE 9IN
RegPrice 5.99 CardSav 1.00
4.99 B
CHOC CREAM PIE
RegPrice 5.99 CardSav 1.00
**** TAX 6.76 BAL 144.25
144.25
VF MC XXXXXXXXX
.00
CHANGE
TOTAL SAVINGS 16.97
NUMBER OF ITEMS = 35
SAFEWAY
SAVE MORE AT SAFEWAY
Month: April 2006
Total Food Units: 1527
Total Price:
$527

itemized energy feedback





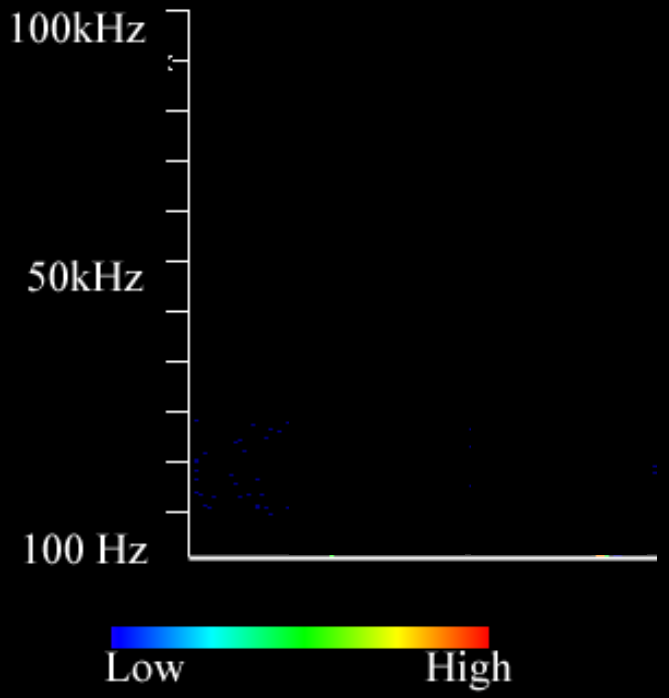
At the flick of a switch: Detecting and Classifying Unique Electrical Events on the Residential Power Line.

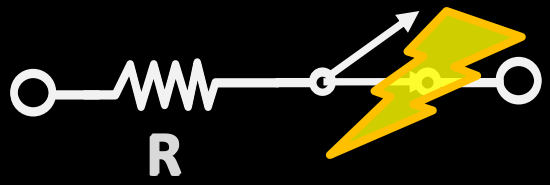
Shwetak N. Patel, Thomas Robertson, Julie A. Kientz, Matthew S. Reynolds, and Gregory D. Abowd

UbiComp 2007

how flick of a switch works

mechanical switches

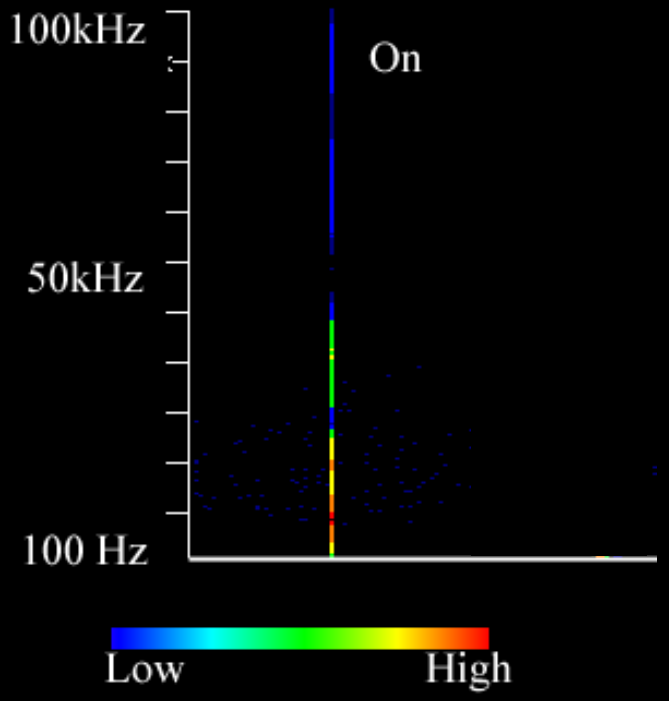


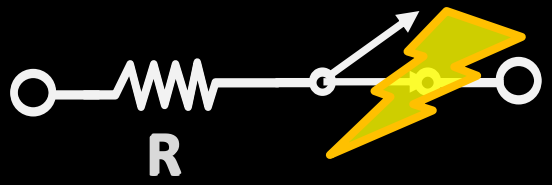


electrical noise transient

how flick of a switch works

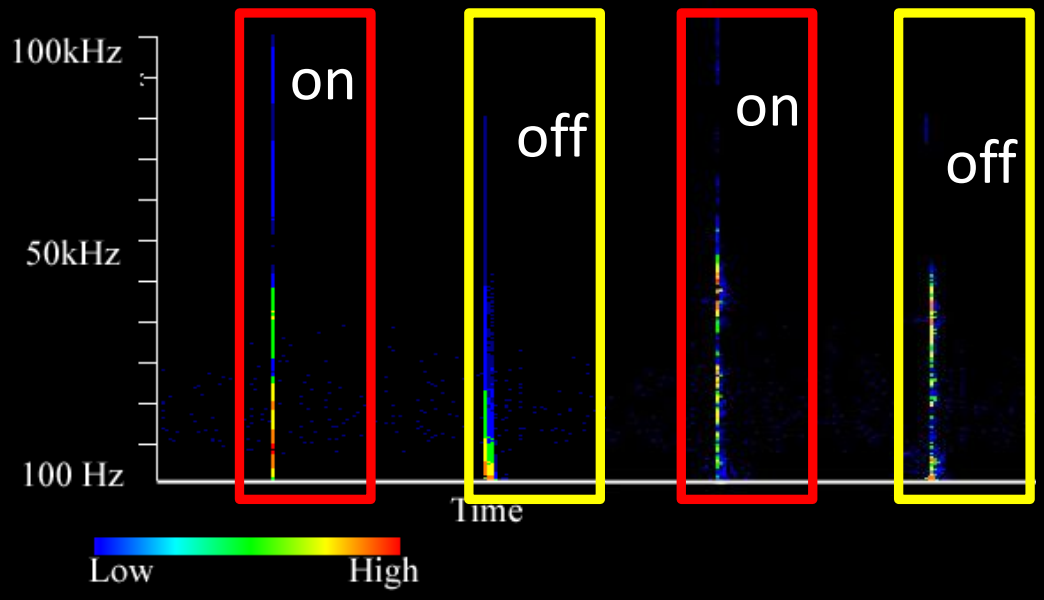
mechanical switches





electrical noise transient

each switch has a unique transient signature



based on:

1. switching mechanisms
2. load characteristics
3. position on transmission line

switch 1

switch 2

transient noise is generated when a physical switch is turned on/off

key problem is signal depends on both the device and switch

most modern consumer electronics have a soft-switch

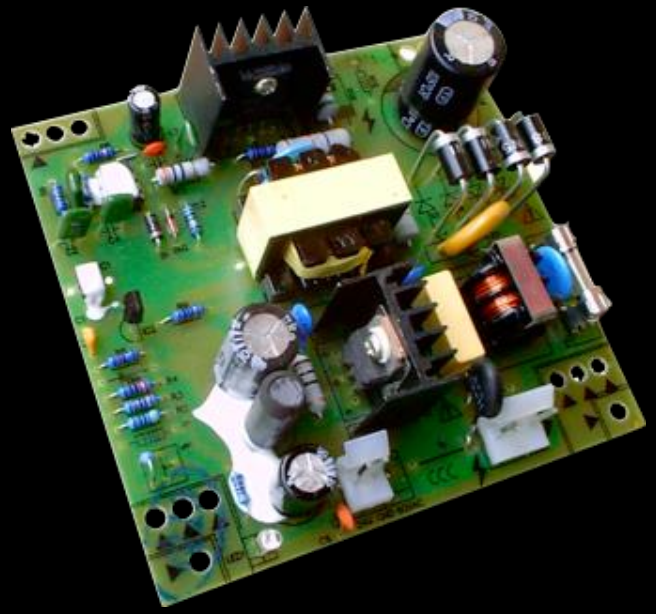
switched mode power supply

smps based appliances are becoming increasingly prevalent

SONY

PLAYSTATION 3
SONY

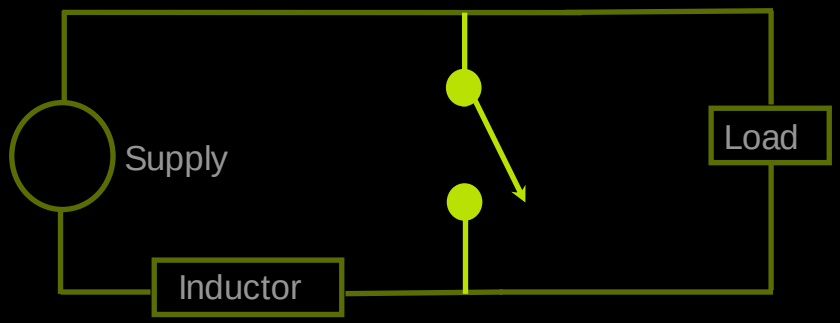
Replacement AC Adapter
WARNING
MADE IN CHINA



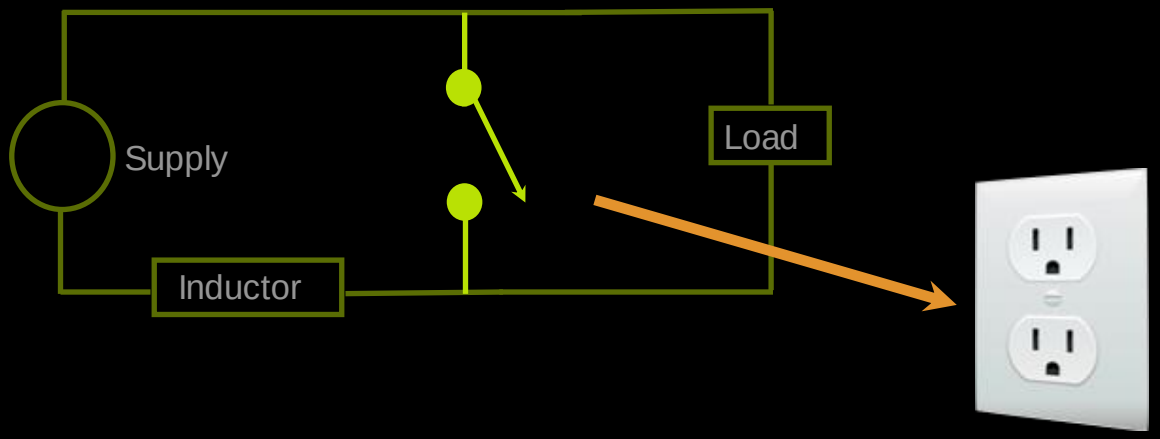
efficient and small in size.

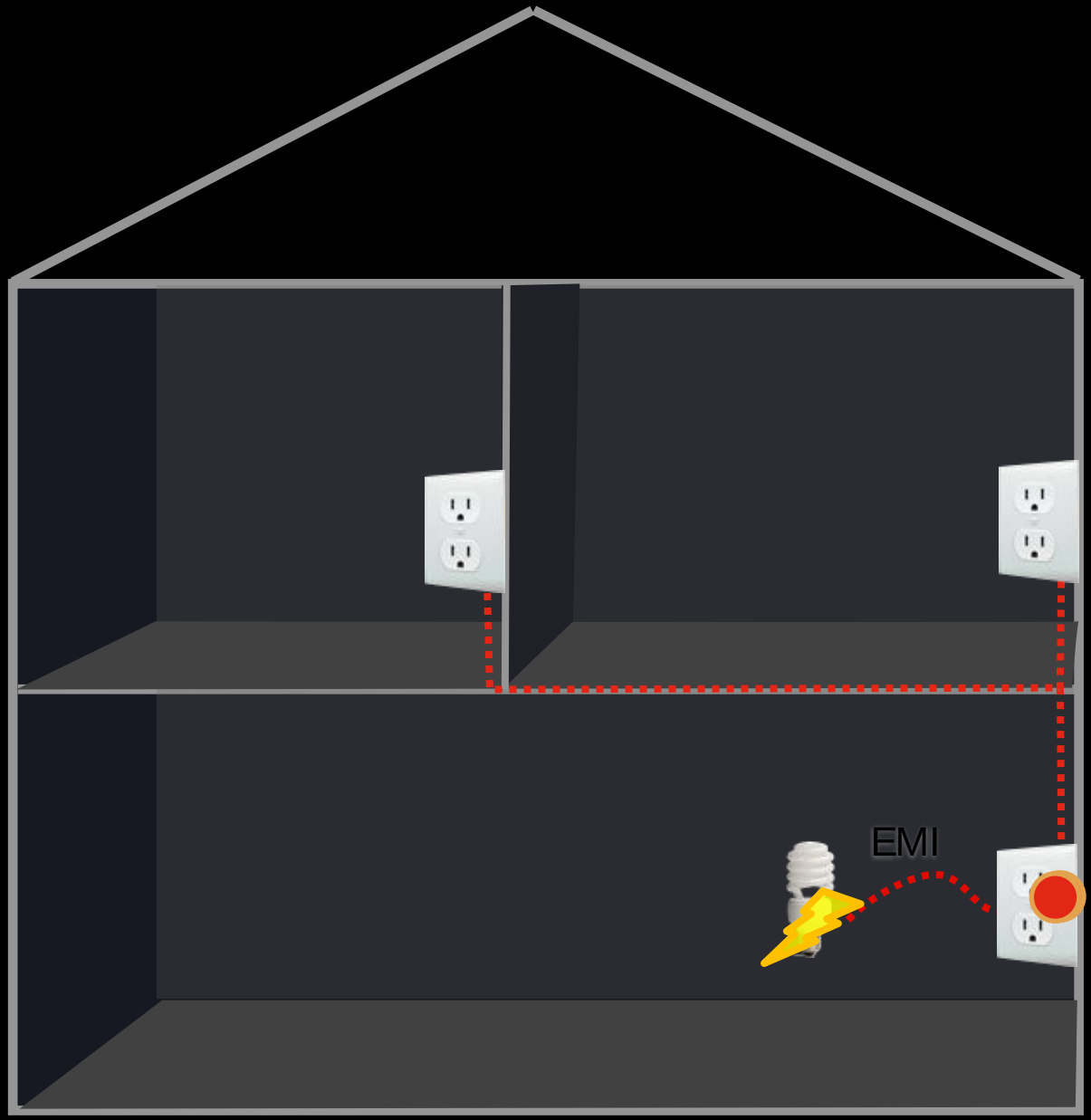
stores energy in inductors & switches it in and out at high frequency.

switching operation generates high frequency electro magnetic interference (emi)



switching operation generates high frequency
electro magnetic interference (emi)




EMI

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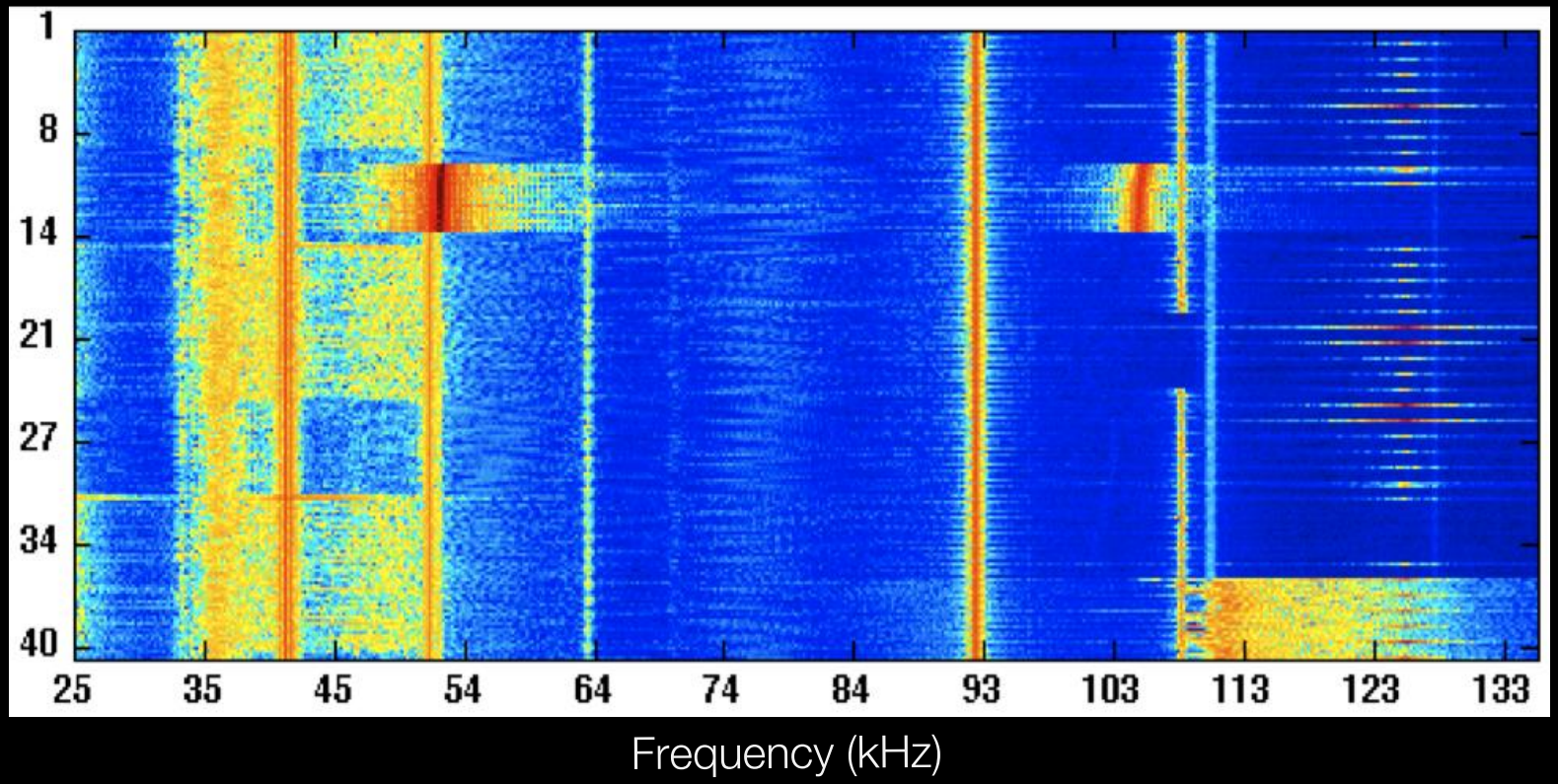
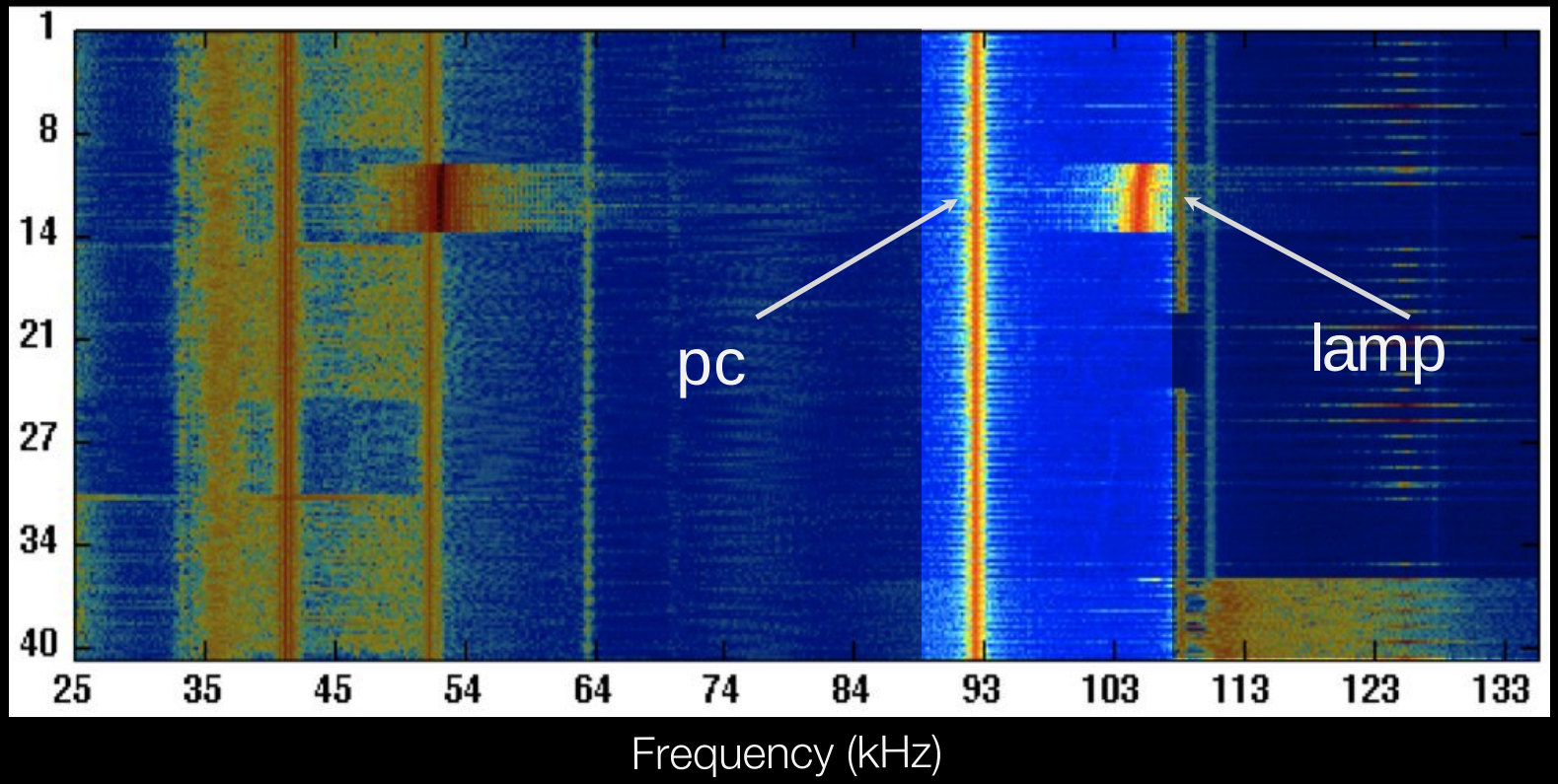
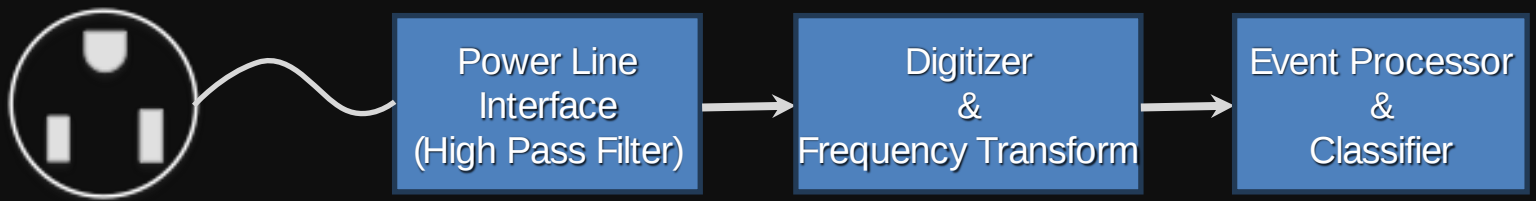
what emi on power line looks like



what emi on power line looks like

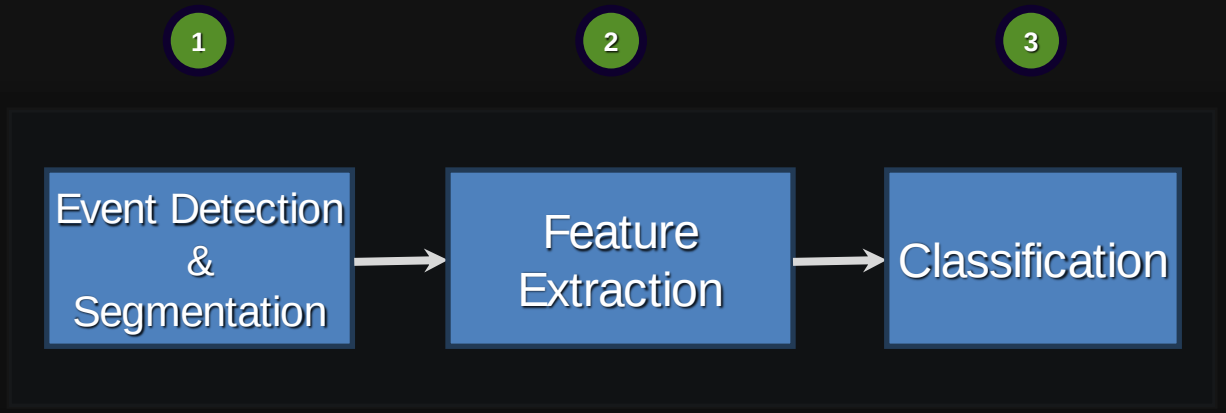


capture system



Any electrical outlet

event processing



1 event detection & segmentation

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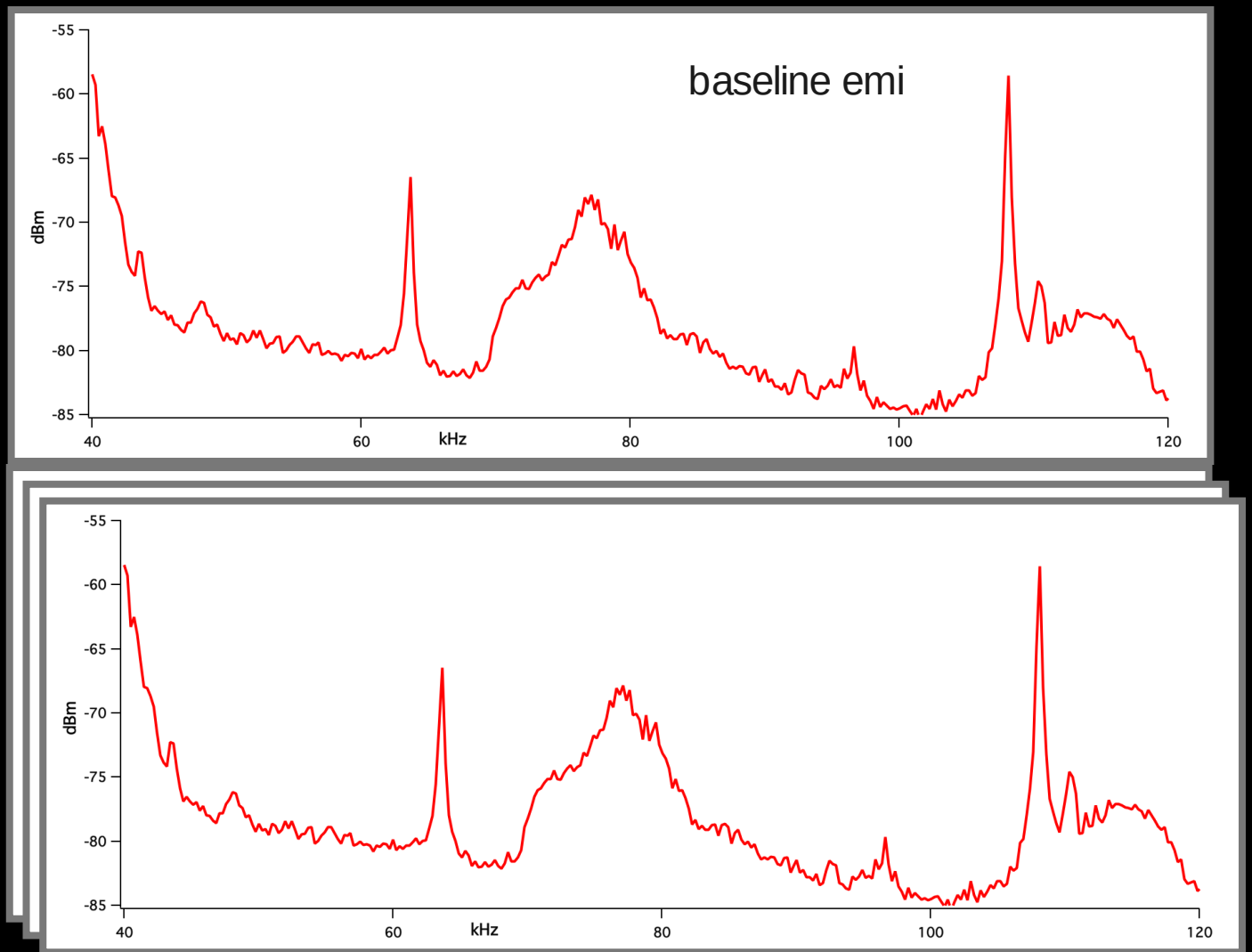
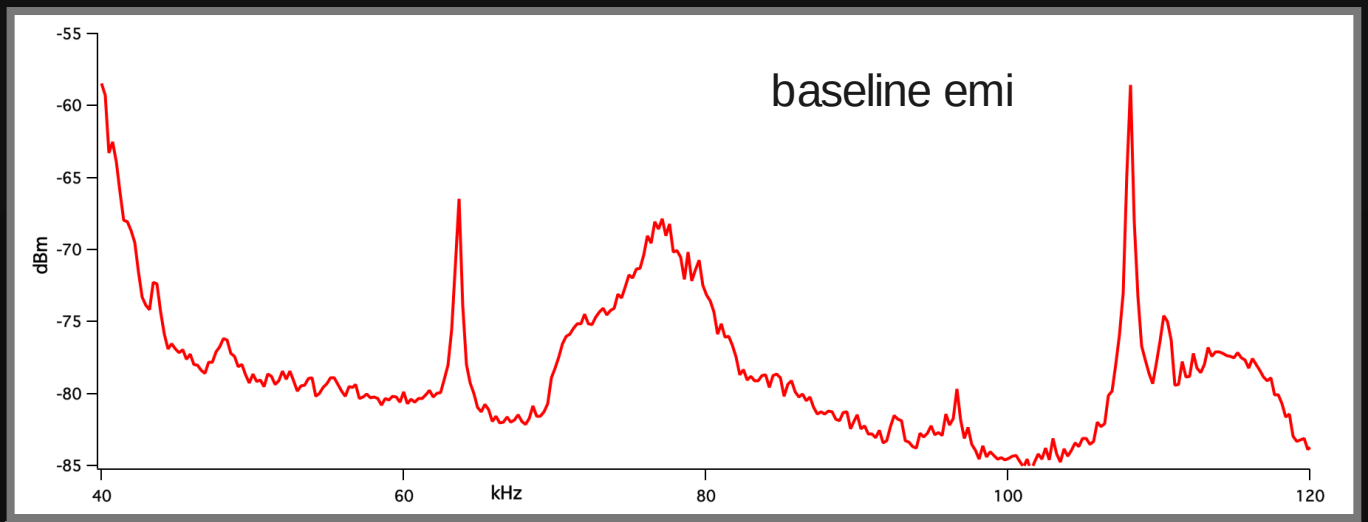
Frequency (kHz)

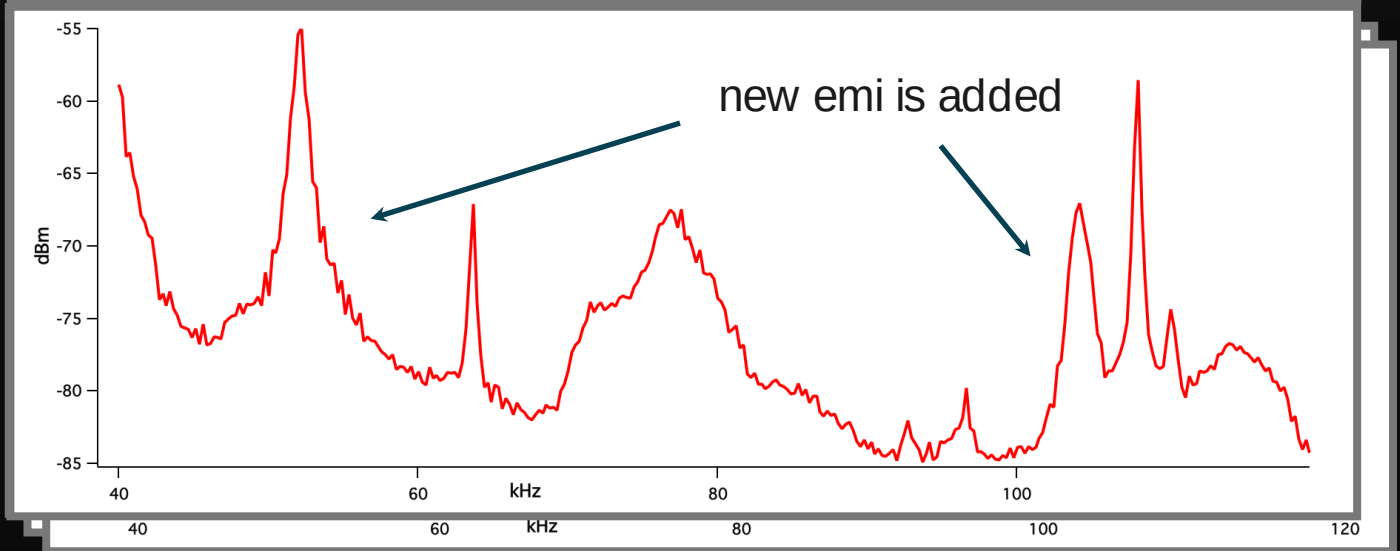
1

event detection & segmentation

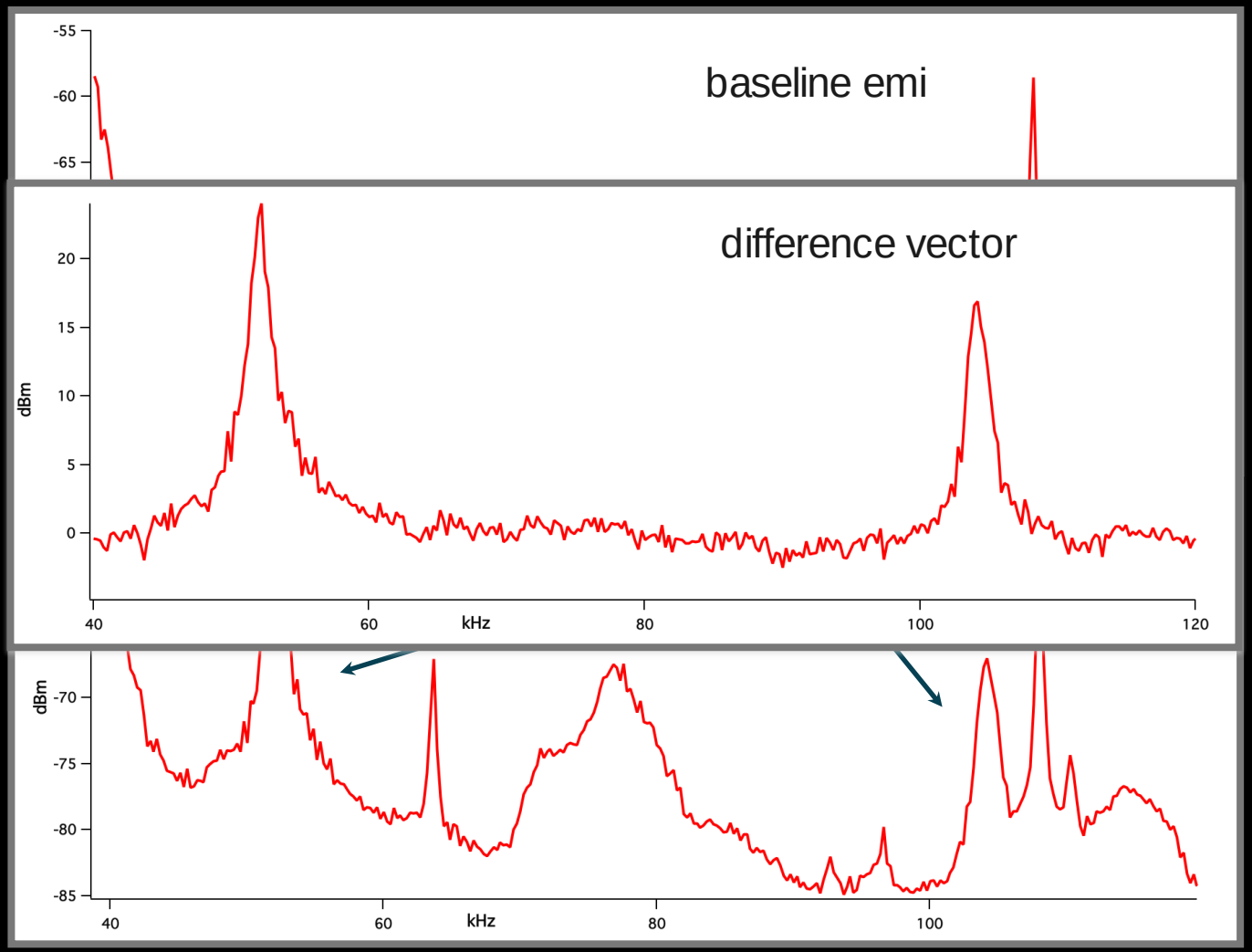


1 event detection & segmentation





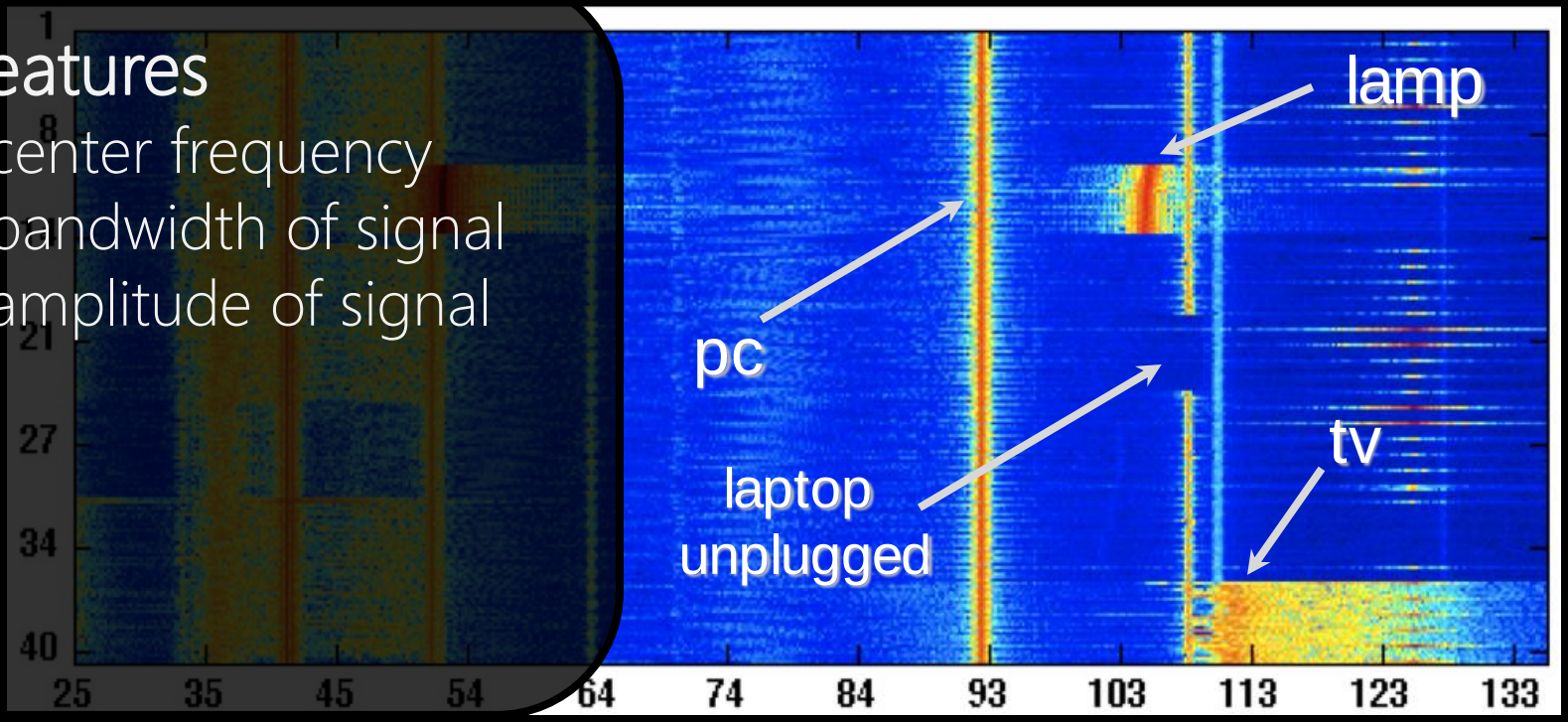
1 event detection & segmentation



2 feature extraction

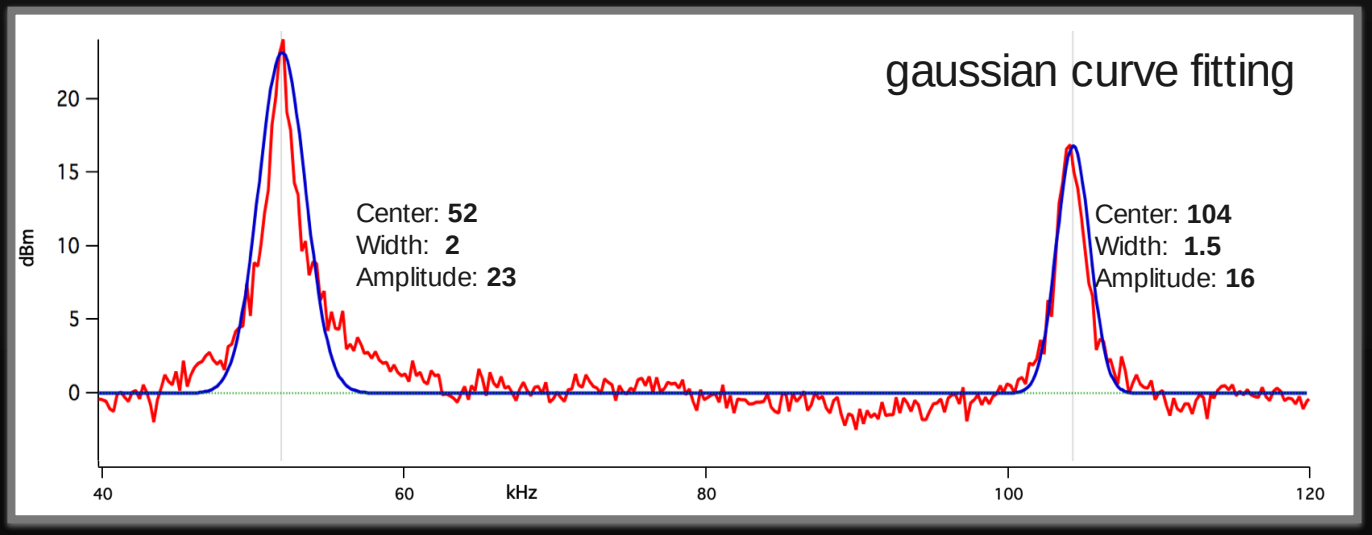
3 features

1. center frequency
2. bandwidth of signal
3. amplitude of signal



2

feature extraction



three features are extracted for each peak

3 event classification

three features from strongest peak → nearest neighbor classifier

(i) are these features good enough for accurate identification?

(ii) do signatures remain stable over long period of time?

(iii) can training be minimized by applying signature from one home to another?

experiments in 7 homes

apartments & houses

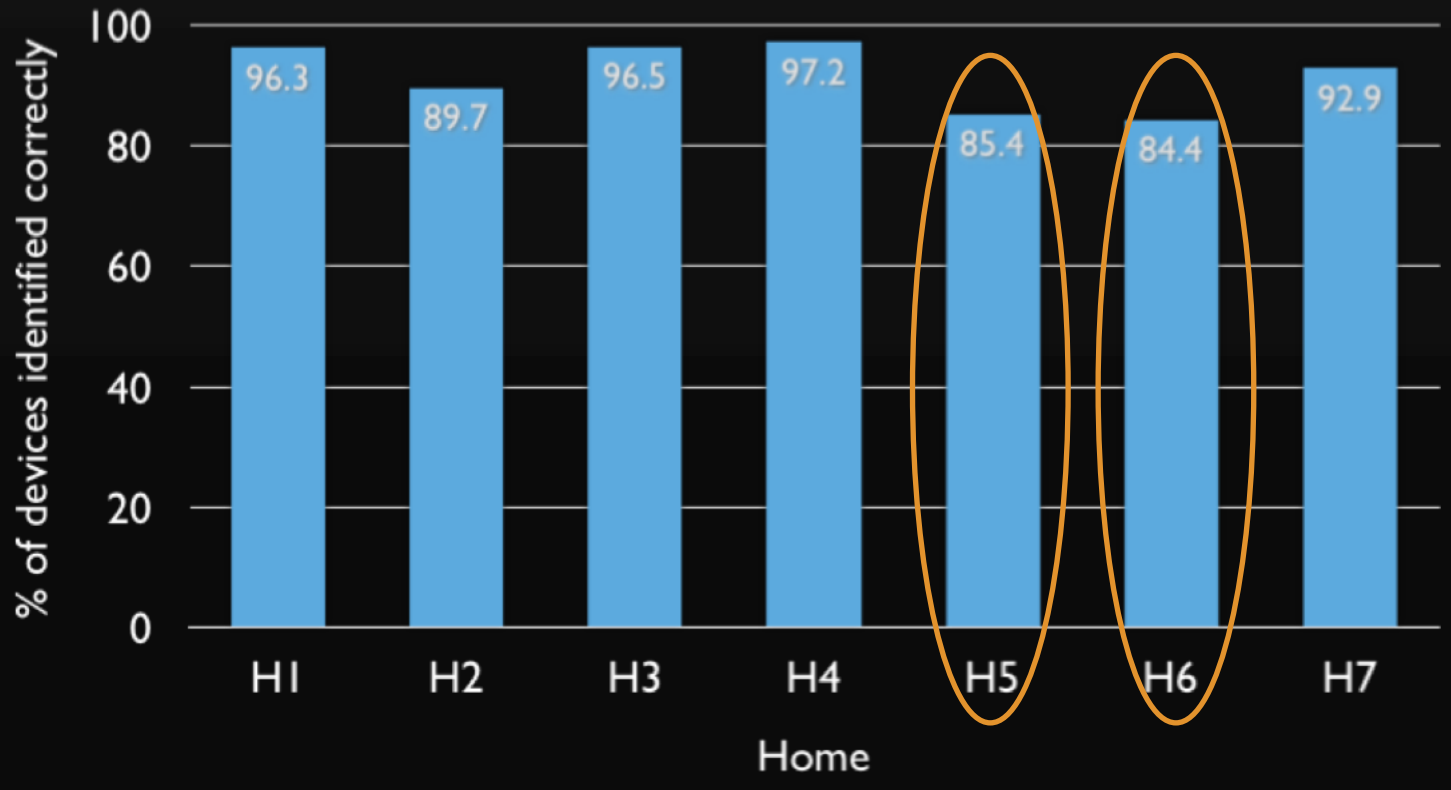
home sizes: 650 - 3000 sq. ft.

a total of 2576 electrical events

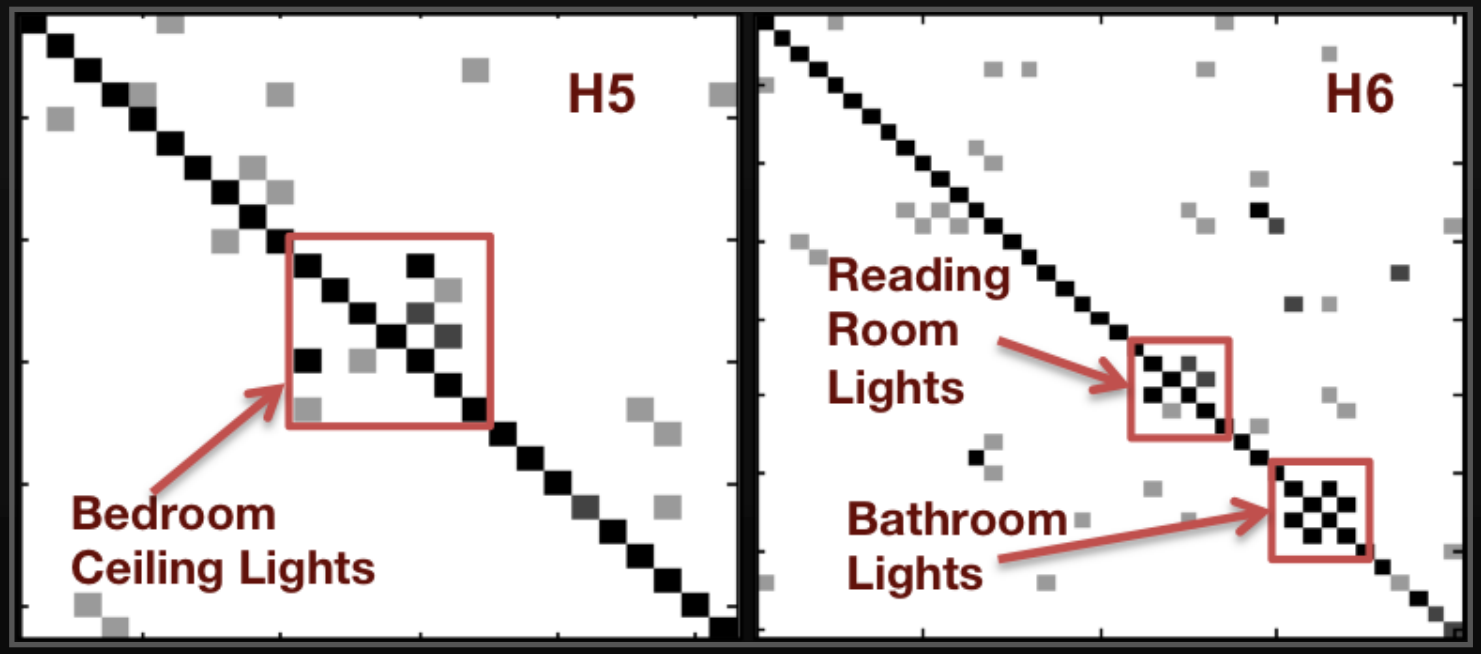
94 different devices

10 fold cross validation

average %: 91.75

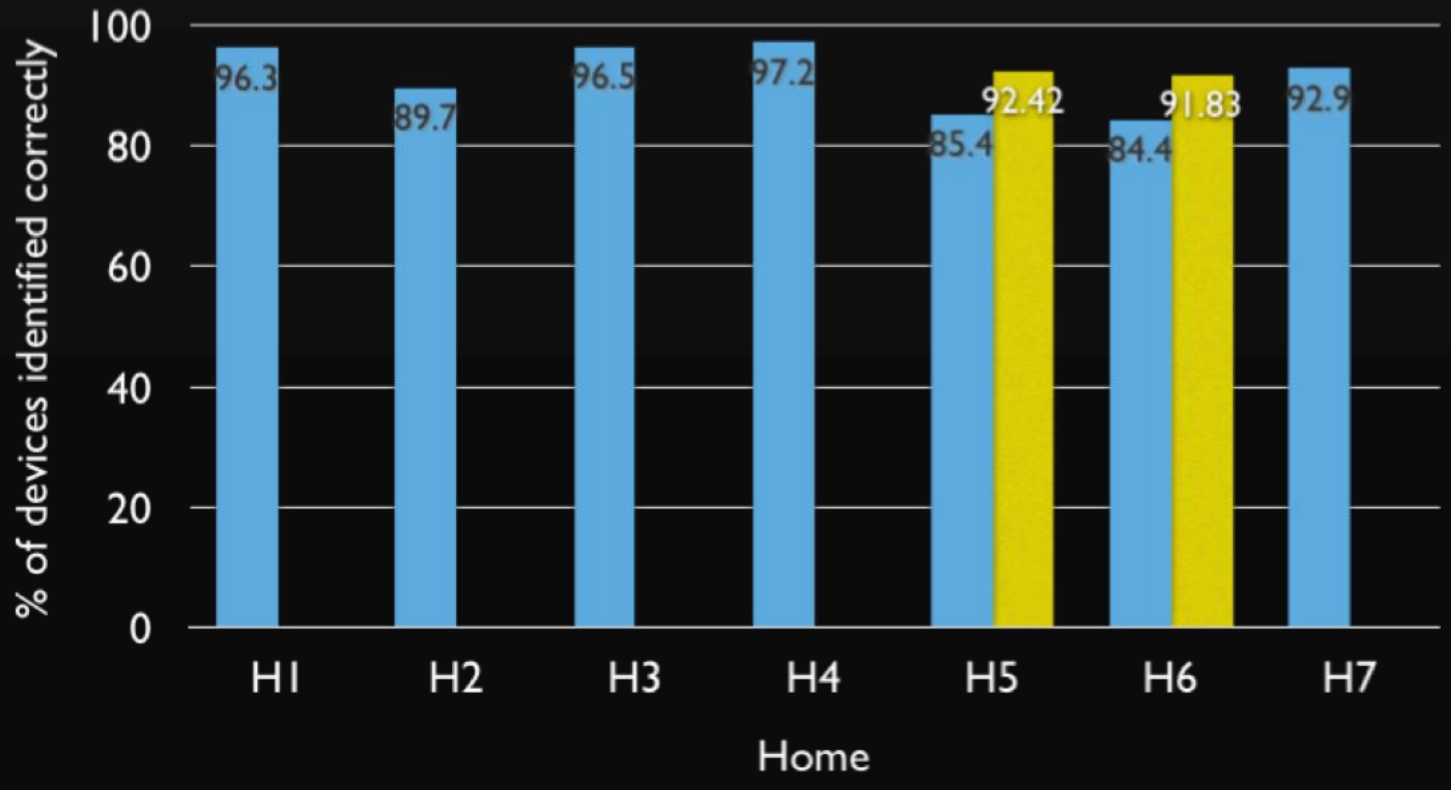


confusion matrices



10 fold cross validation

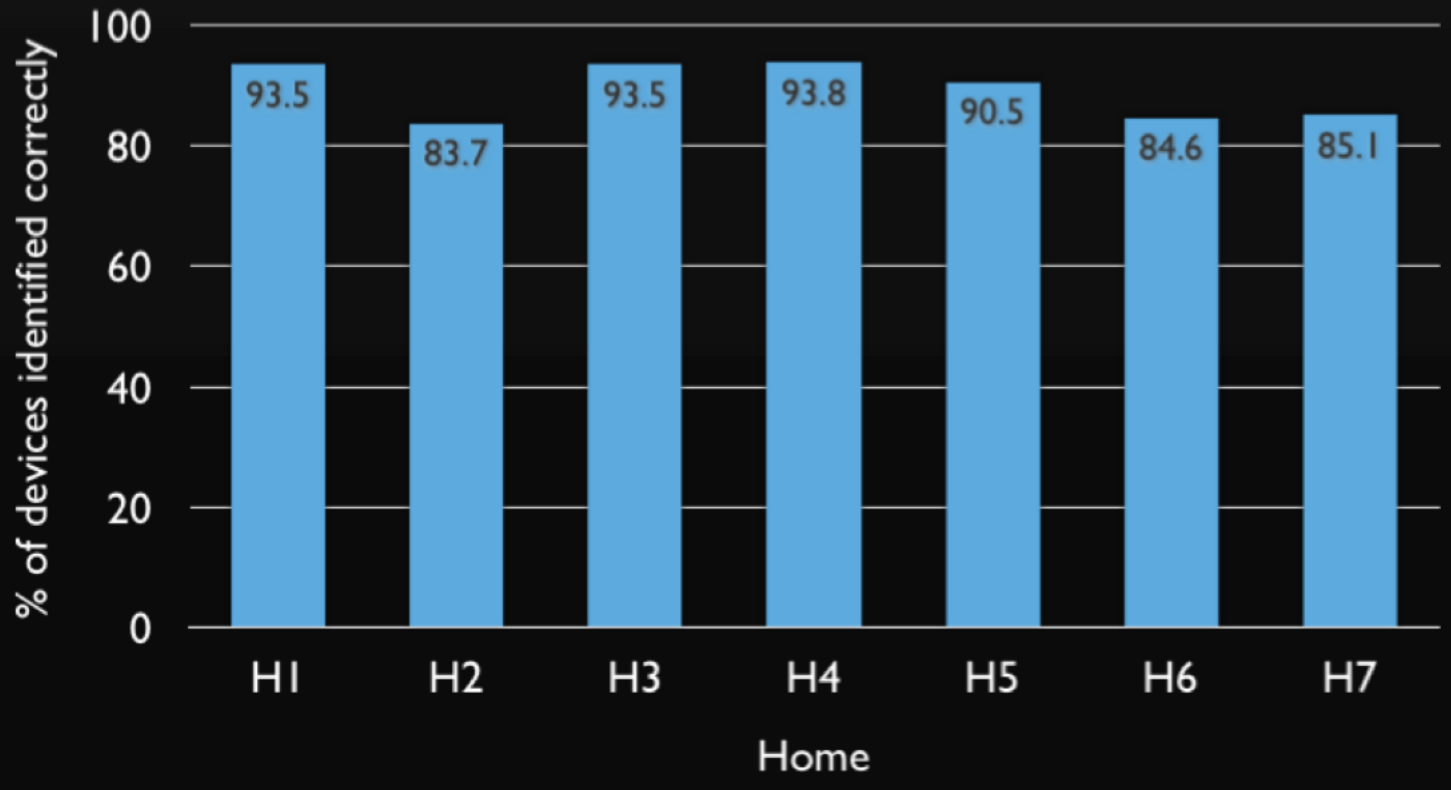
Average %: 93.82



training on a single sample
for each event

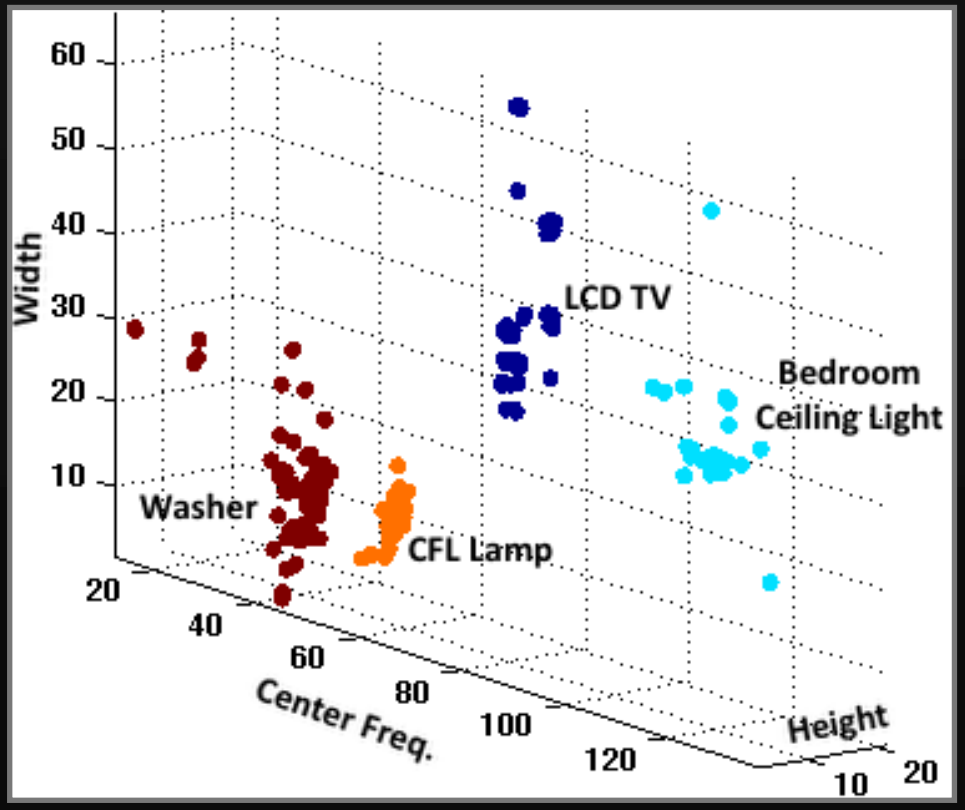
minimal training performance

Average %: 89.25



stability of signals over time

samples in feature space



potentially minimizing training by applying signatures across home

we collected data for four of our own devices that we brought to each home

two of the three features remain consistent

average accuracy: 100%

can signatures from one device be applied to another given they are similar models?

signature similar enough to yield an accuracy of 100%

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water

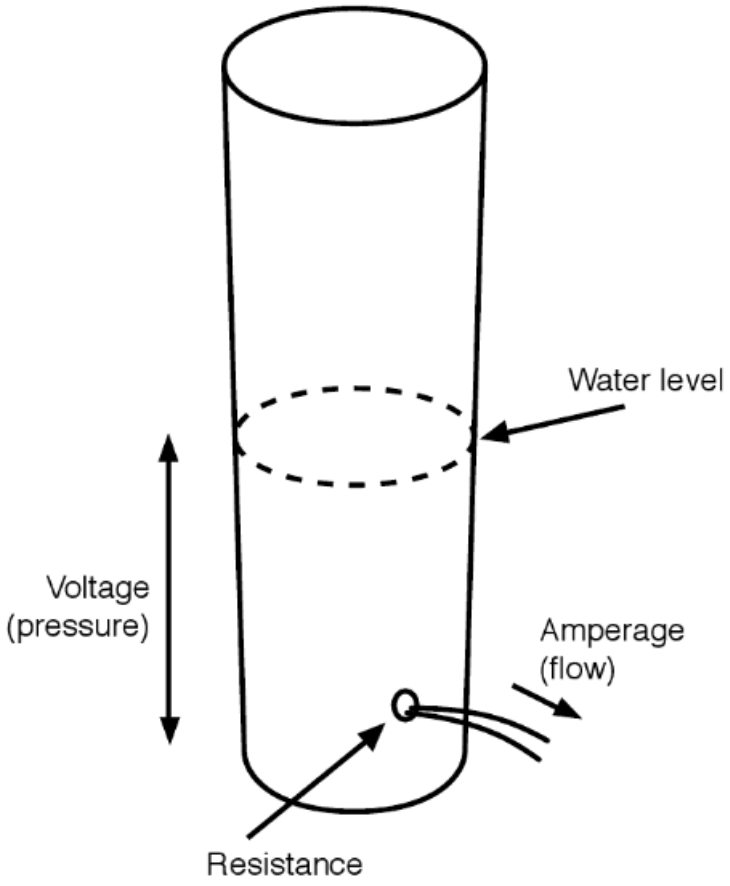


Figure 1-33. *Think of voltage as pressure, and amperes as flow.*

MAKE: Electronics: Learning Through Discovery , by Charles Platt

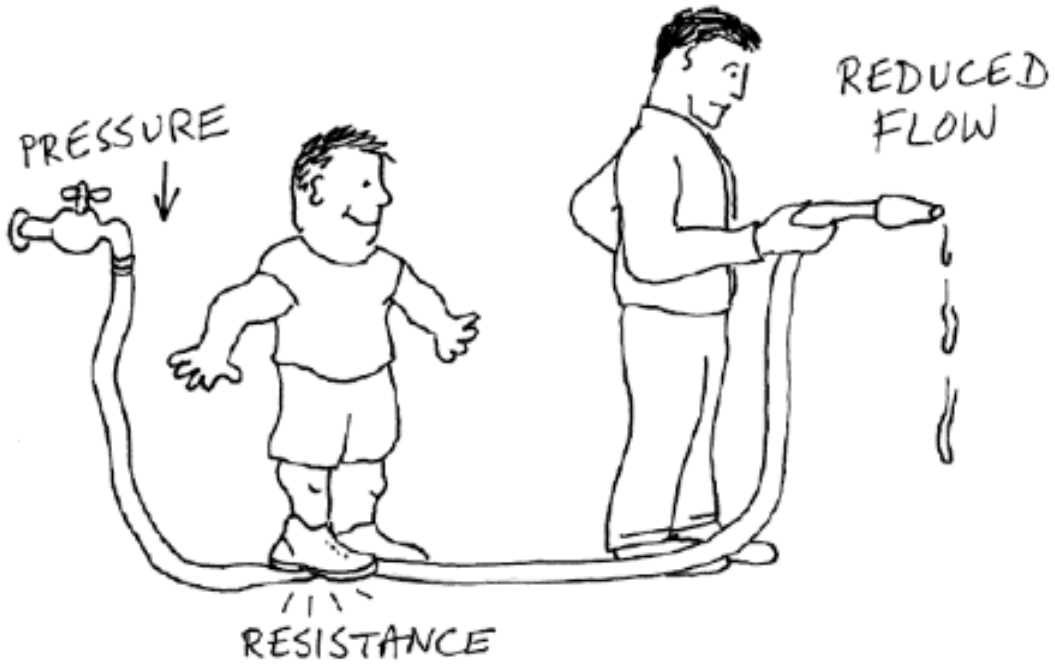
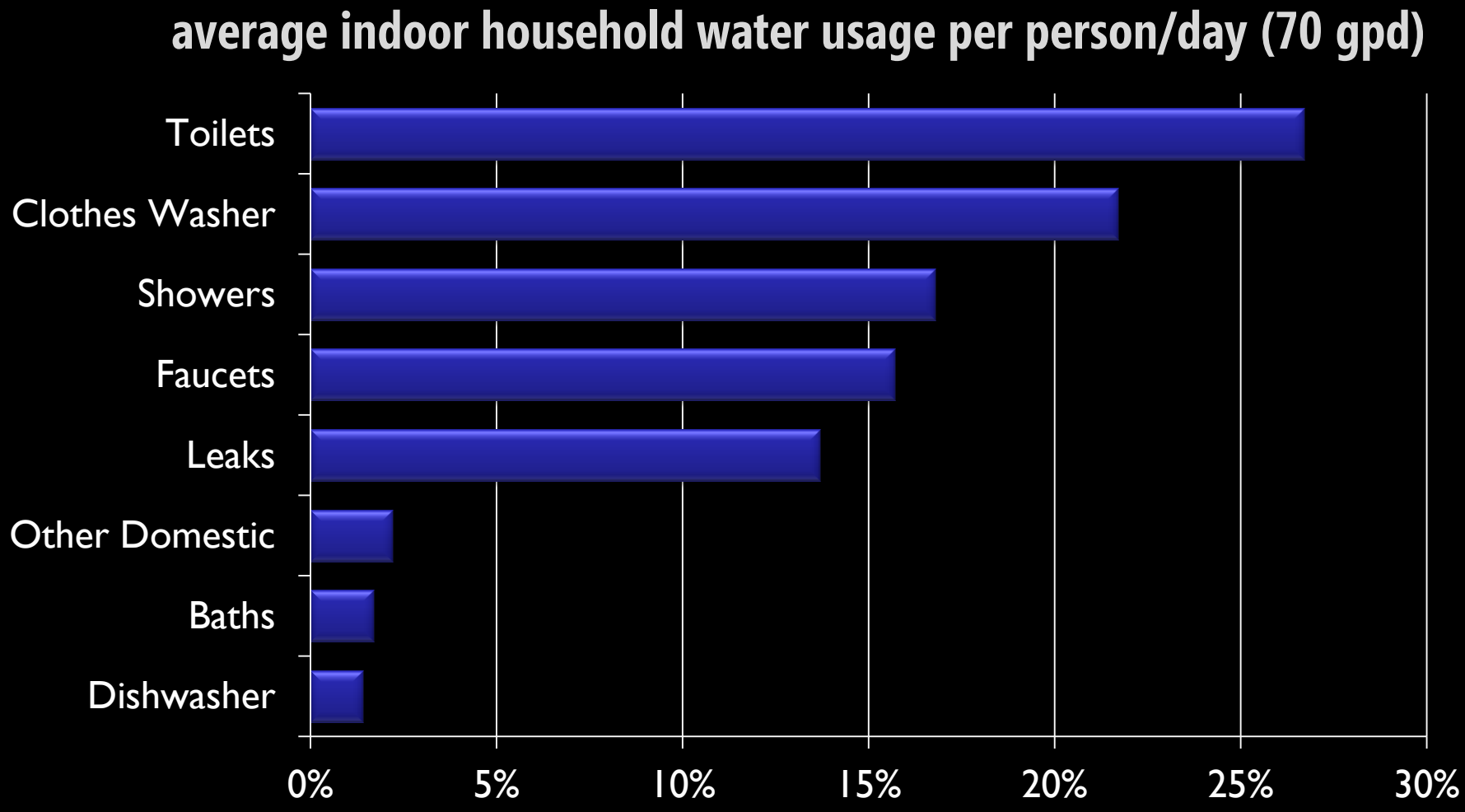


Figure 1-34. *Larger resistance results in smaller flow—but if you increase the pressure, it may overcome the resistance and increase the flow.*

MAKE: Electronics: Learning Through Discovery , by Charles Platt

what are the most consuming water activities in your home?



Vickers, 2001

hydrosense

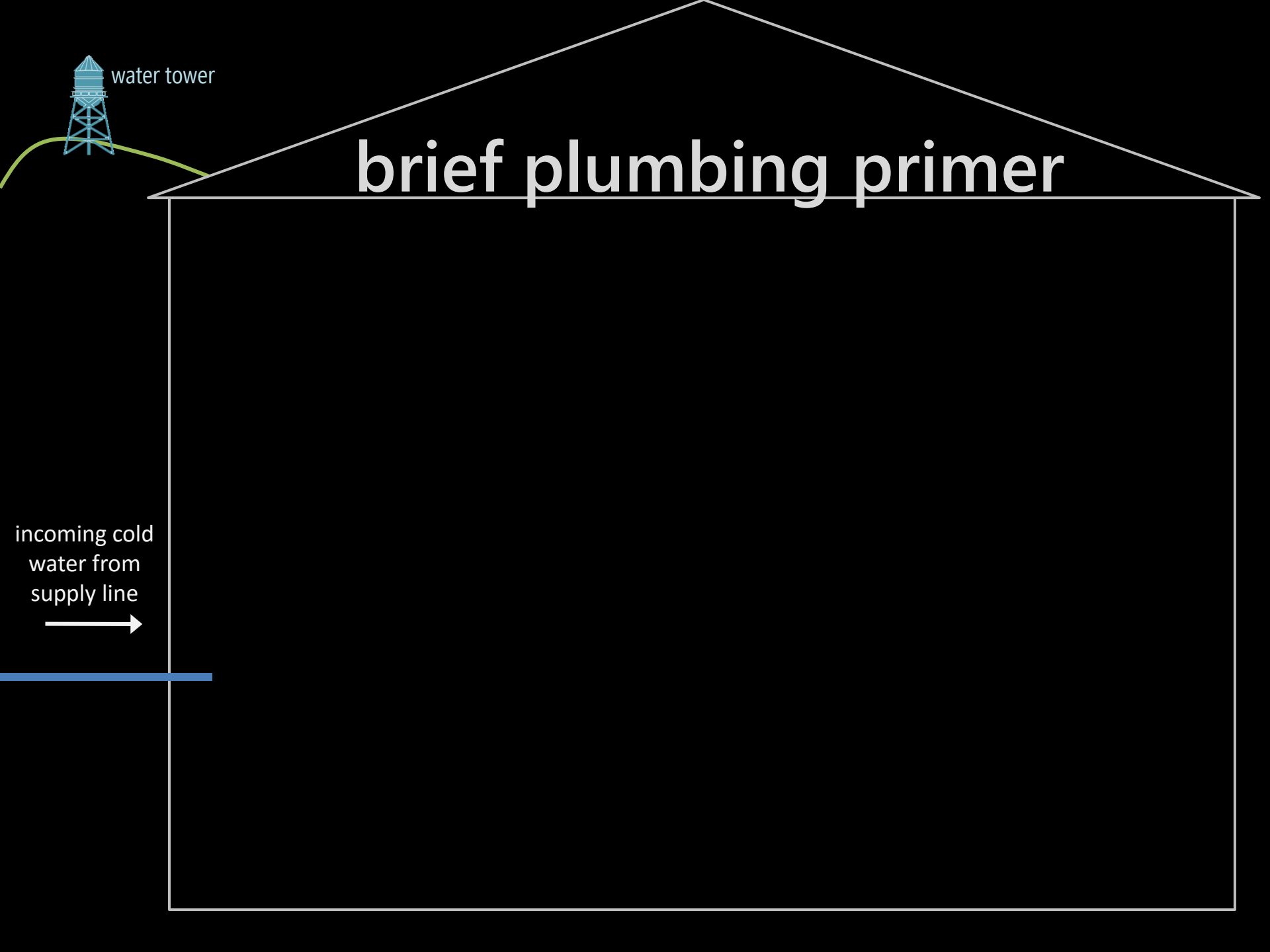
single-point pressure-based sensor of water usage

identifies water usage activity **down to its source**(e.g., toilet)

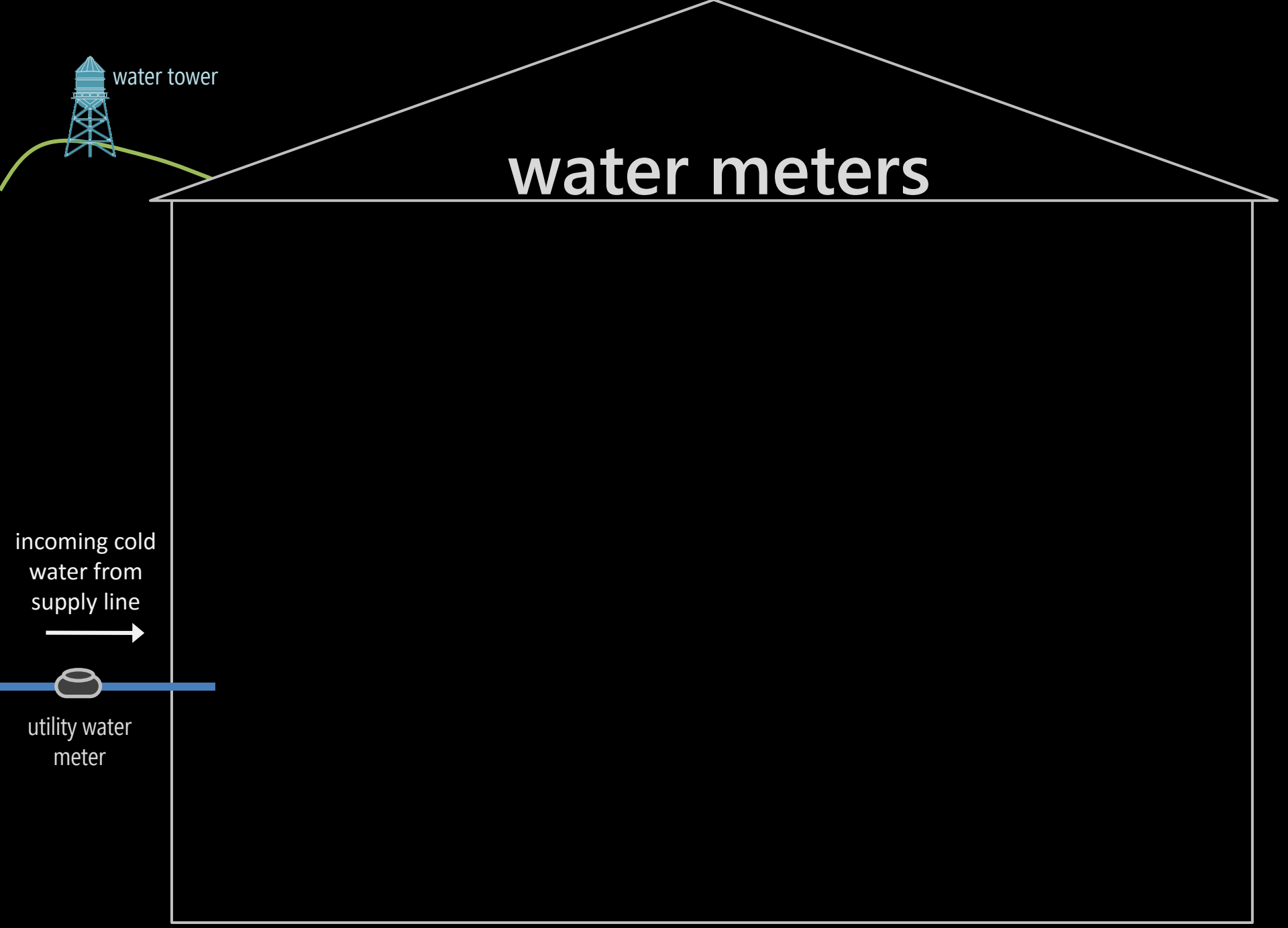
provides **estimates of flow** at **each fixture**

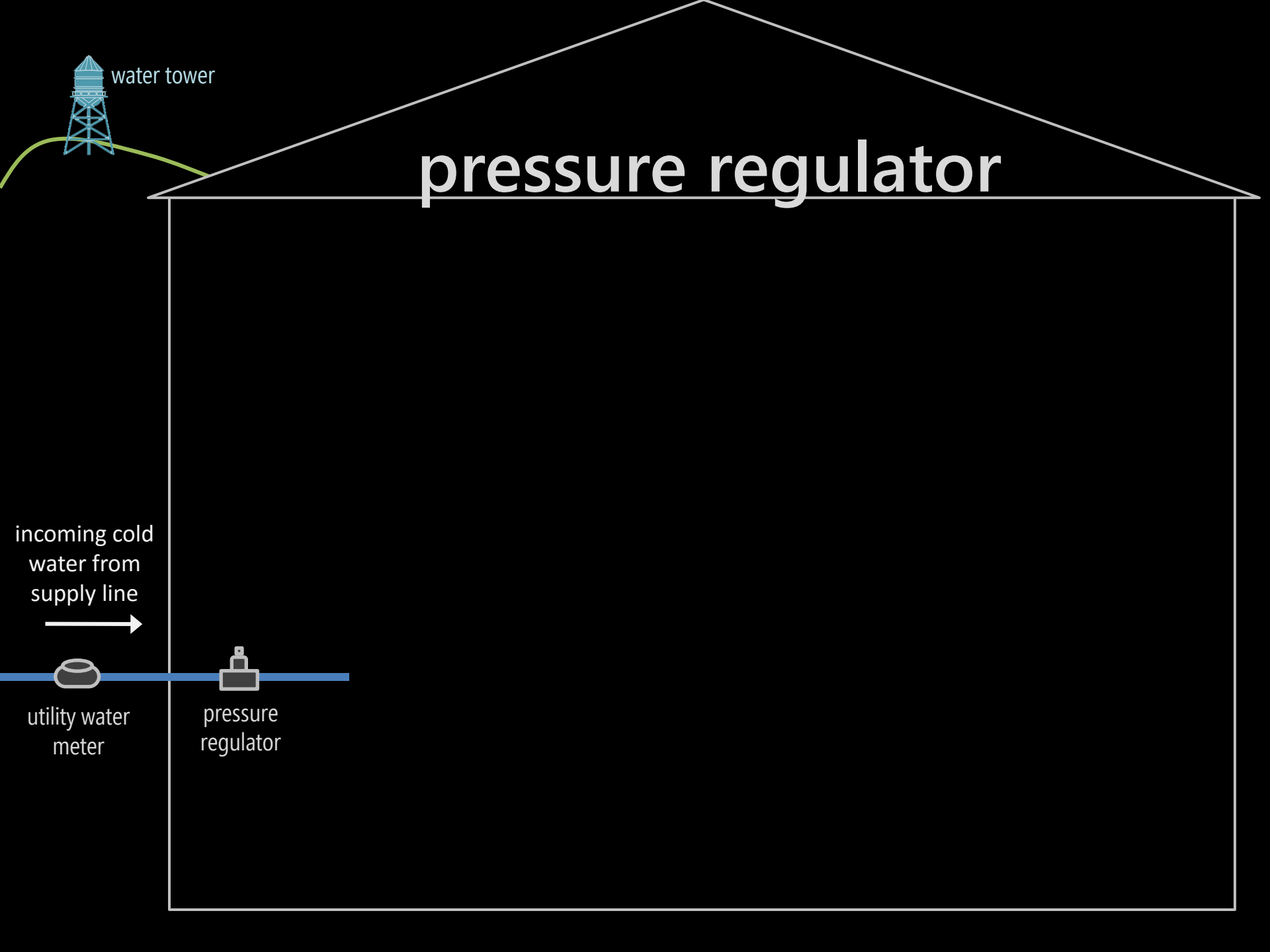
typical water meters
- only **provide aggregate information** on water usage
- **require pipe modification** for installation
traditional inline water meter

brief plumbing primer


water tower
brief plumbing primer
incoming cold water from supply line

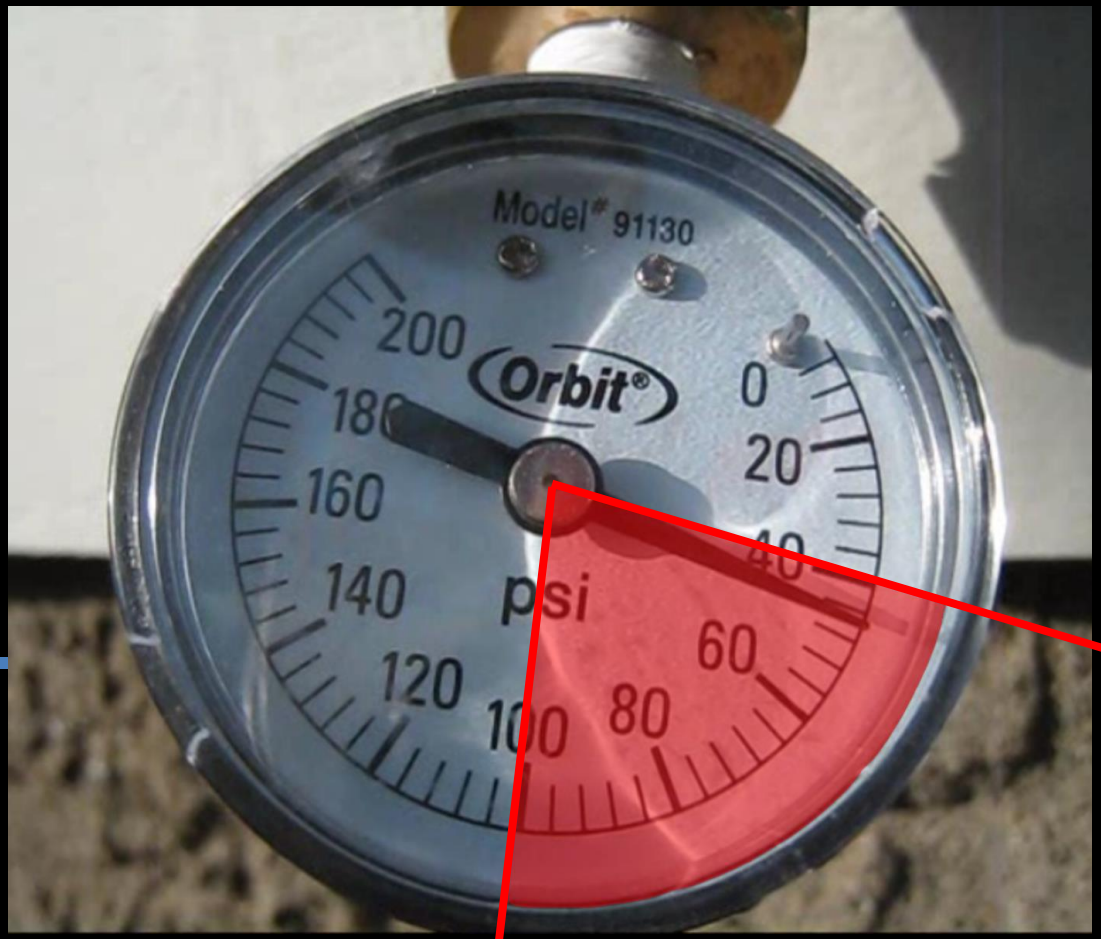
water meters




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

water tower

pressure regulator

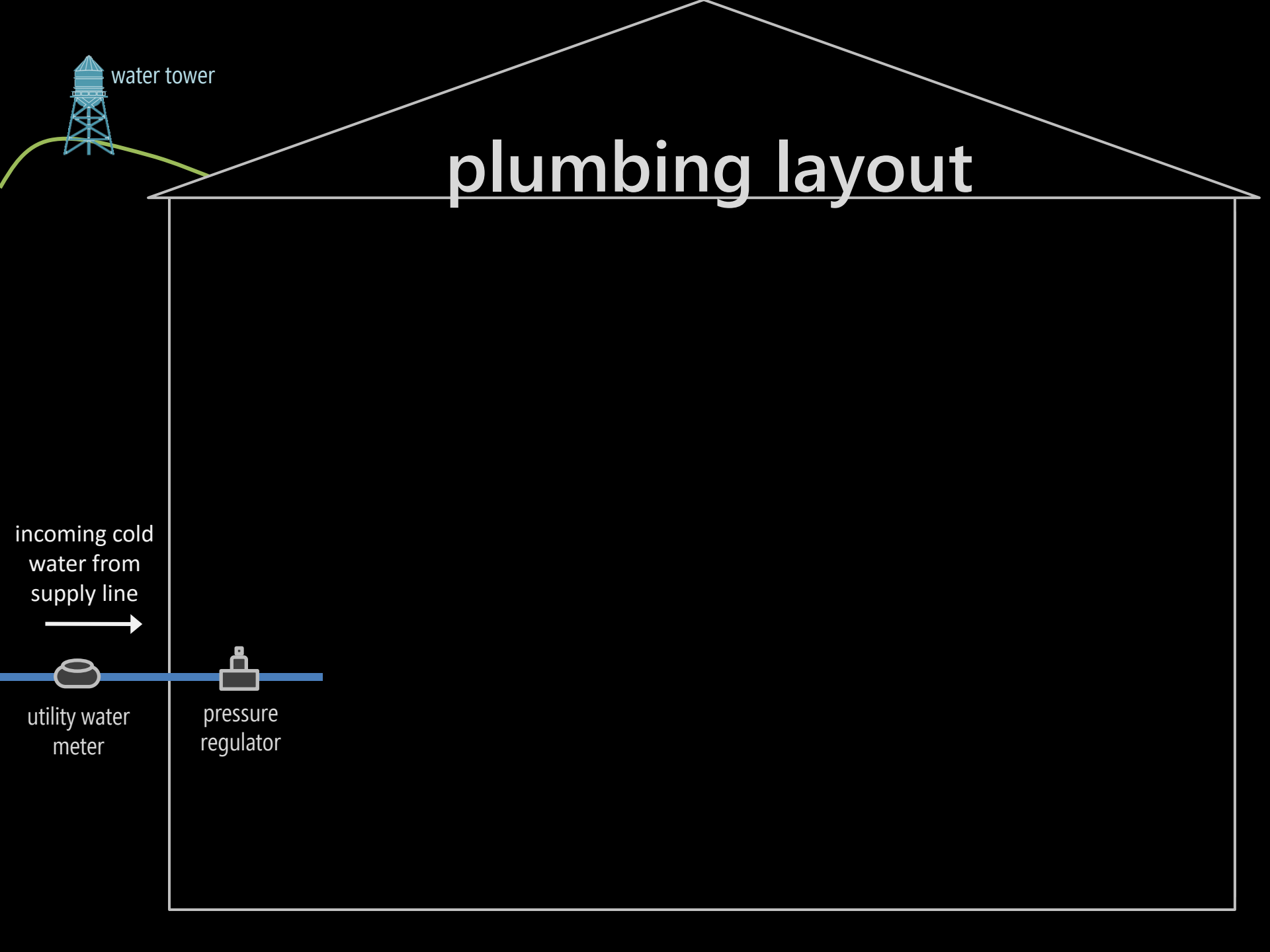


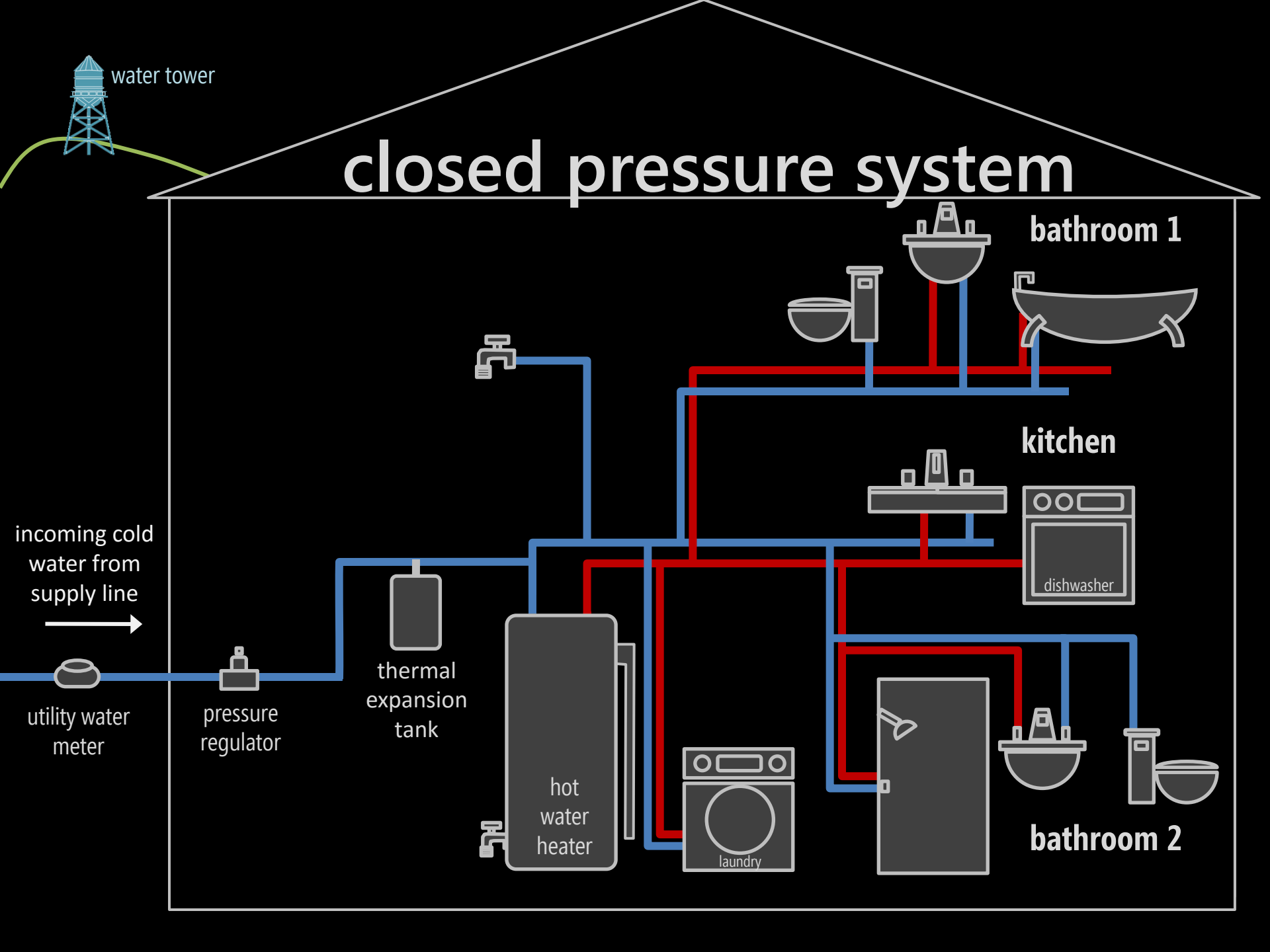
incoming cold water from supply line

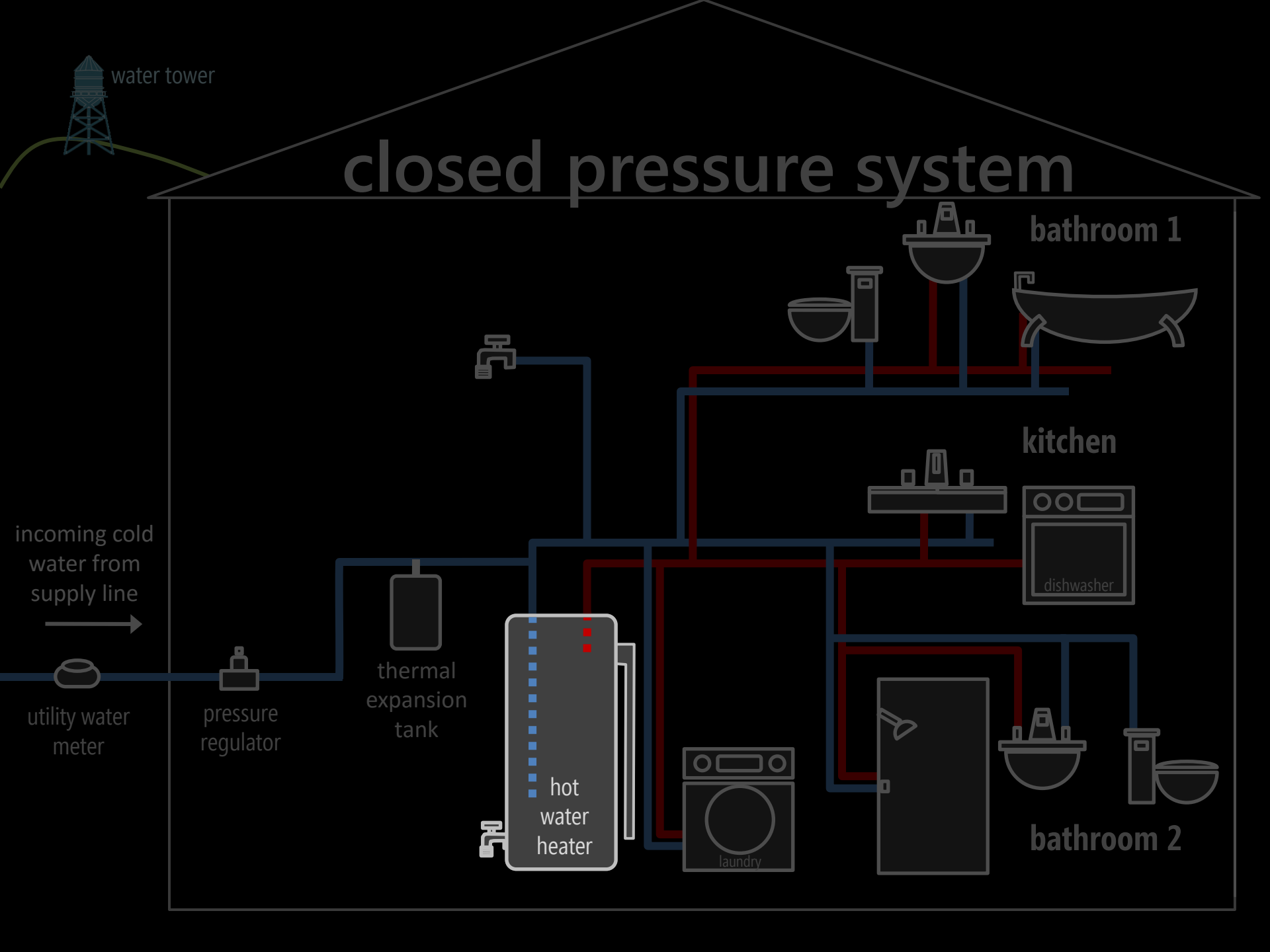
utility water meter

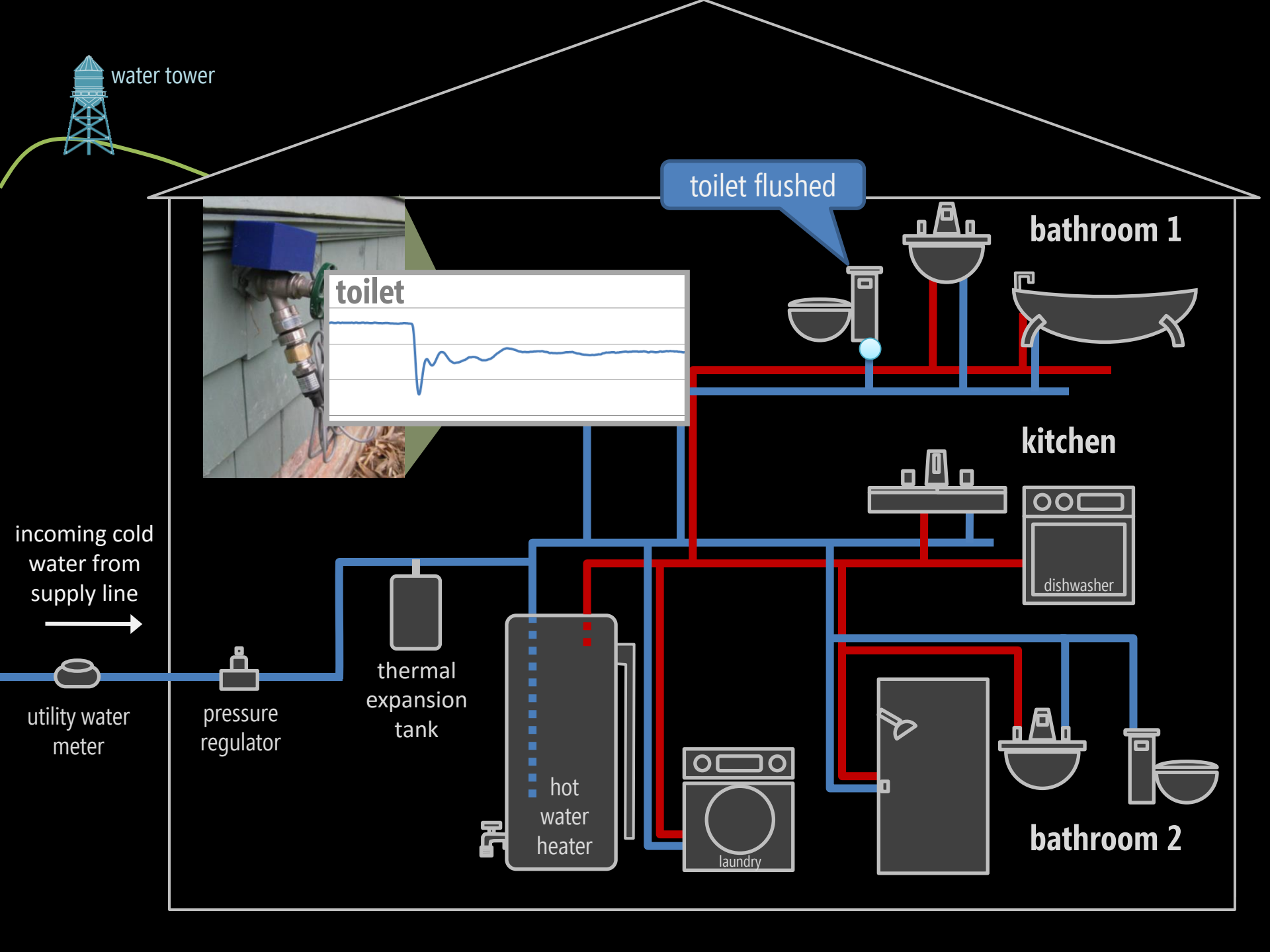
pressure regulator

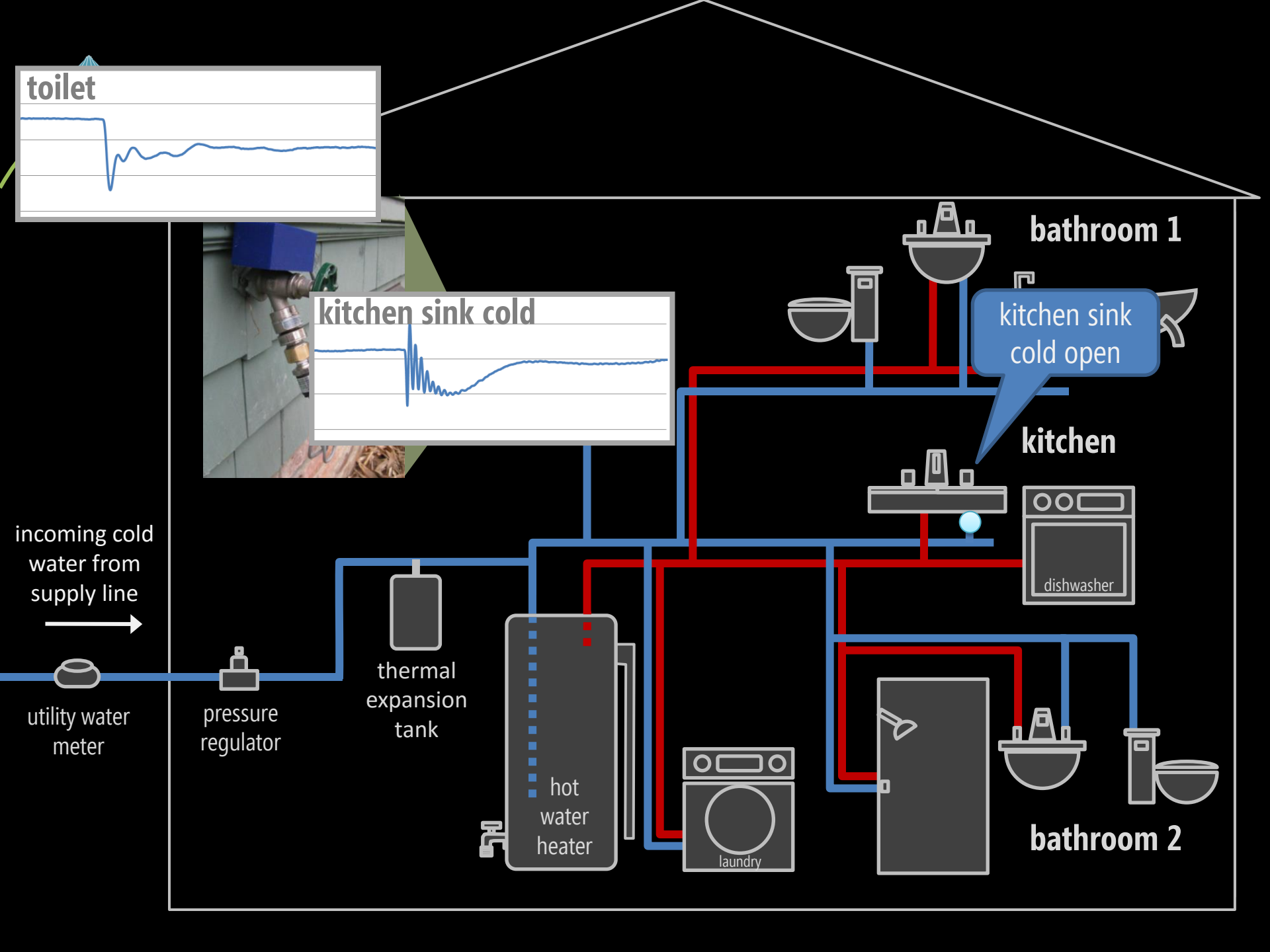
plumbing layout

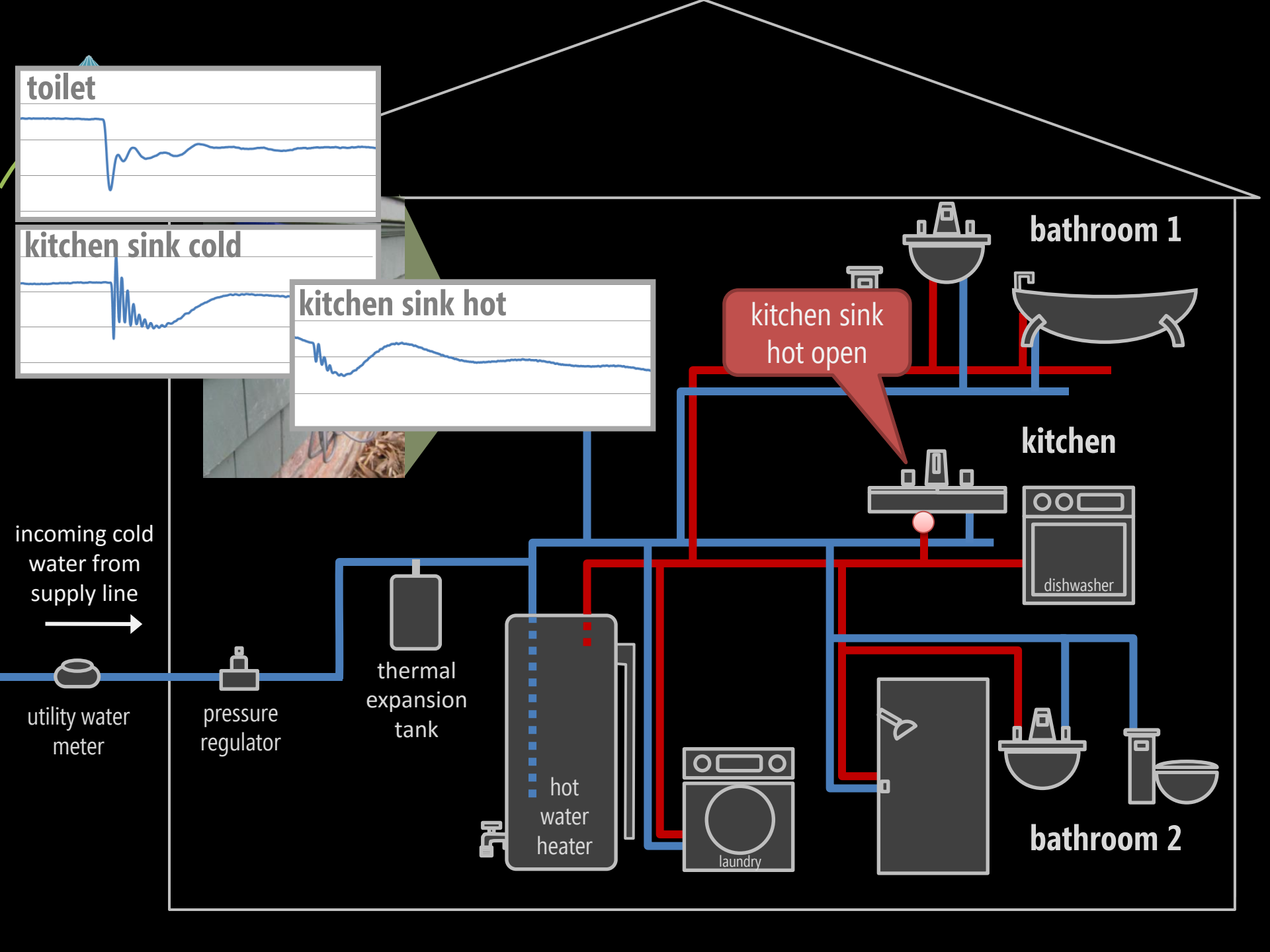


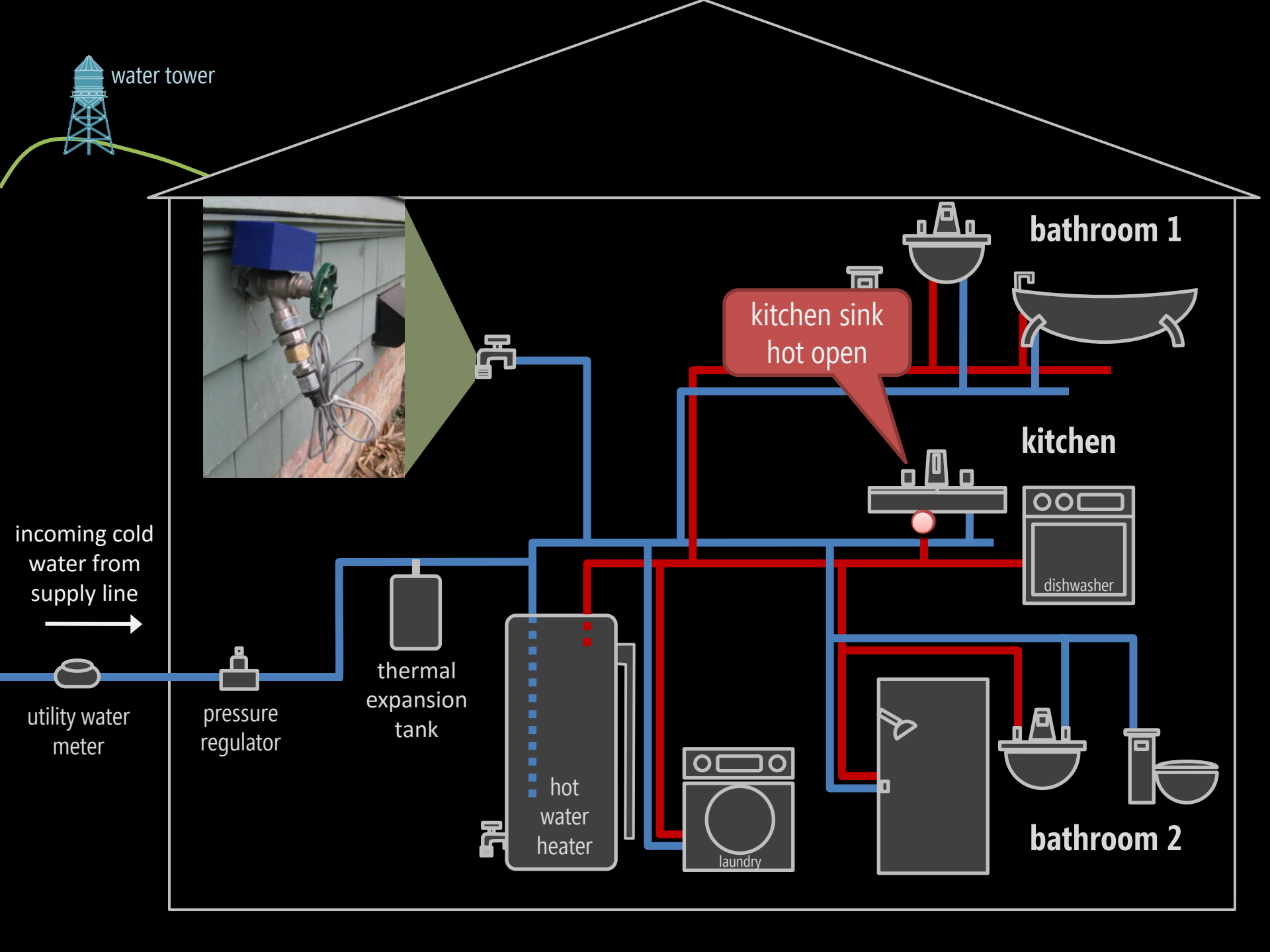

water tower
closed pressure system
bathroom 1
kitchen
dishwasher
incoming cold water from supply line
utility water meter
pressure regulator
thermal expansion tank
hot water heater
laundry
bathroom 2

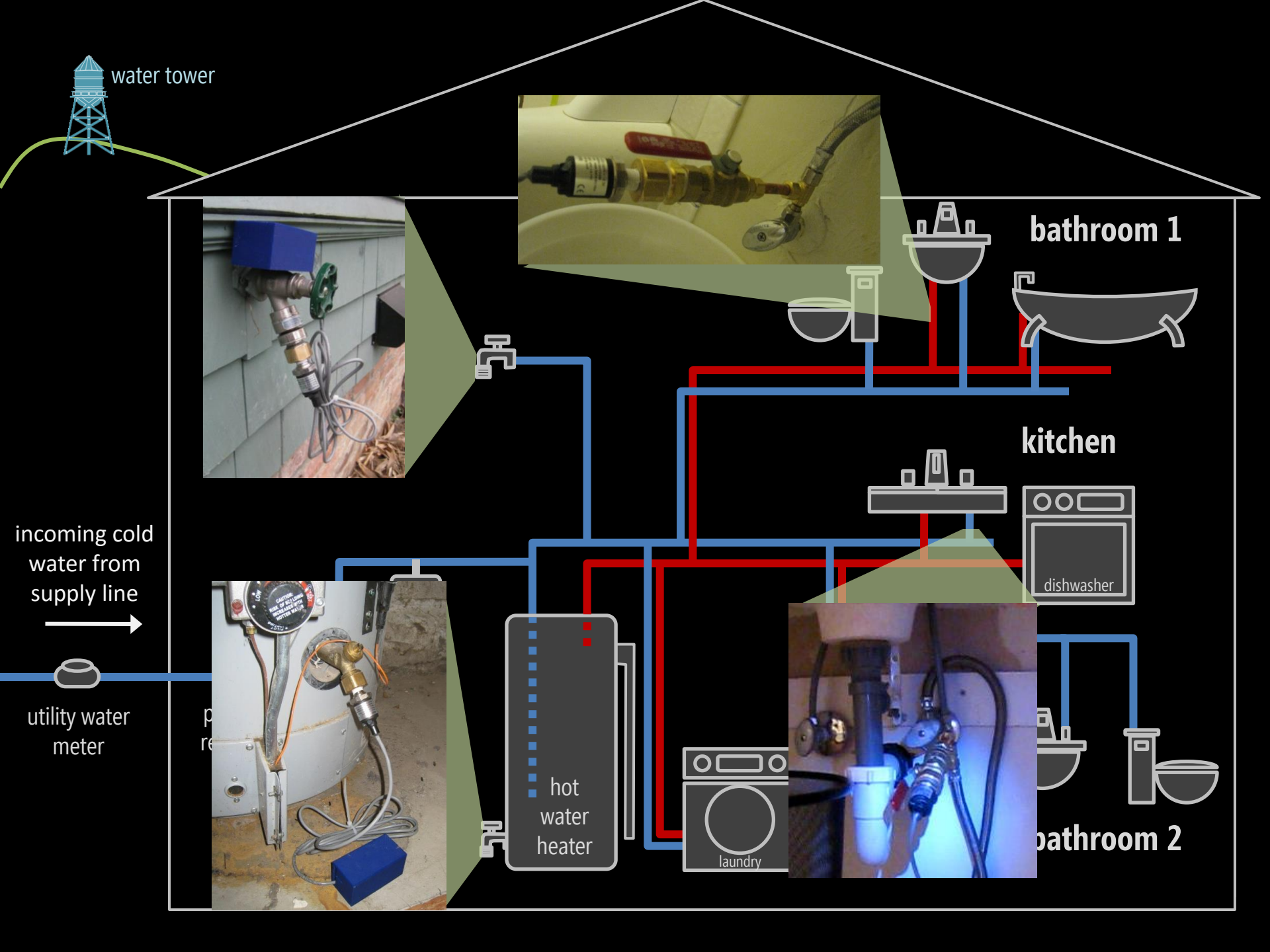

water tower
closed pressure system
bathroom 1
kitchen
dishwasher
incoming cold water from supply line
utility water meter
pressure regulator
thermal expansion tank
hot water heater
laundry
bathroom 2

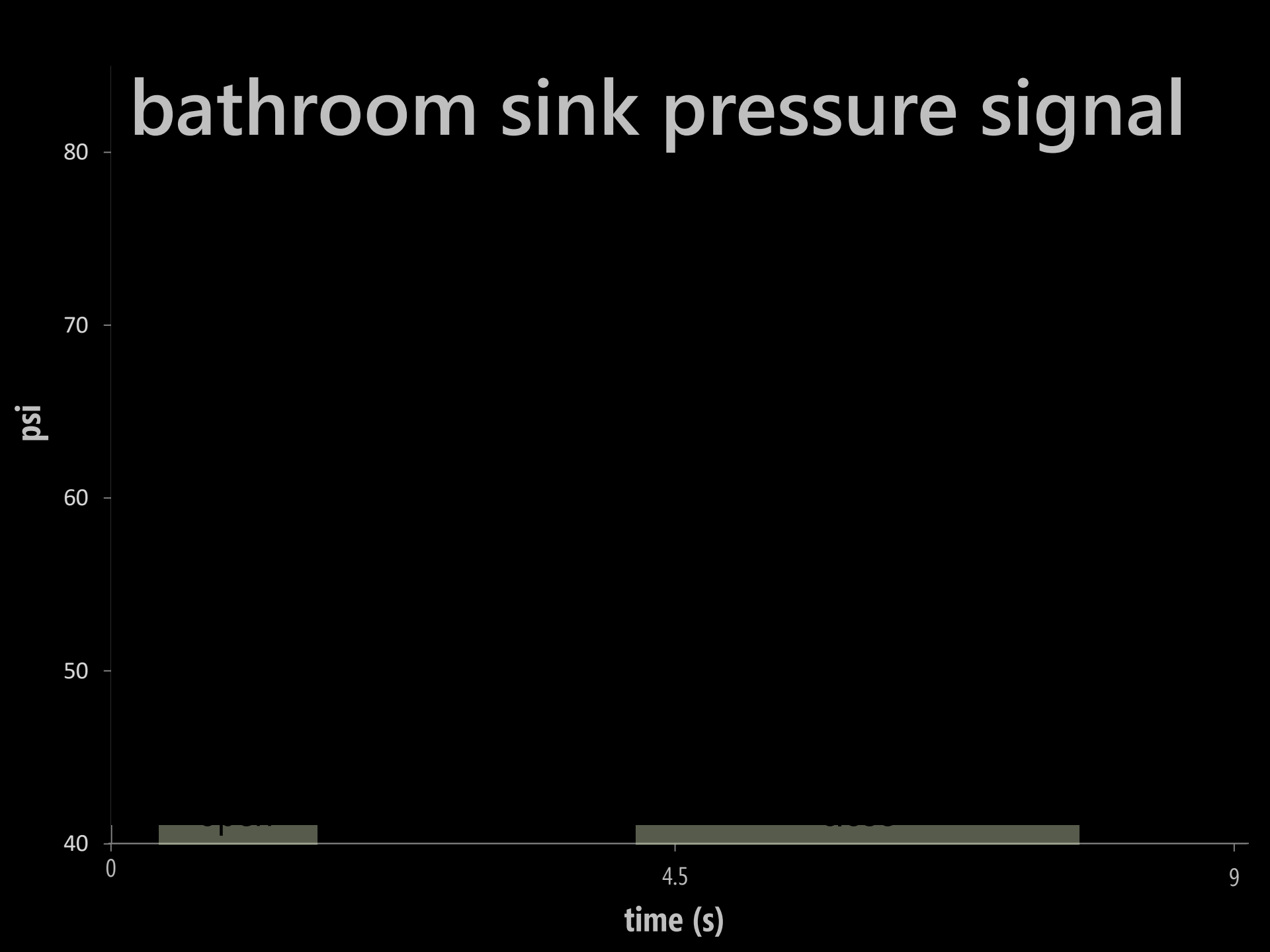

water tower
toilet flushed
bathroom 1
toilet
kitchen
dishwasher
incoming cold water from supply line
utility water meter
pressure regulator
thermal expansion tank
hot water heater
laundry
bathroom 2

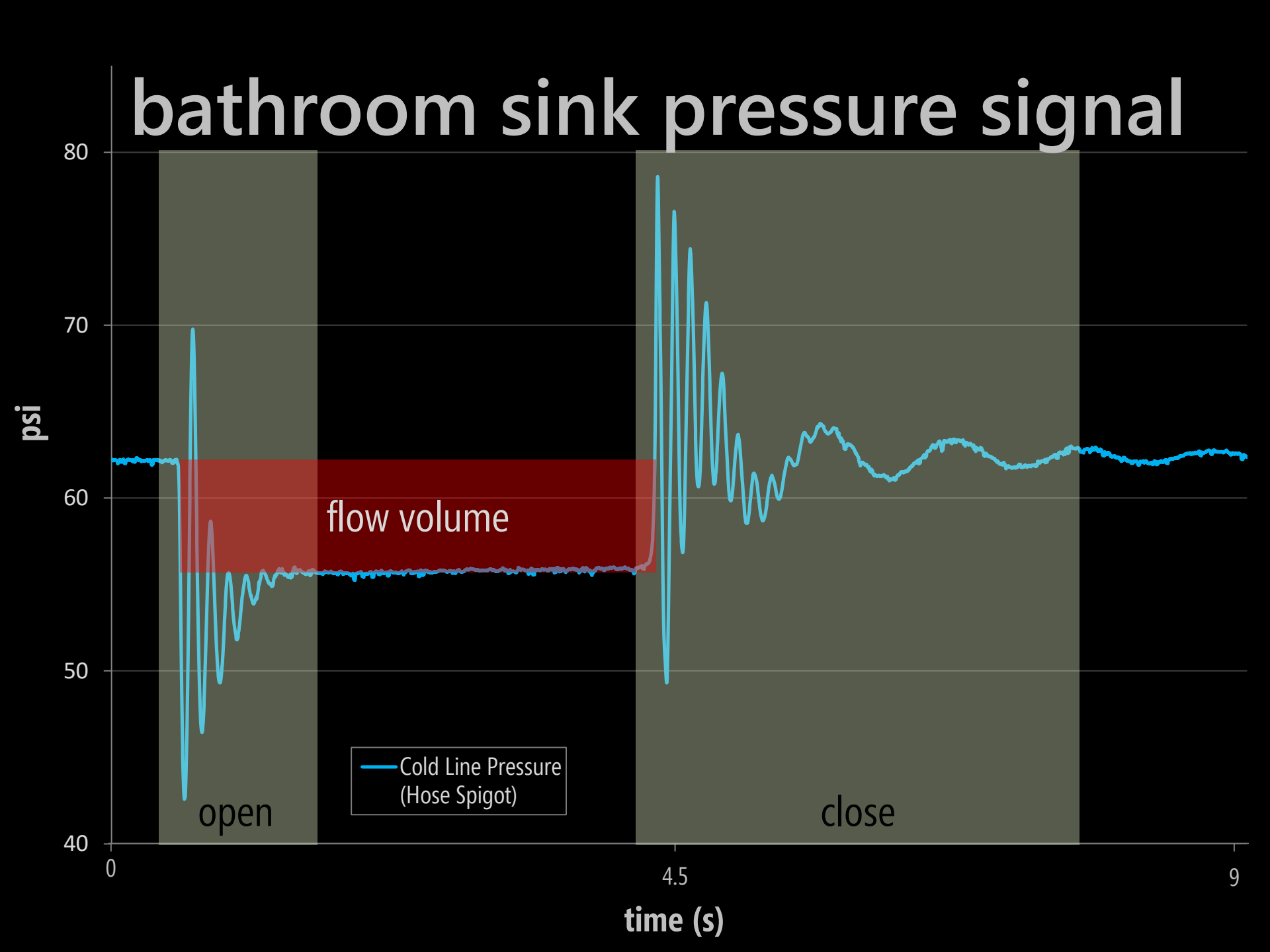

toilet
kitchen sink cold
bathroom 1
kitchen sink cold open
kitchen
dishwasher
incoming cold water from supply line
utility water meter
pressure regulator
thermal expansion tank
hot water heater
laundry
bathroom 2

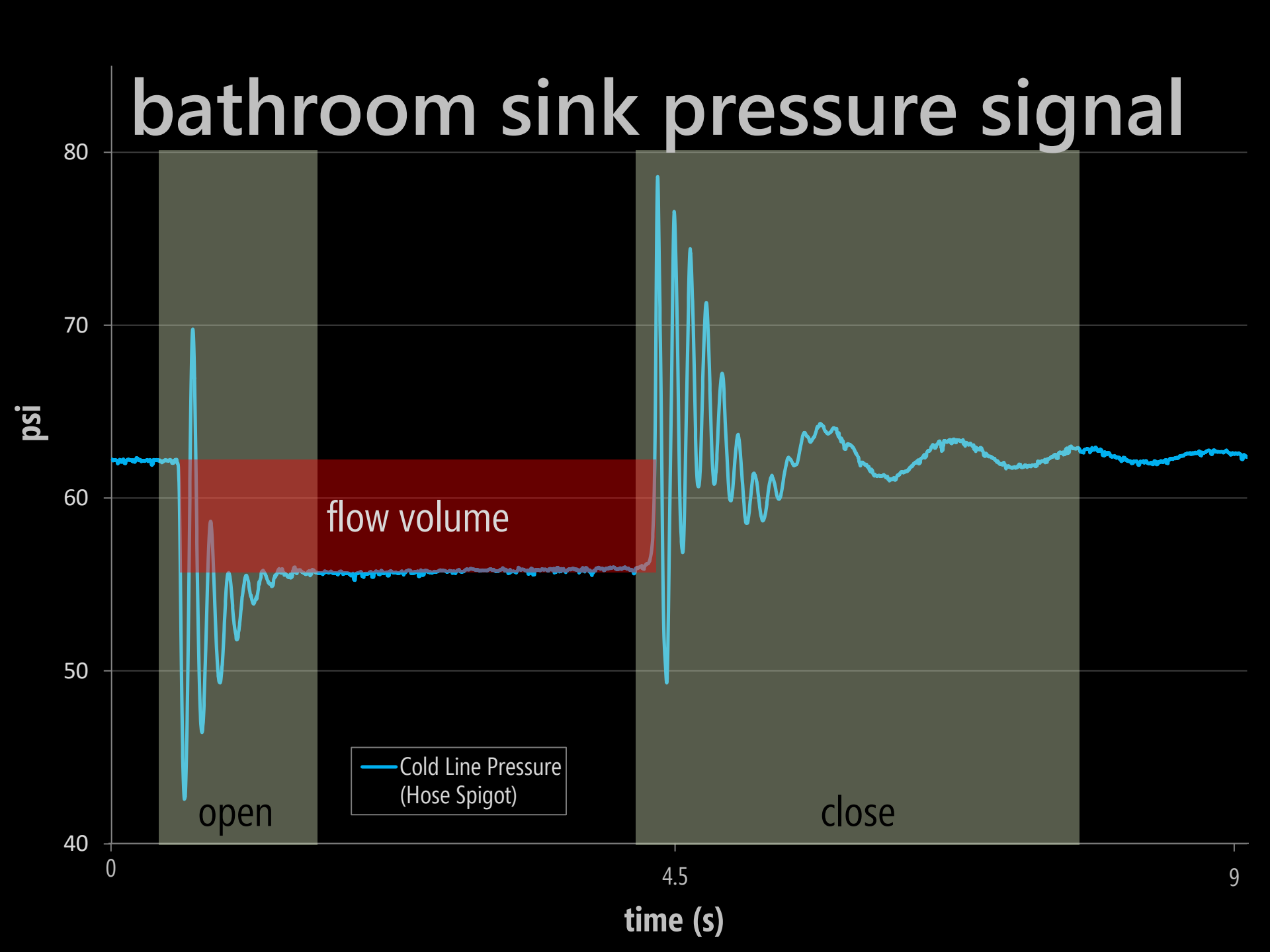

toilet
kitchen sink cold
kitchen sink hot
bathroom 1
kitchen sink hot open
kitchen
dishwasher
incoming cold water from supply line
utility water meter
pressure regulator
thermal expansion tank
hot water heater
laundry
bathroom 2


water tower
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
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 volume
open
close
Cold Line Pressure
(Hose Spigot)
0
4.5
9
time (s)


bathroom sink pressure signal
80
70
60
50
40
psi
flow volume
open
close
Cold Line Pressure
(Hose Spigot)
0
4.5
9
time (s)

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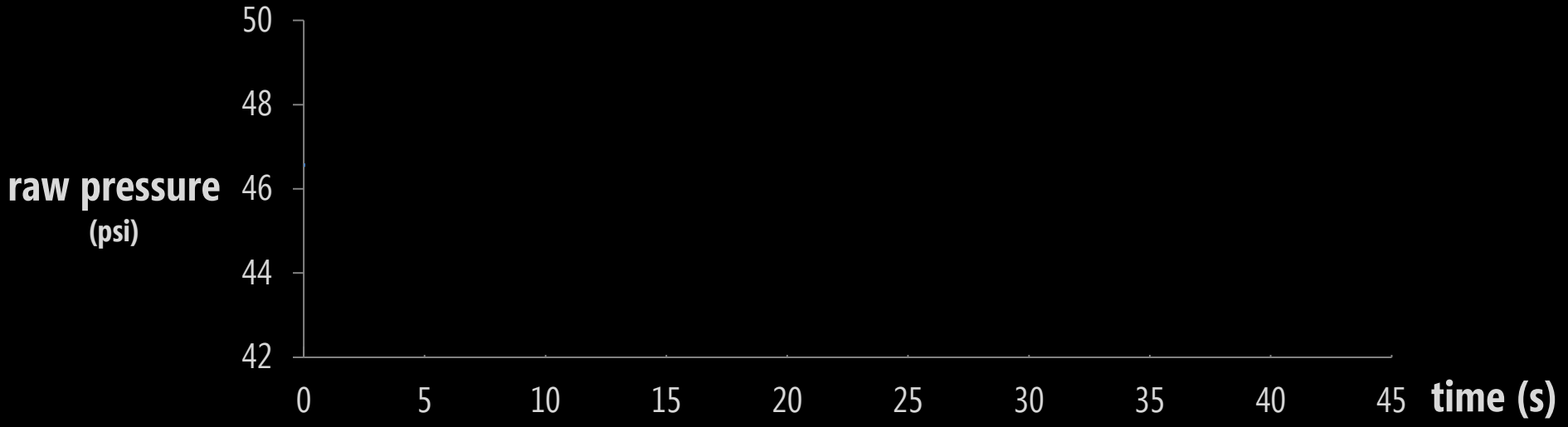
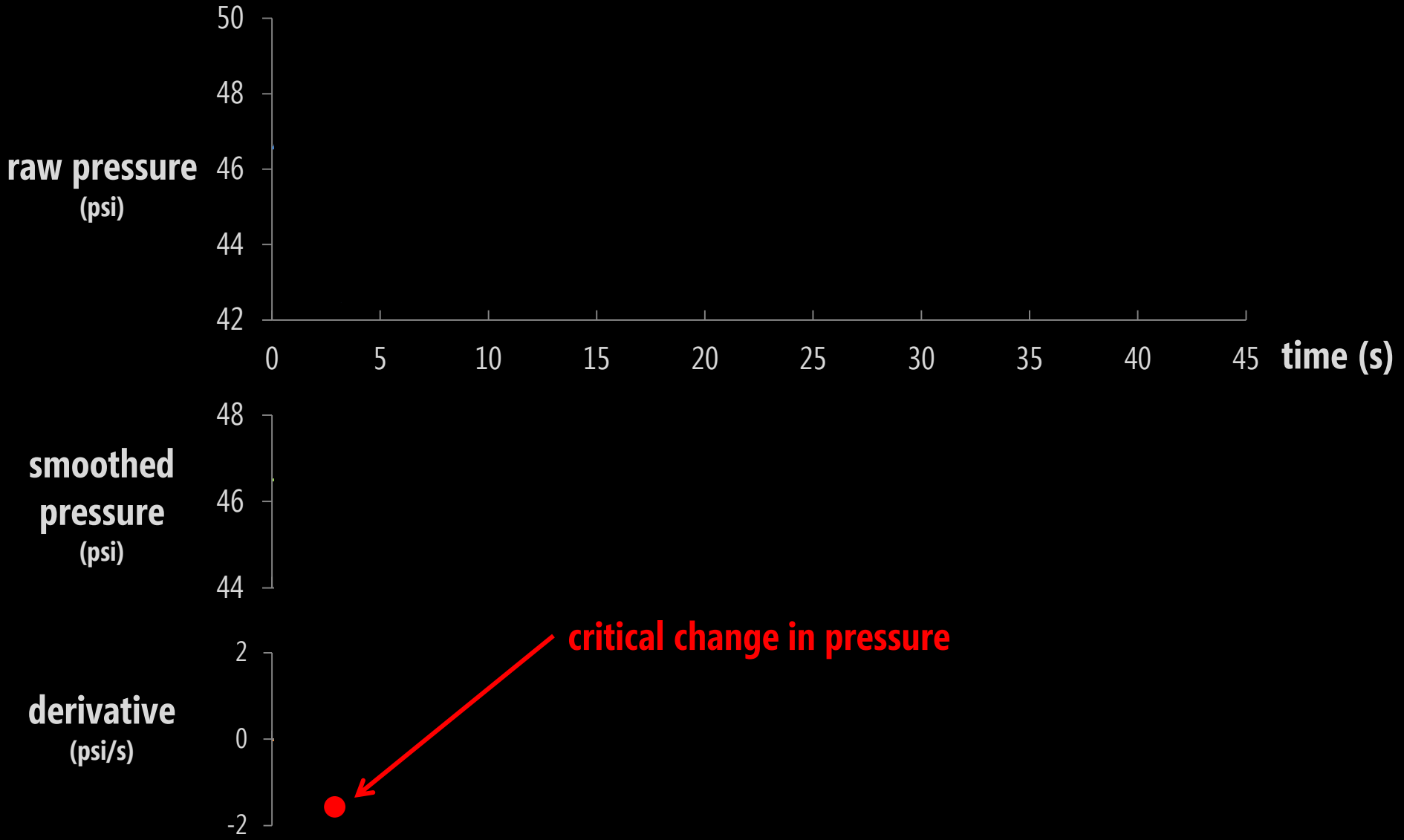
how it works

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

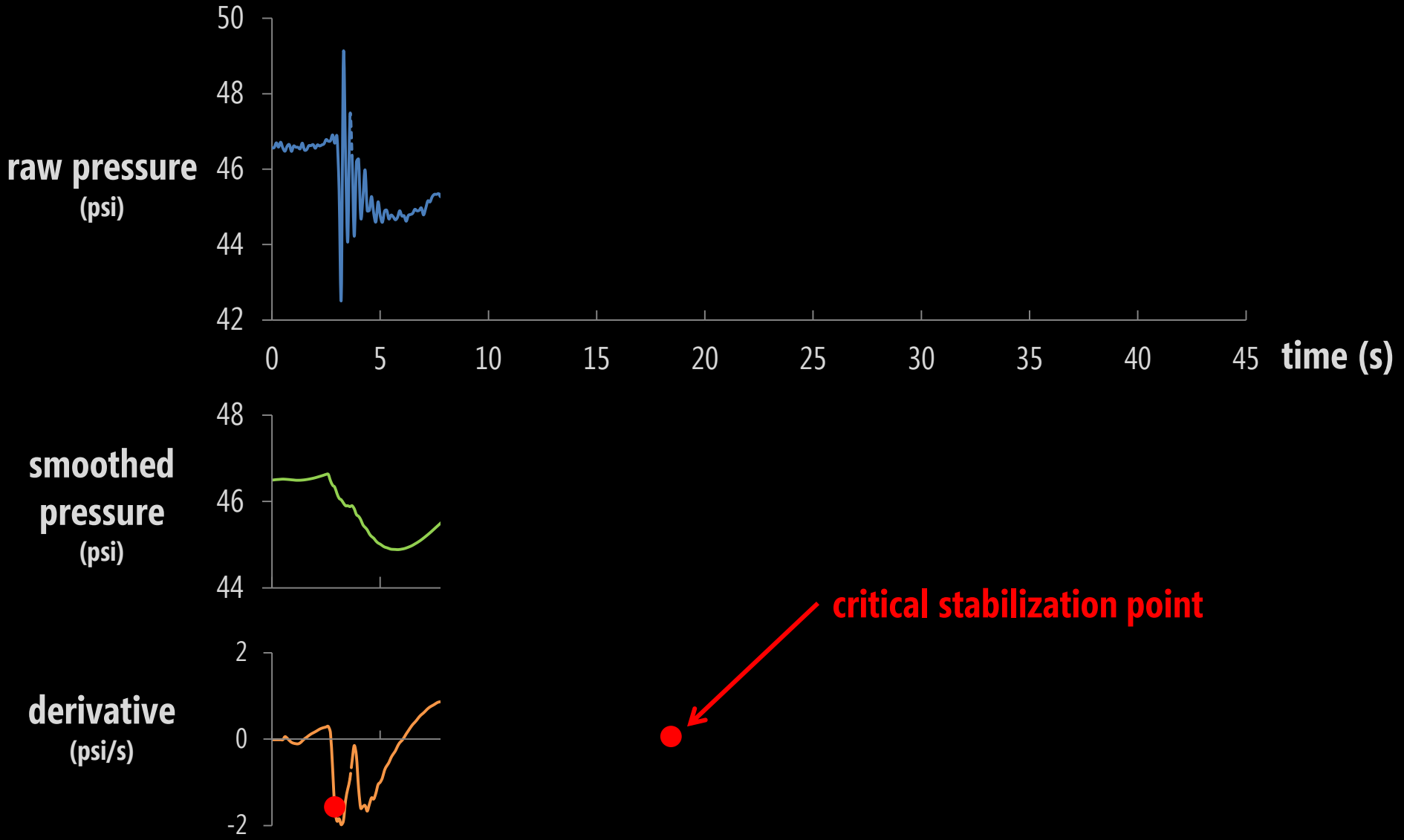
event detection



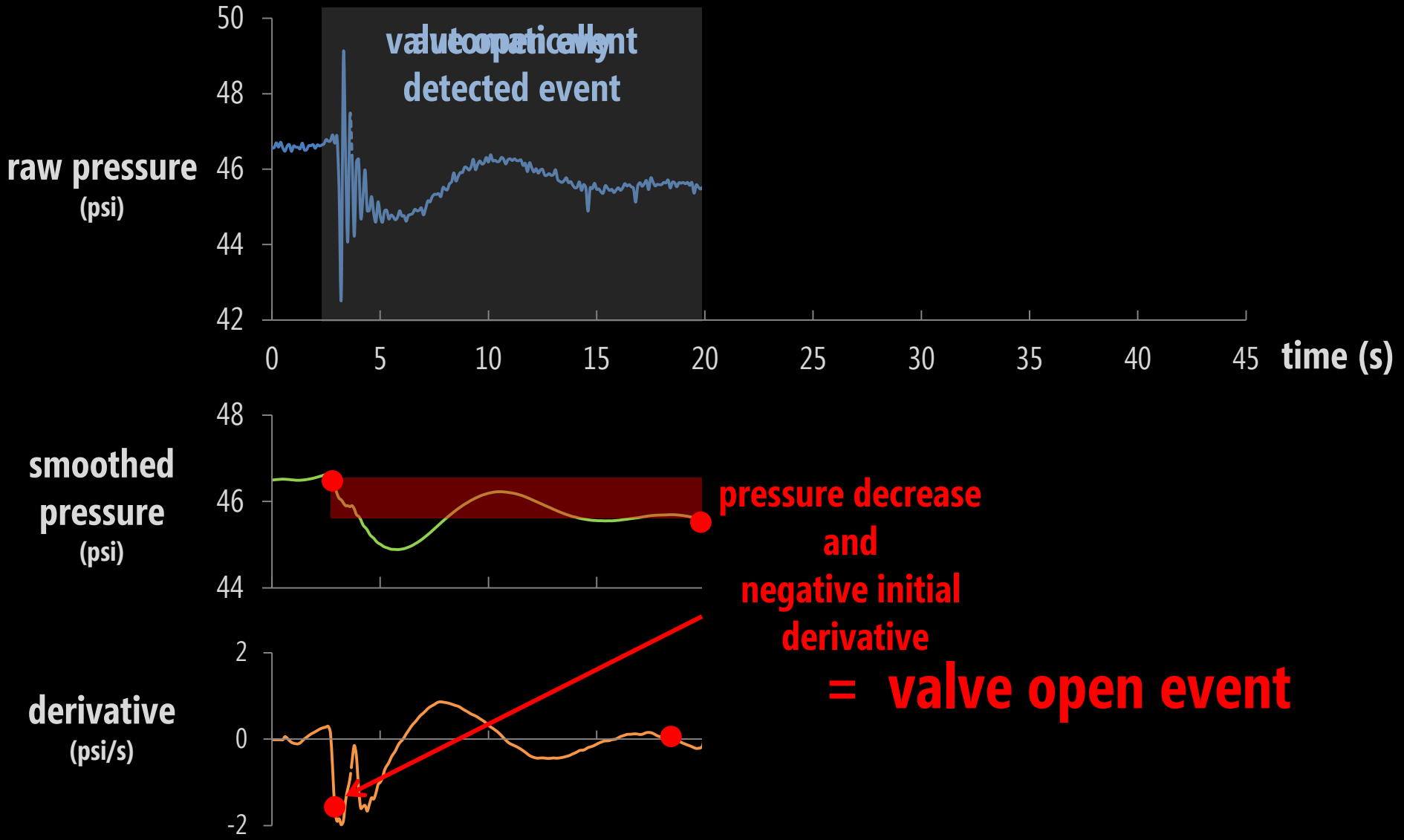
event detection



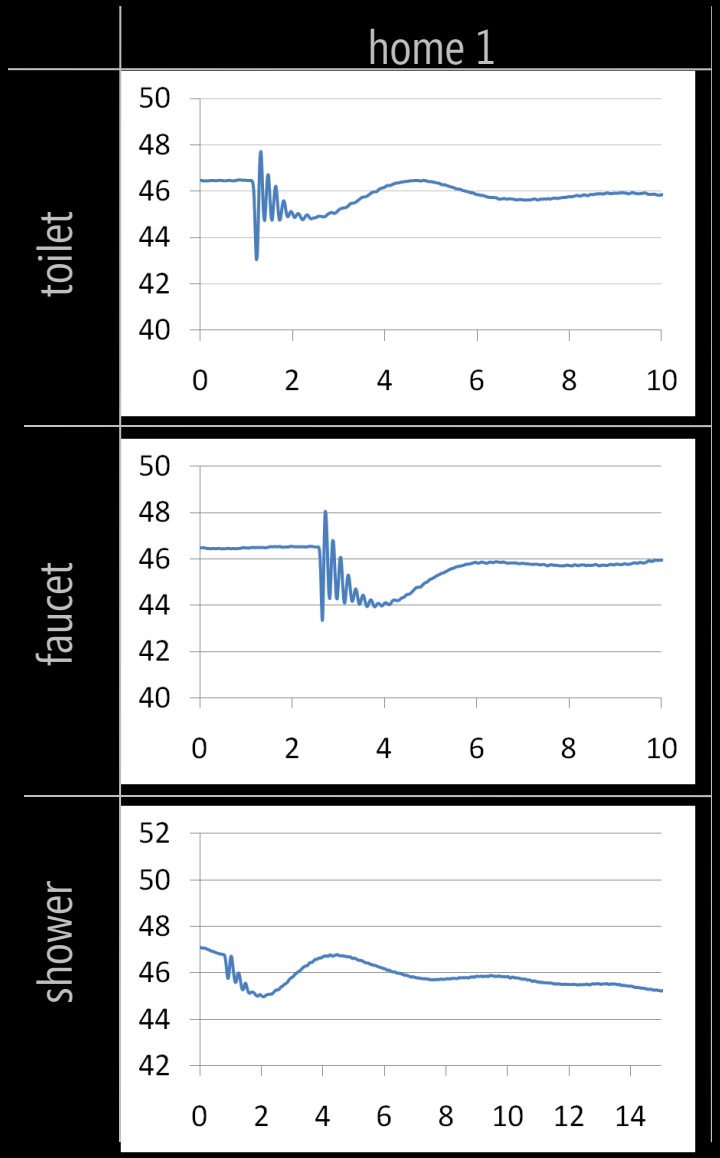
event detection



event detection



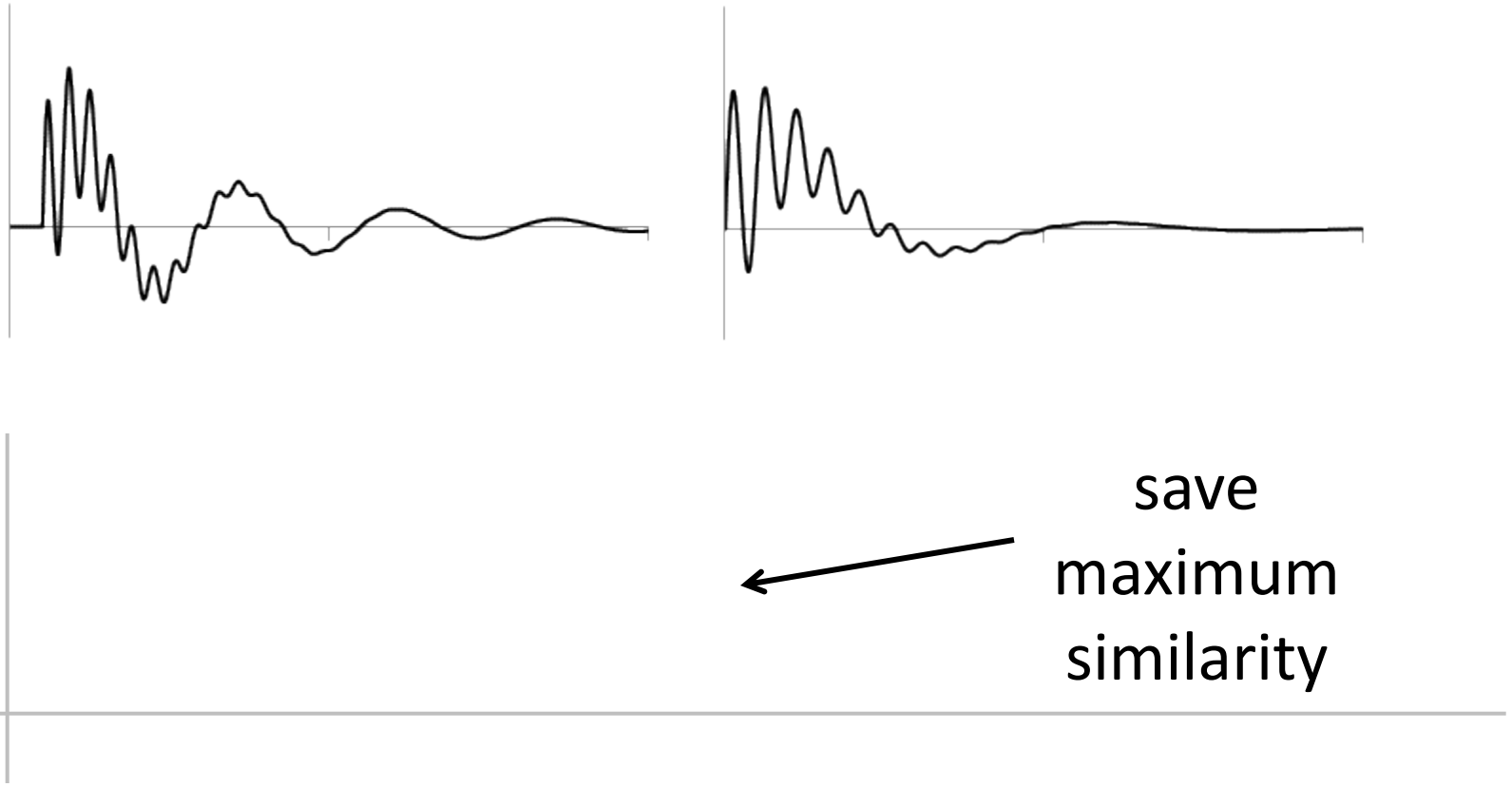
example open events



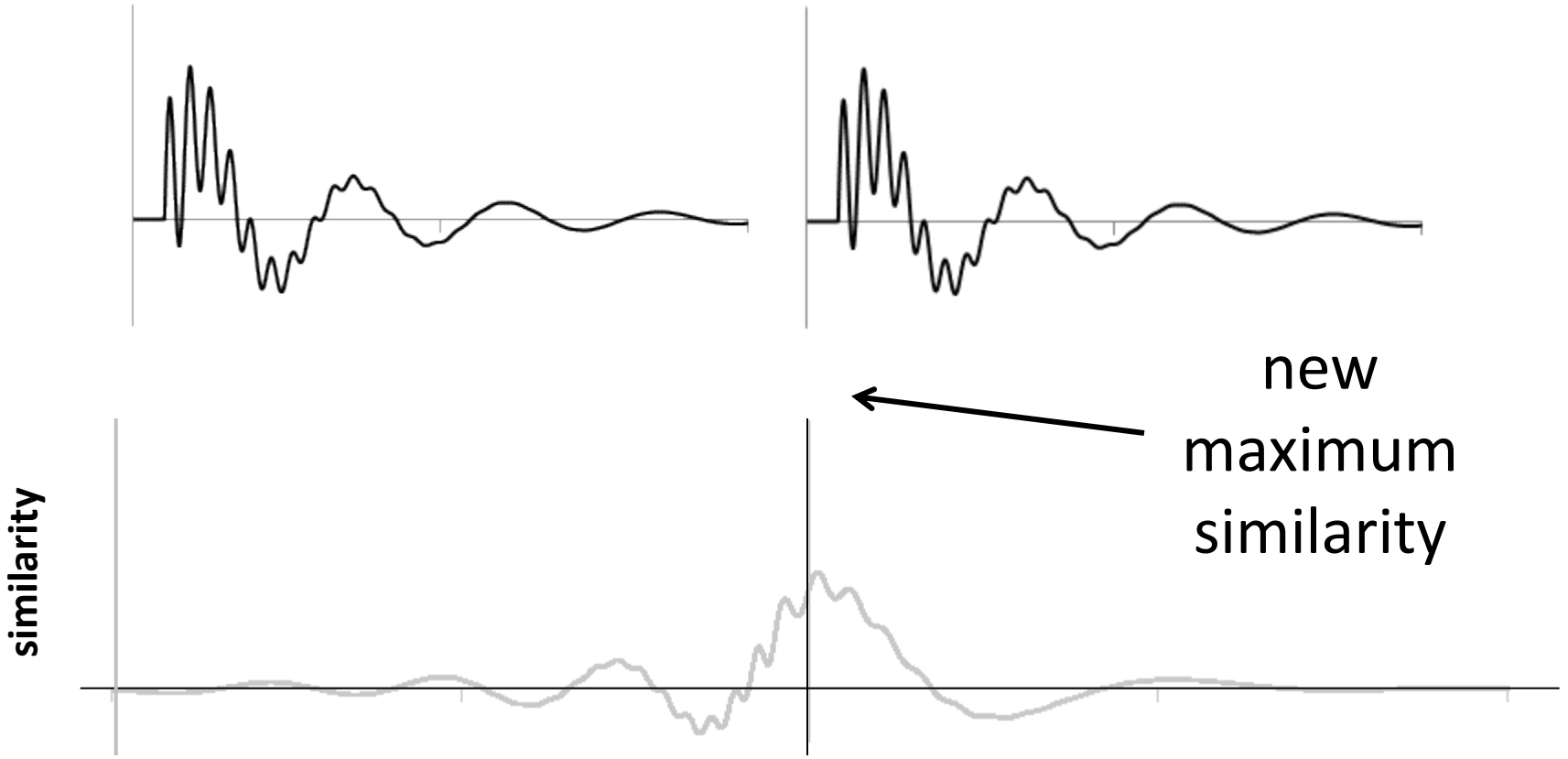
signature dependent on:

- fixture type
- valve type
- valve location in home

matched filtering

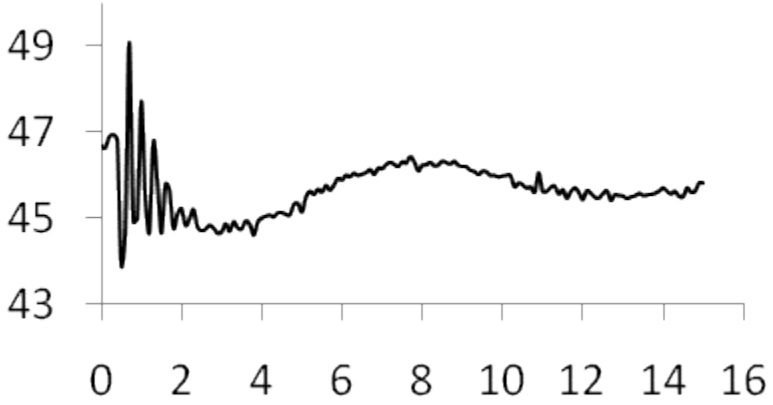


matched filtering

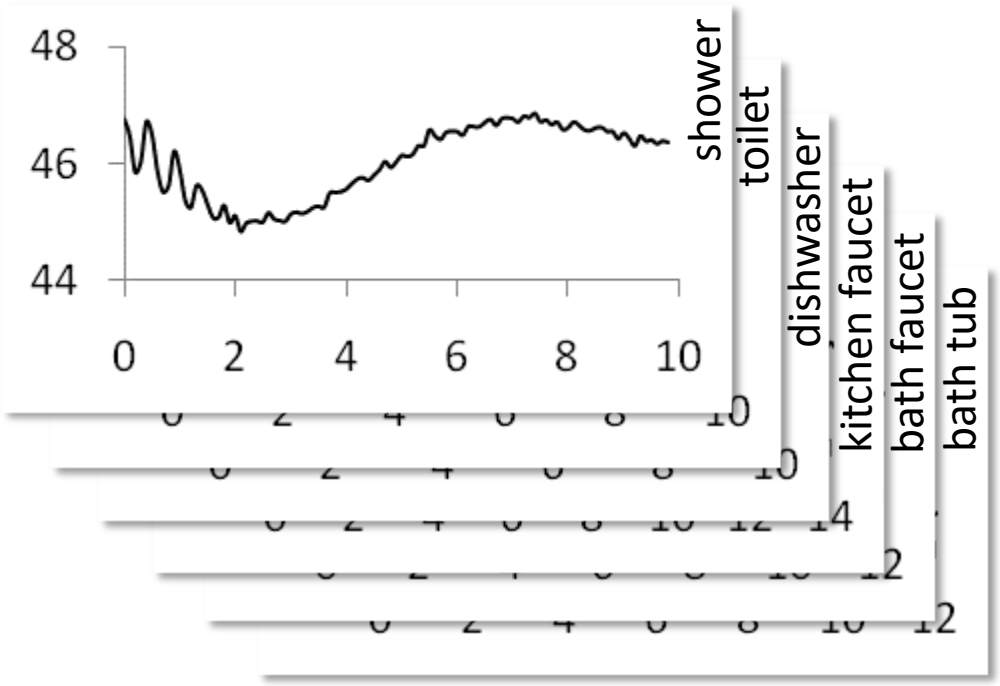


fixture classification

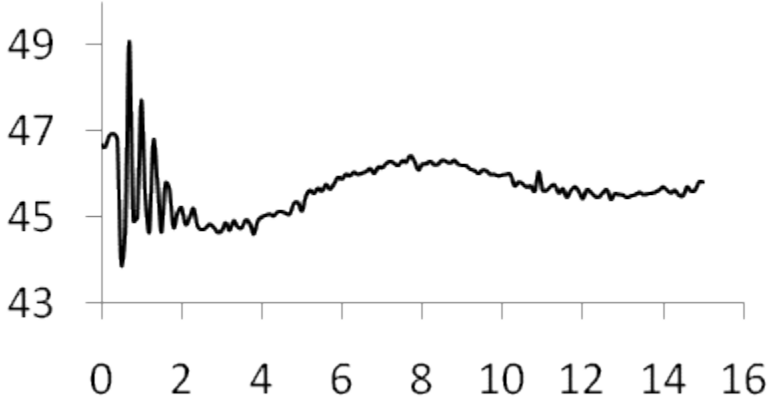
unclassified open event



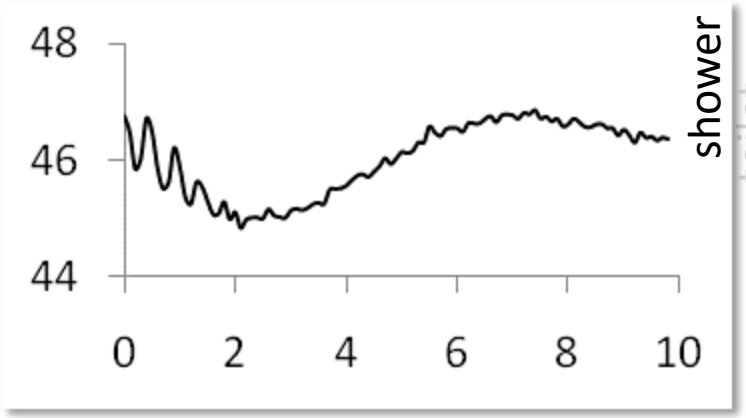
open event library

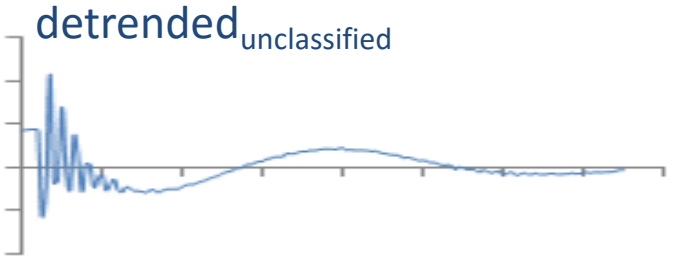


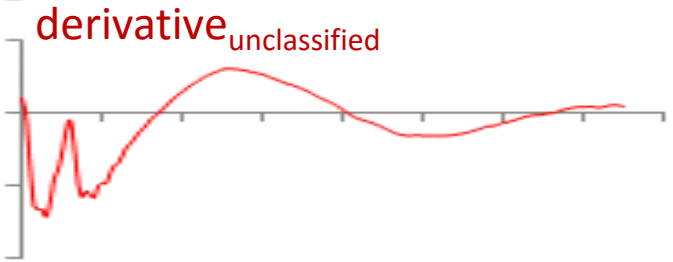
unclassified open event

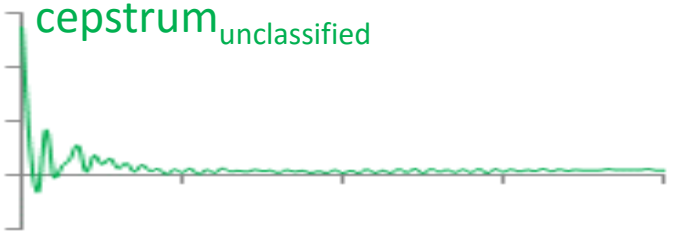


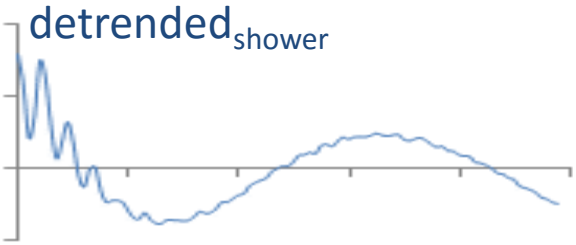
open event library

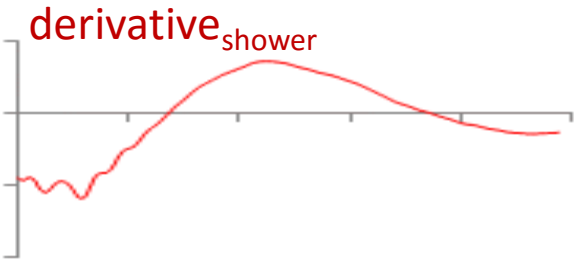


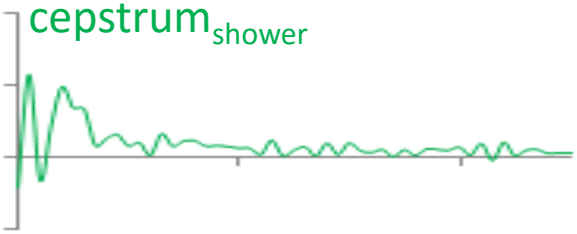


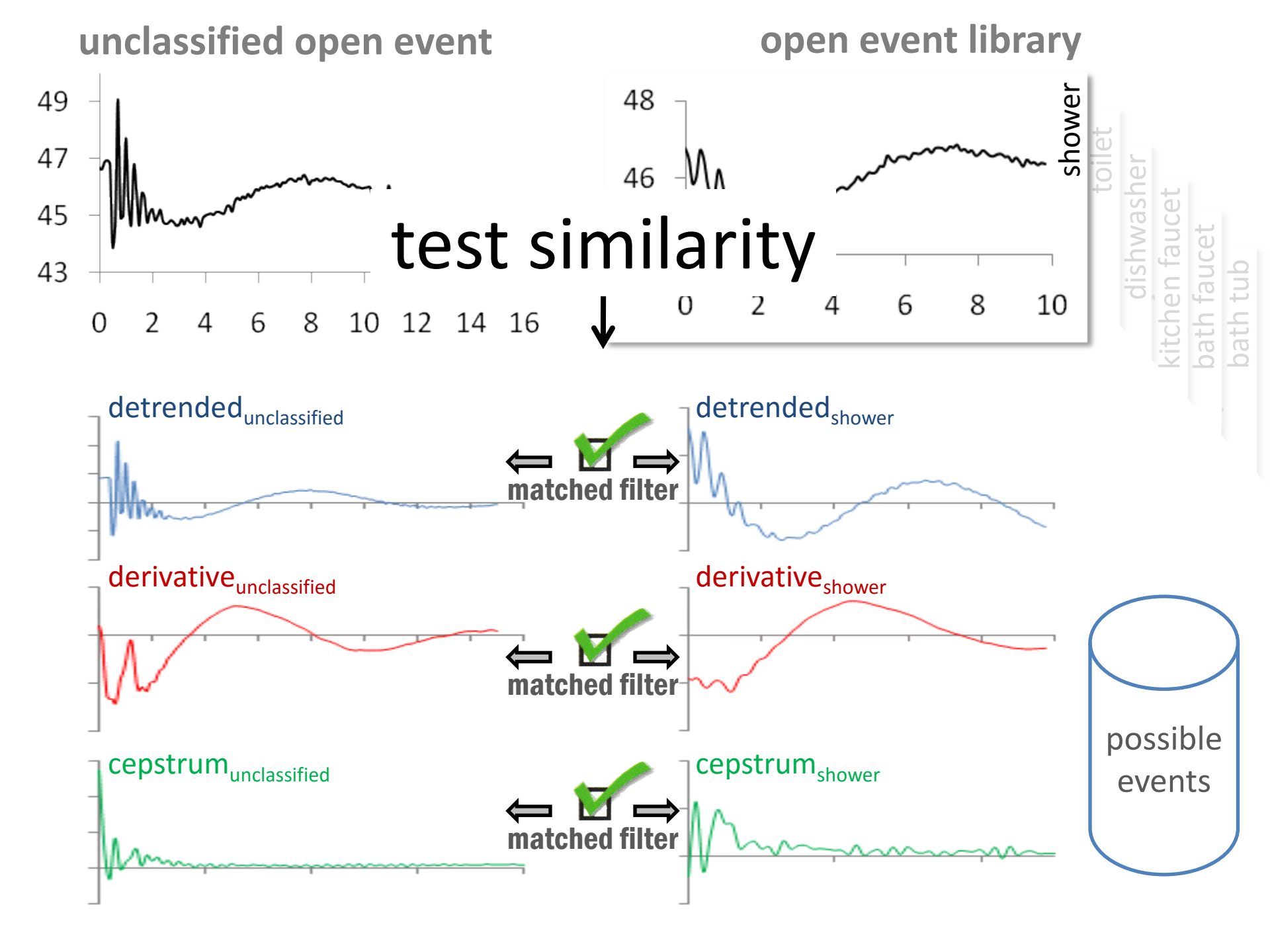




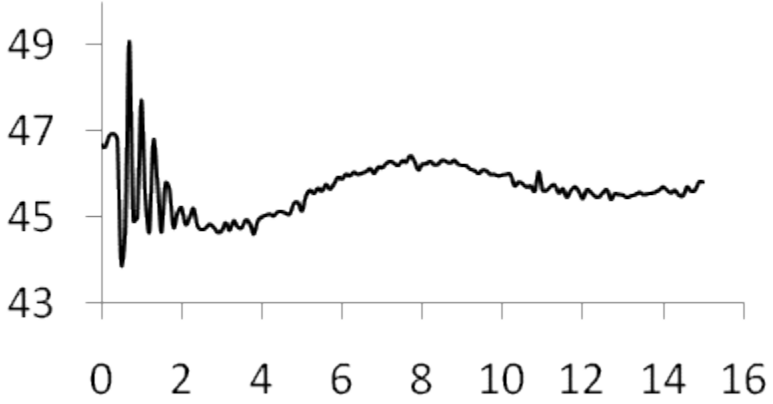




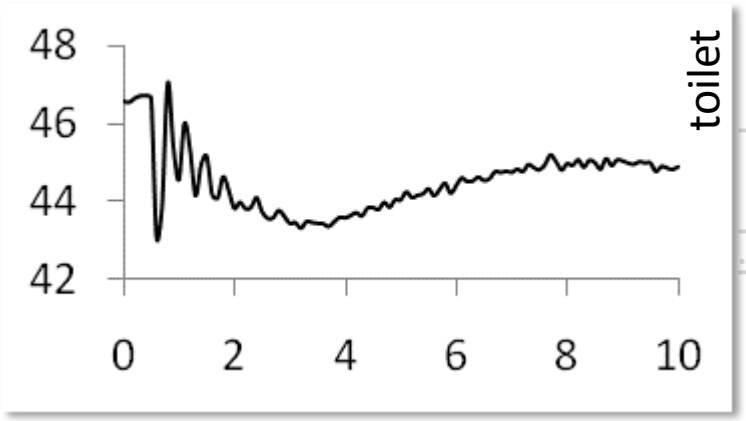


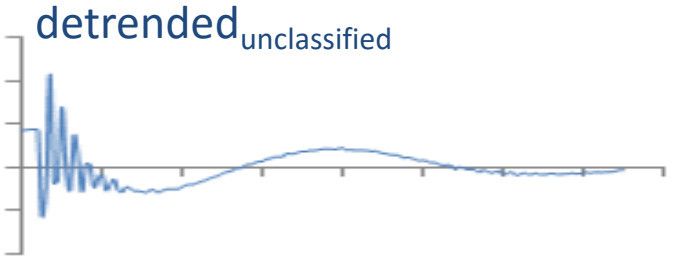

unclassified open event
open event library
49
47
45
43
0 2 4 6 8 10 12 14 16
48
46
0 2 4 6 8 10
shower
toilet
dishwasher
kitchen faucet
bath faucet
bath tub
test similarity
detrended unclassified
detrended shower
matched filter
derivative unclassified
derivative shower
matched filter
cepstrum unclassified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

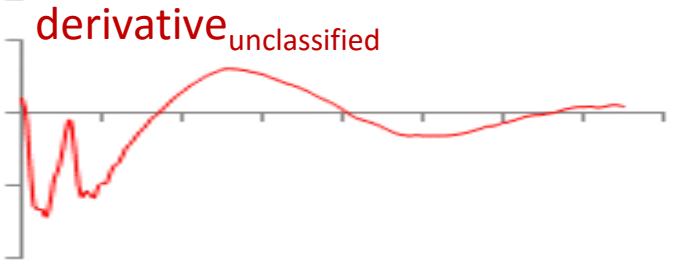
unclassified open event

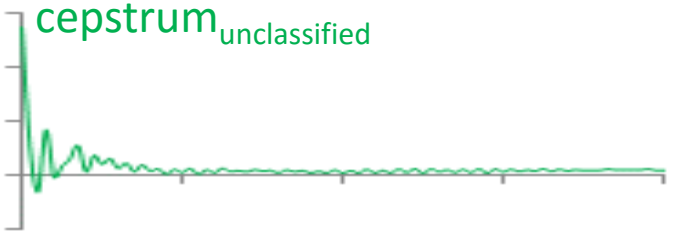


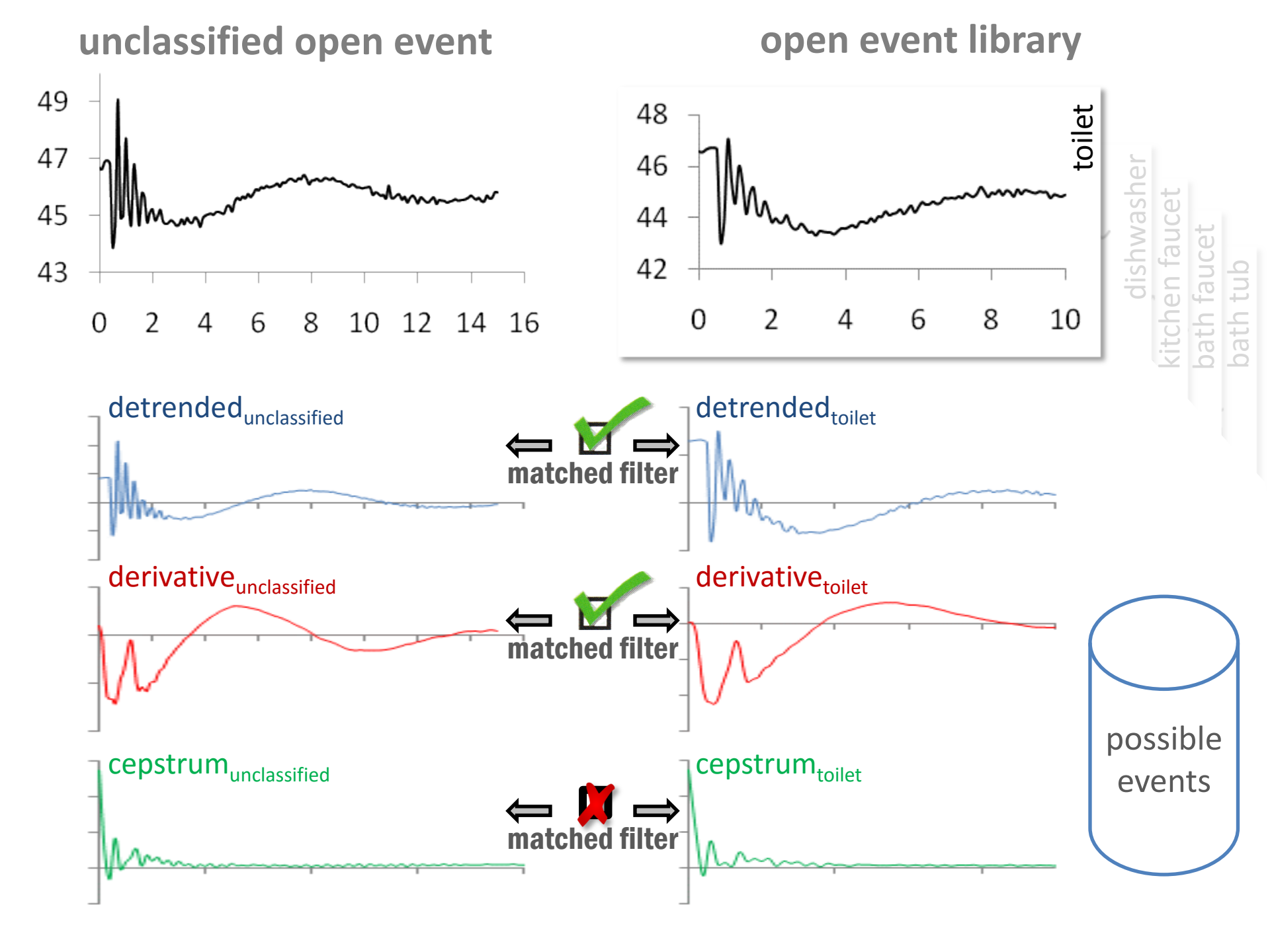
open event library



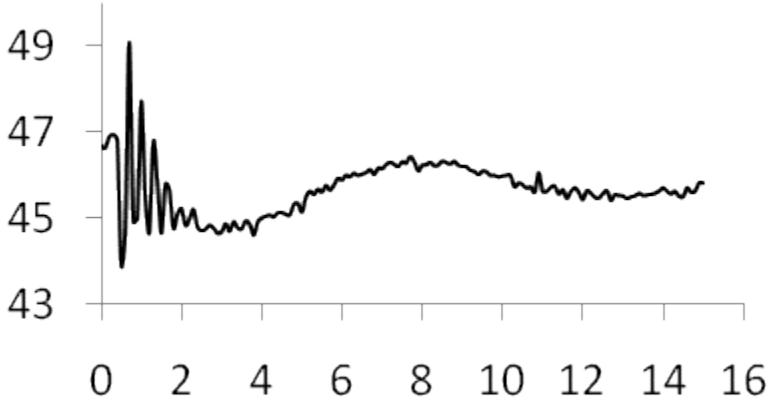


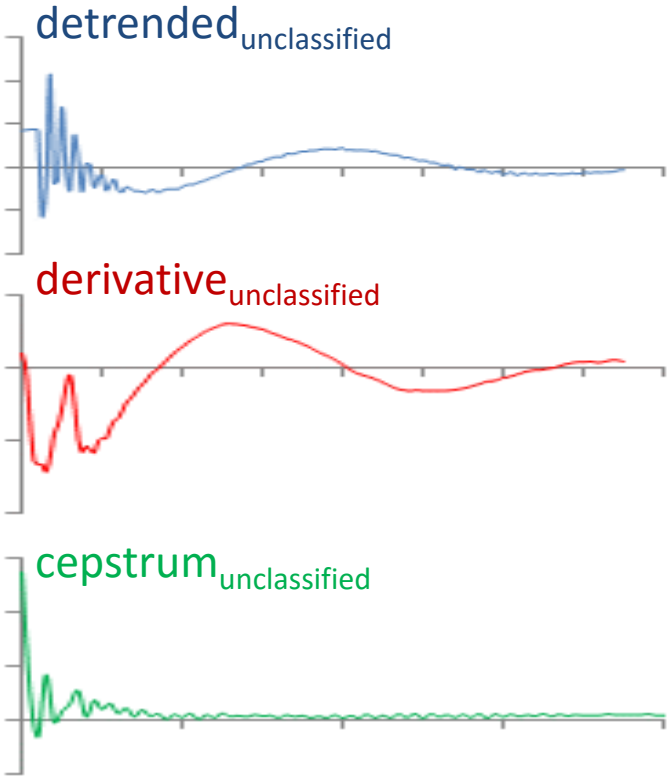





unclassified open event
open event library
49
47
45
43
0 2 4 6 8 10 12 14 16
48
46
44
42
0 2 4 6 8 10
toilet
dishwasher
kitchen faucet
bath faucet
bath tub
detrended unclassified
matched filter
detrended toilet
derivative unclassified
matched filter
derivative toilet
cepstrum unclassified
matched filter
cepstrum toilet
possible events

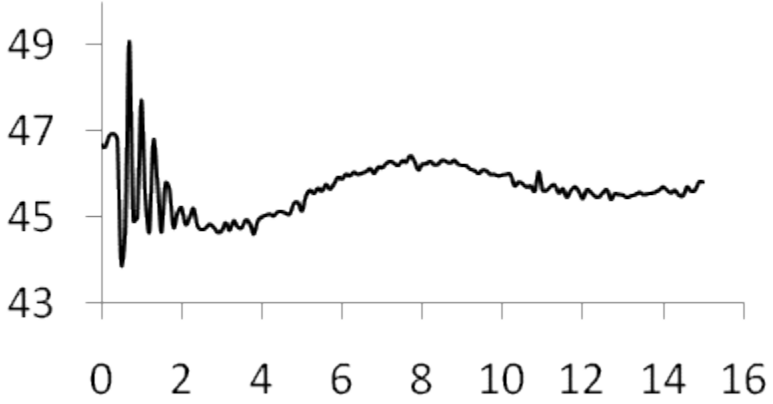
unclassified open event

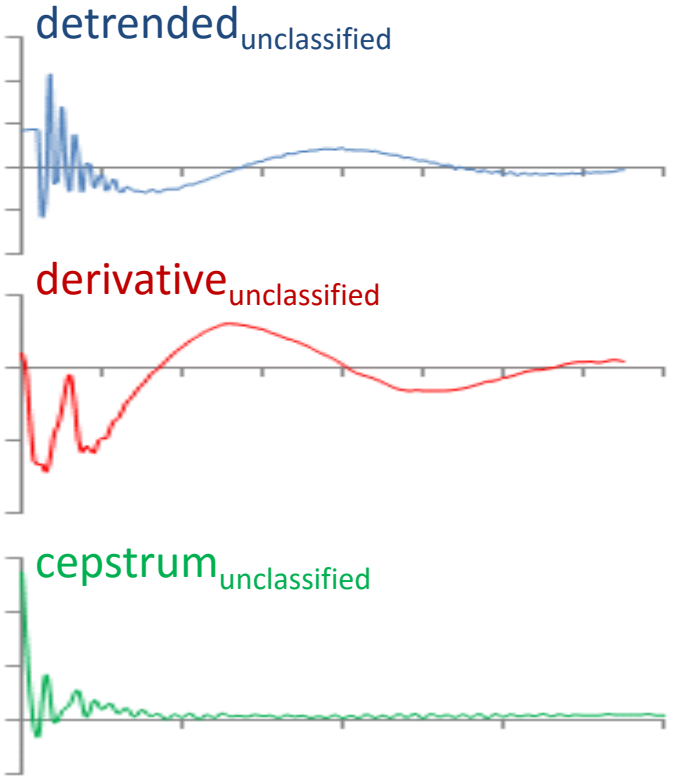




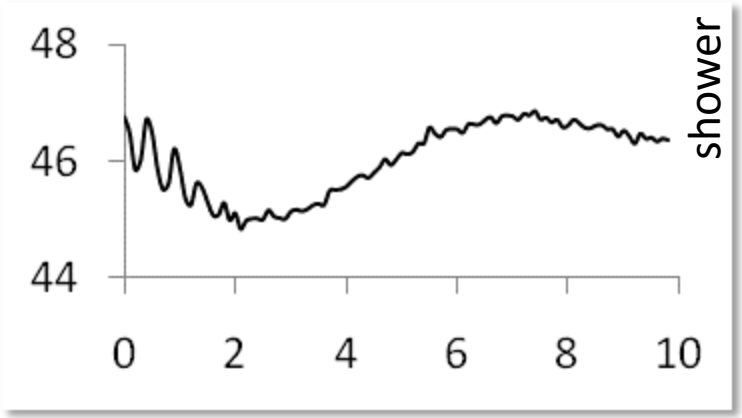
open event library

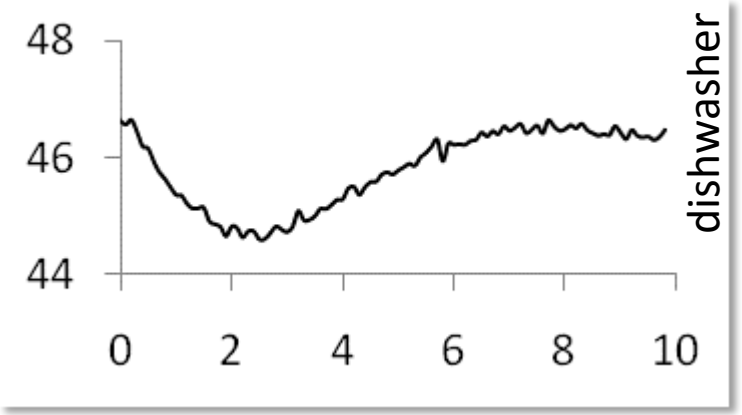
unclassified open event

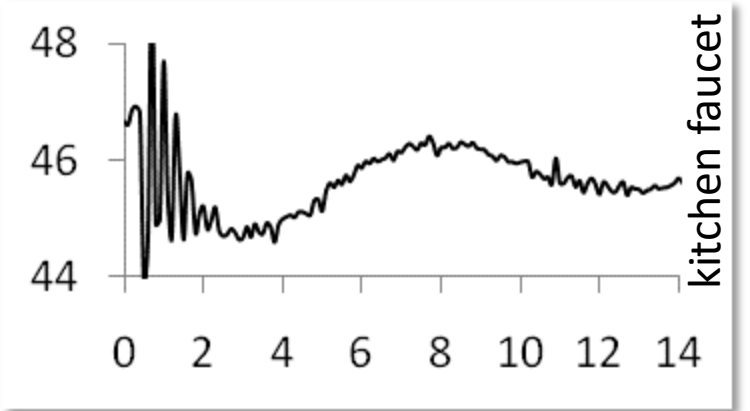




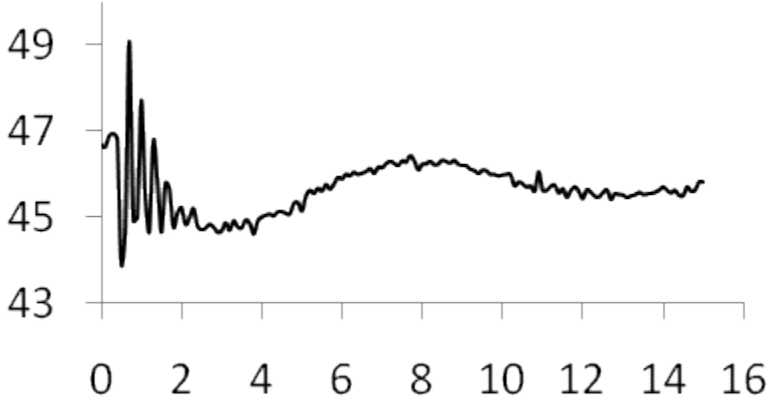
open event library

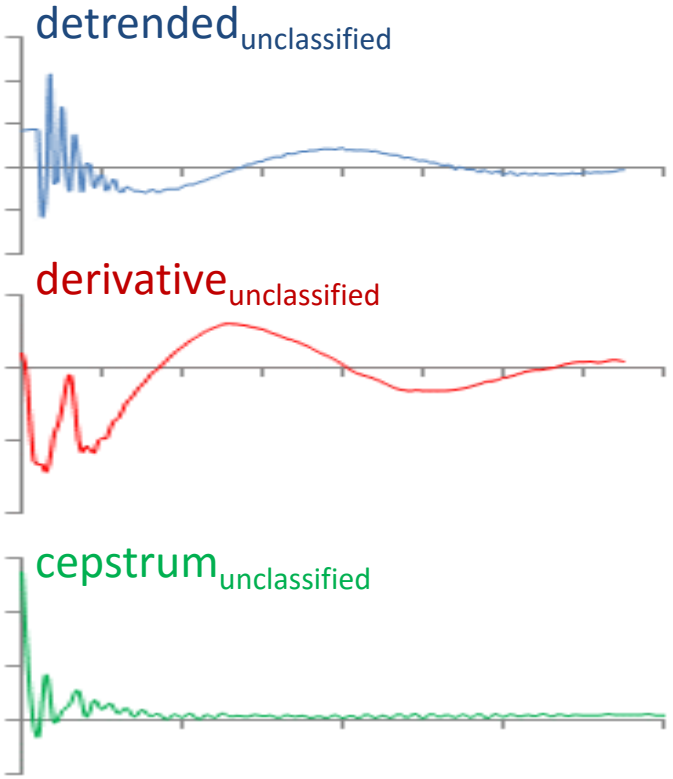




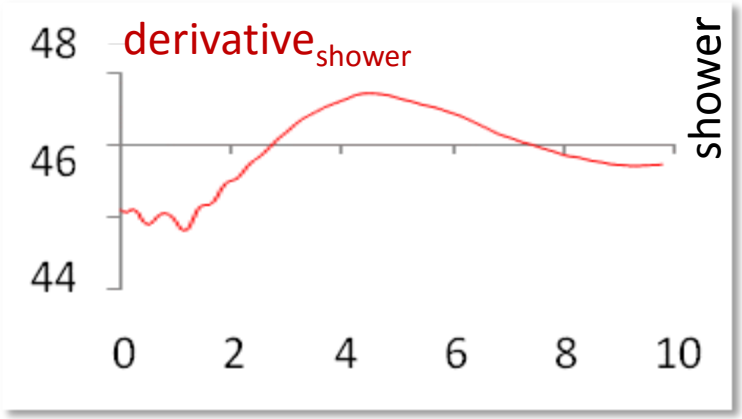


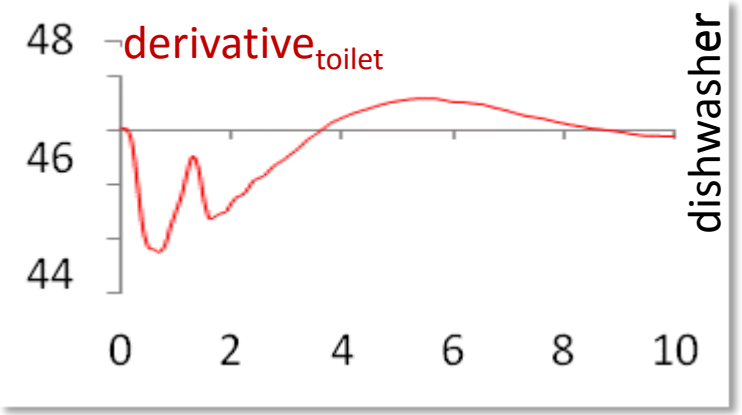
unclassified open event

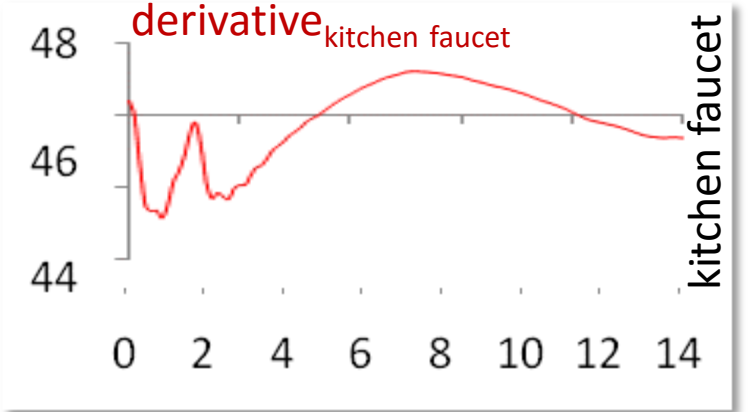


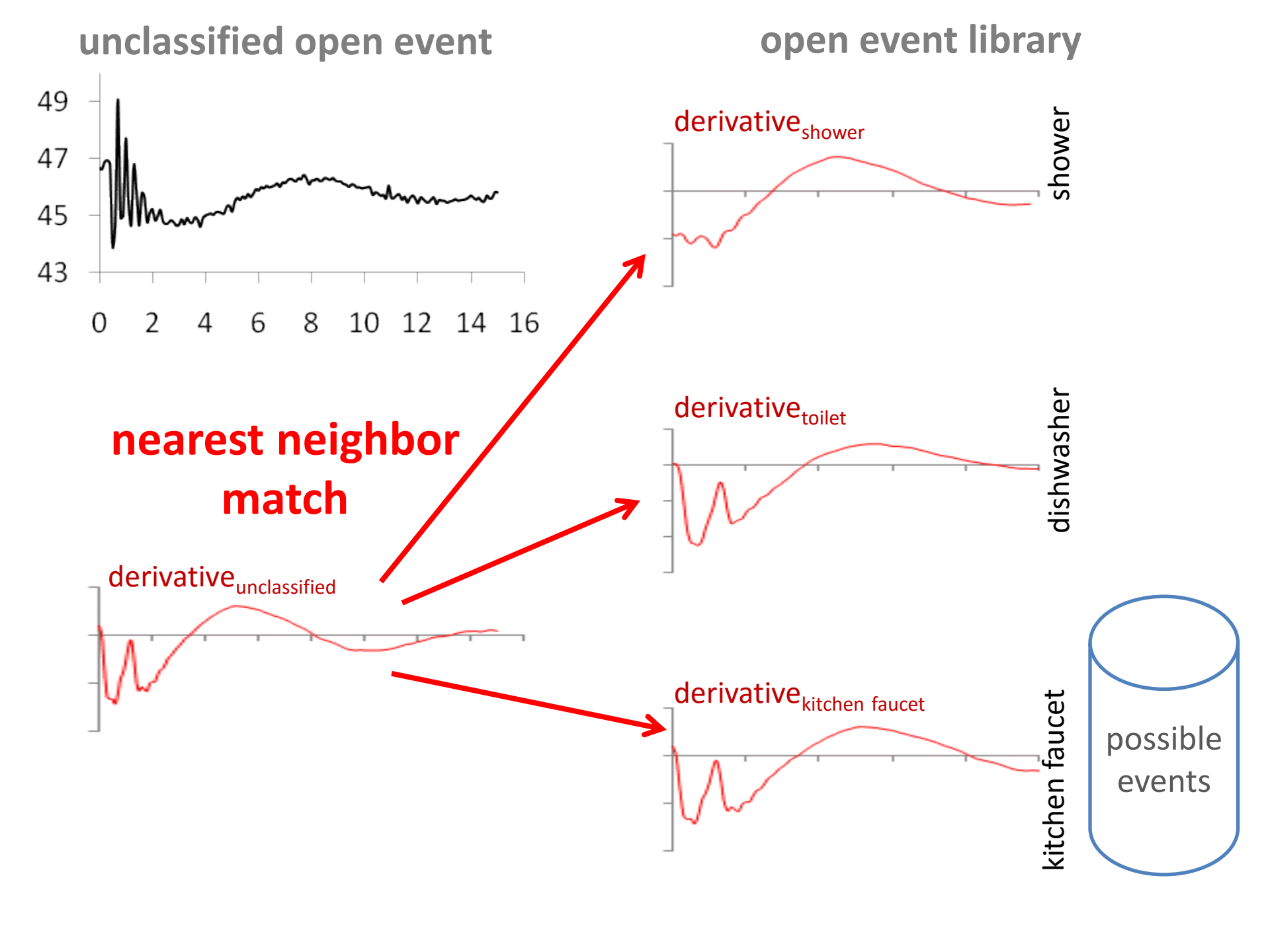


open event library








unclassified open event
open event library
49
47
45
43
0
2
4
6
8
10
12
14
16
derivative shower
shower
derivative toilet
dishwasher
nearest neighbor match
derivative unclassified
derivative kitchen faucet
kitchen faucet
possible events

evaluation

home profiles

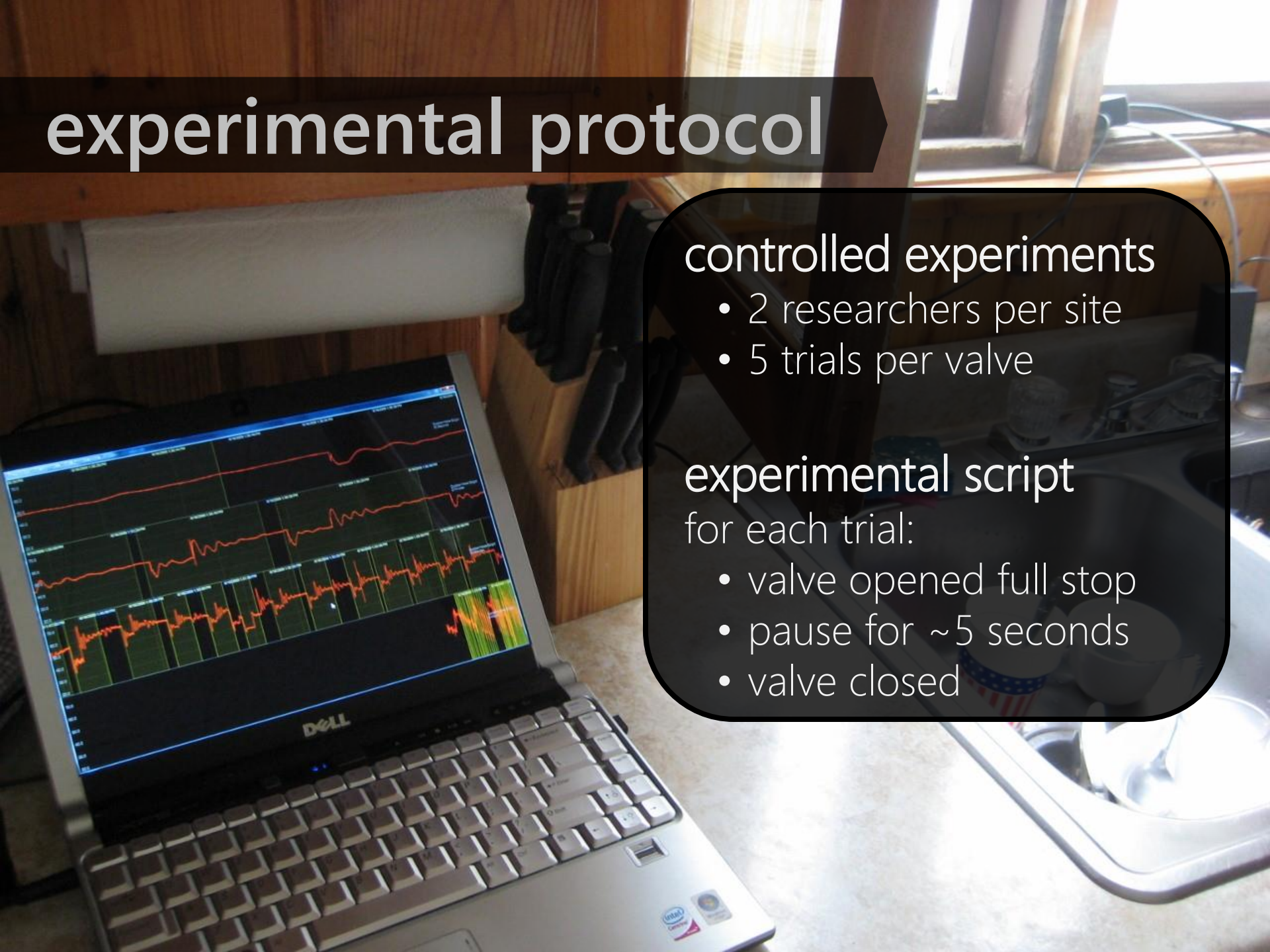
ten test locations

- 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

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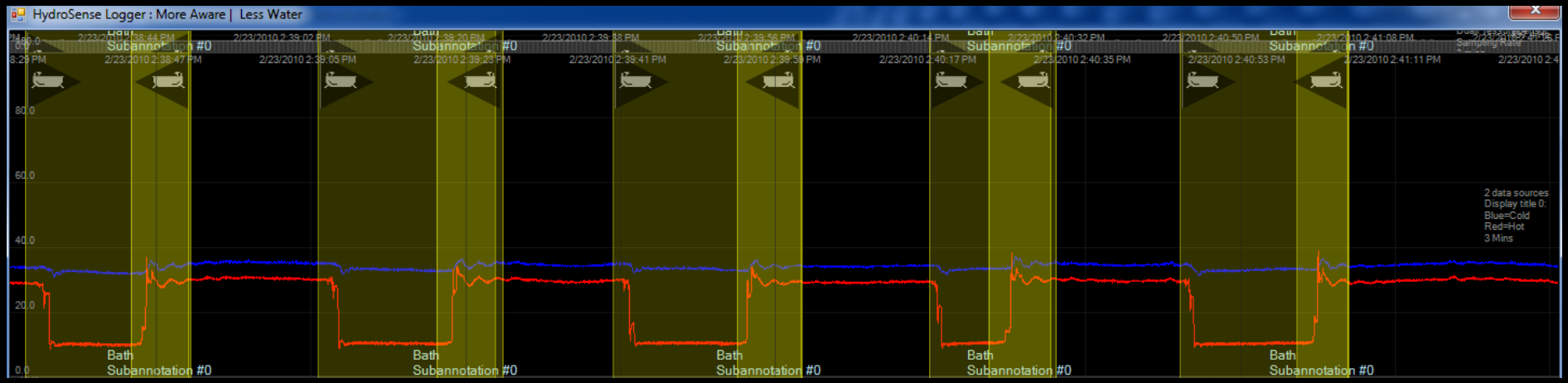
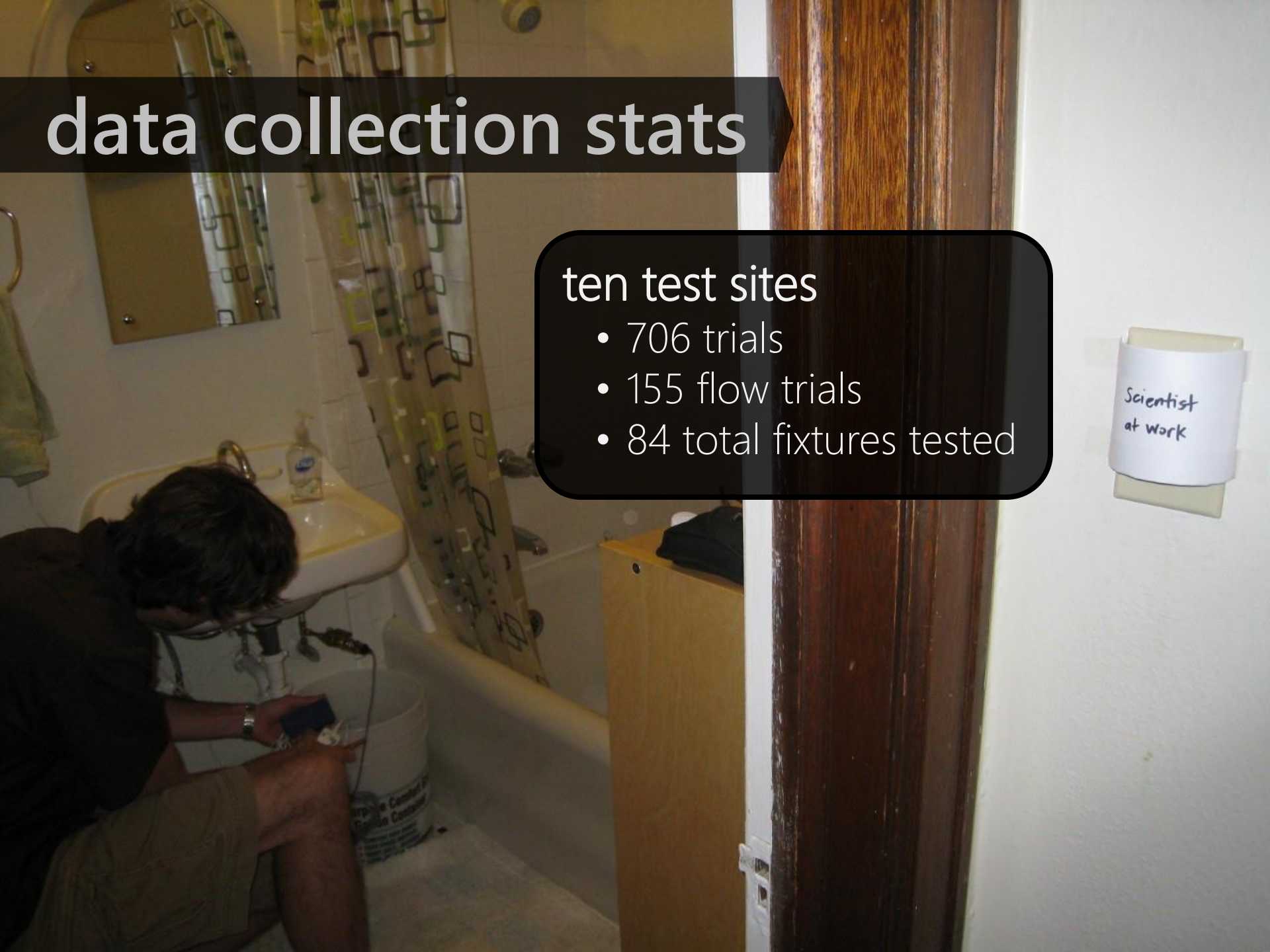
5 manually annotated bath trials



data collection stats

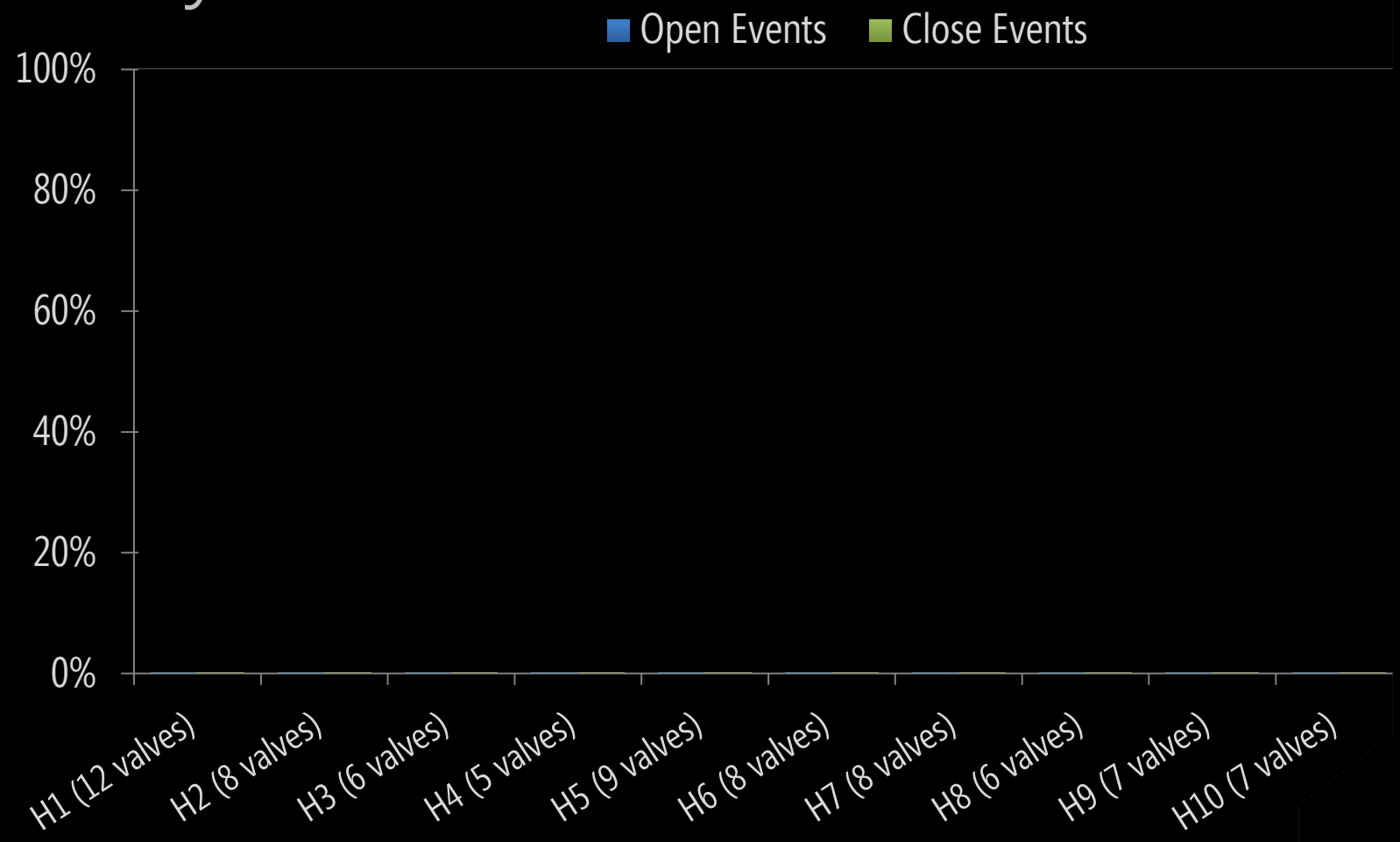


ten test sites

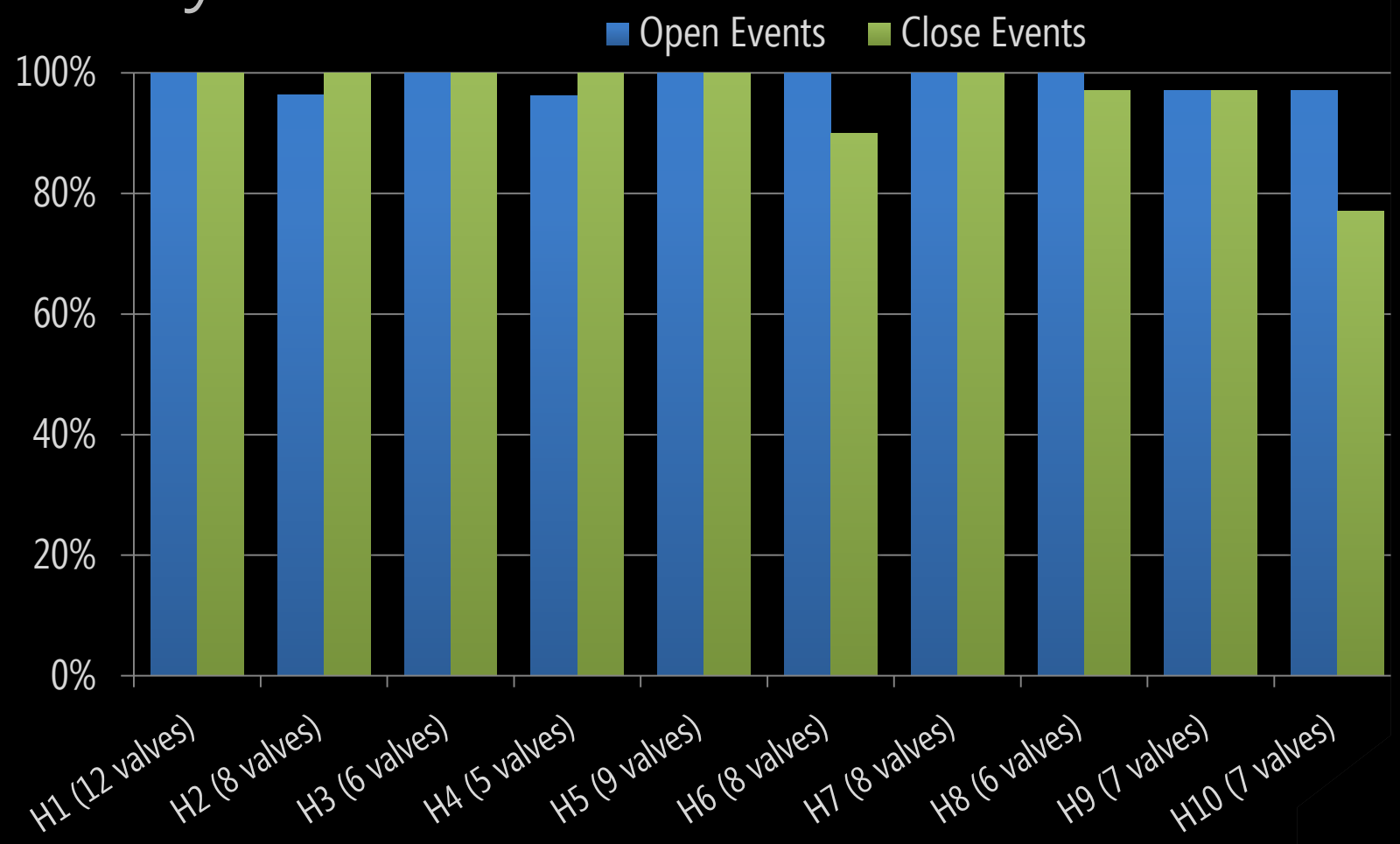
- 706 trials
- 155 flow trials
- 84 total fixtures tested

fixture classification results

by home

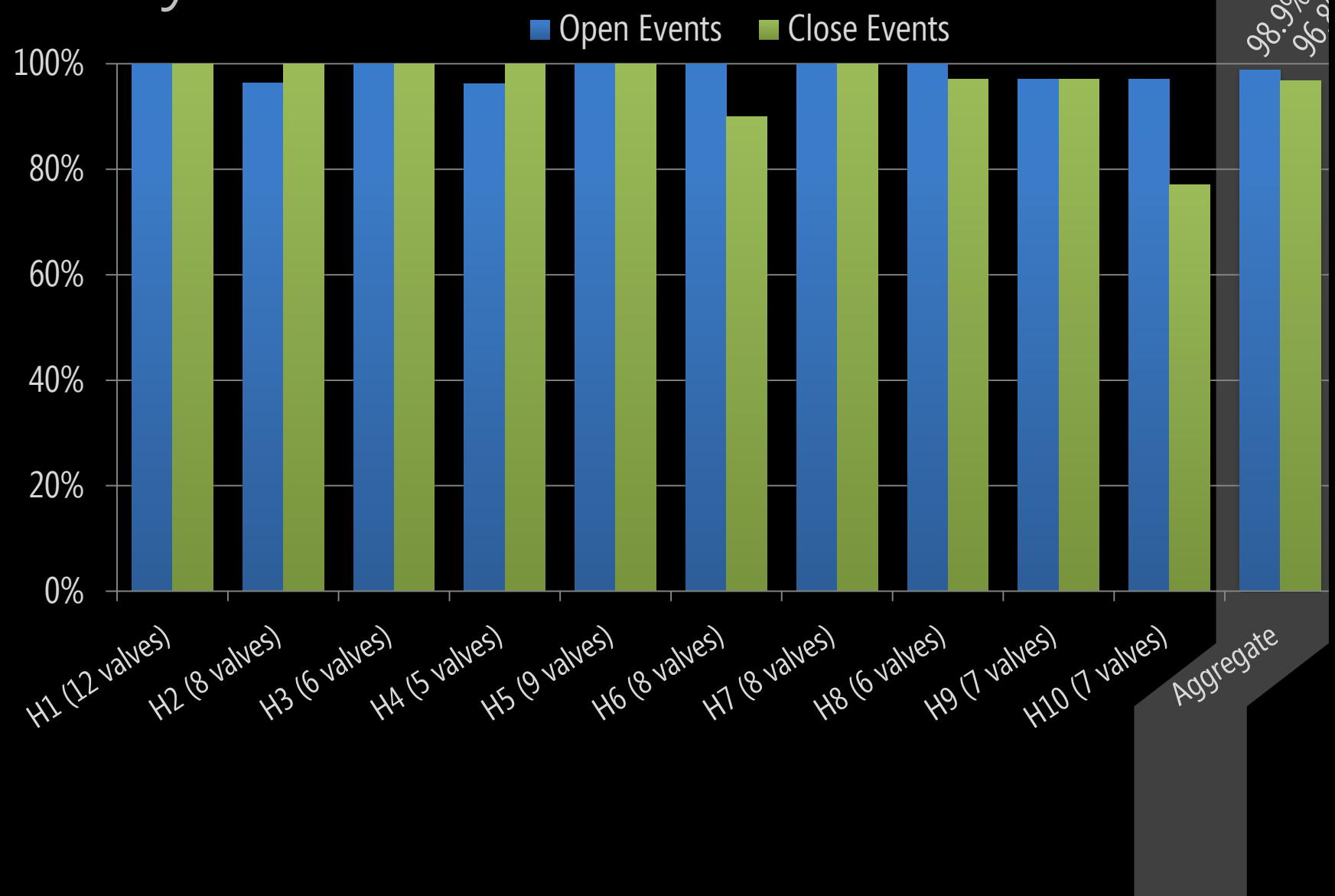


fixture classification results
by home



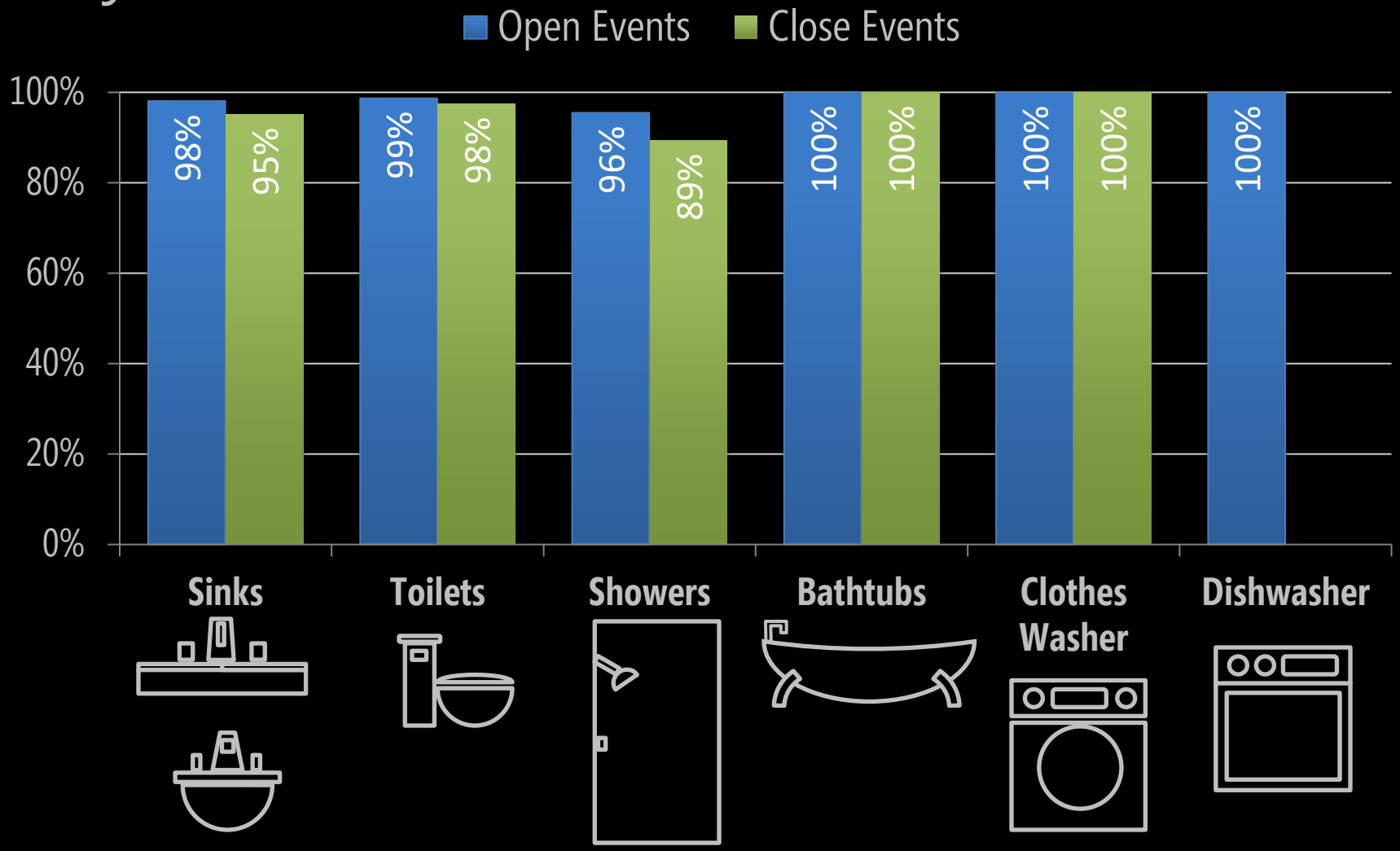
98.9%
96.8%

fixture classification results
by home



fixture classification results

by fixture



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

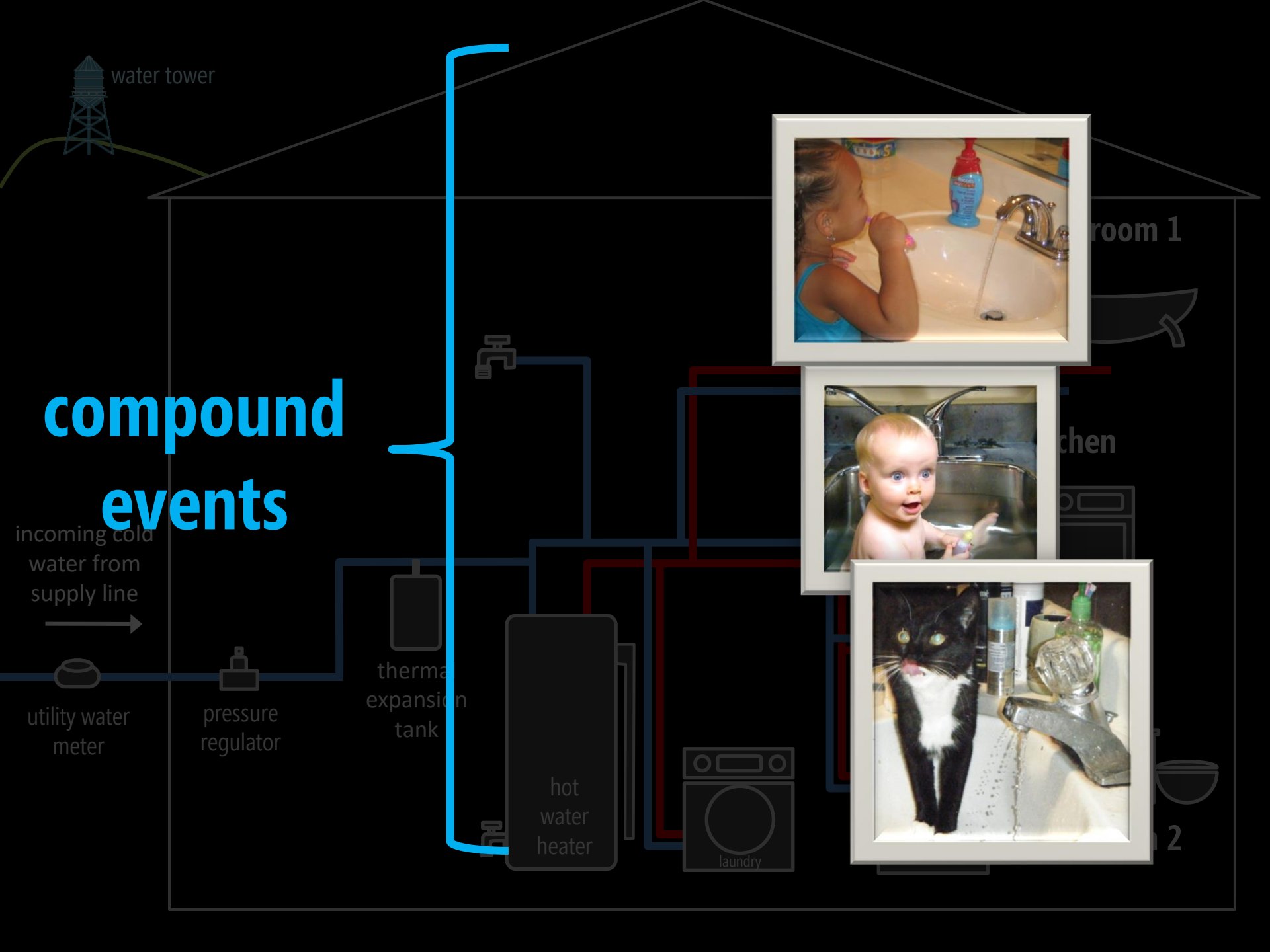
but....

brushing teeth

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
room 1
chen

how can we study naturalistic uses of water?

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how can we collect
“ground truth labels”?

our failed attempts

X10 buttons

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

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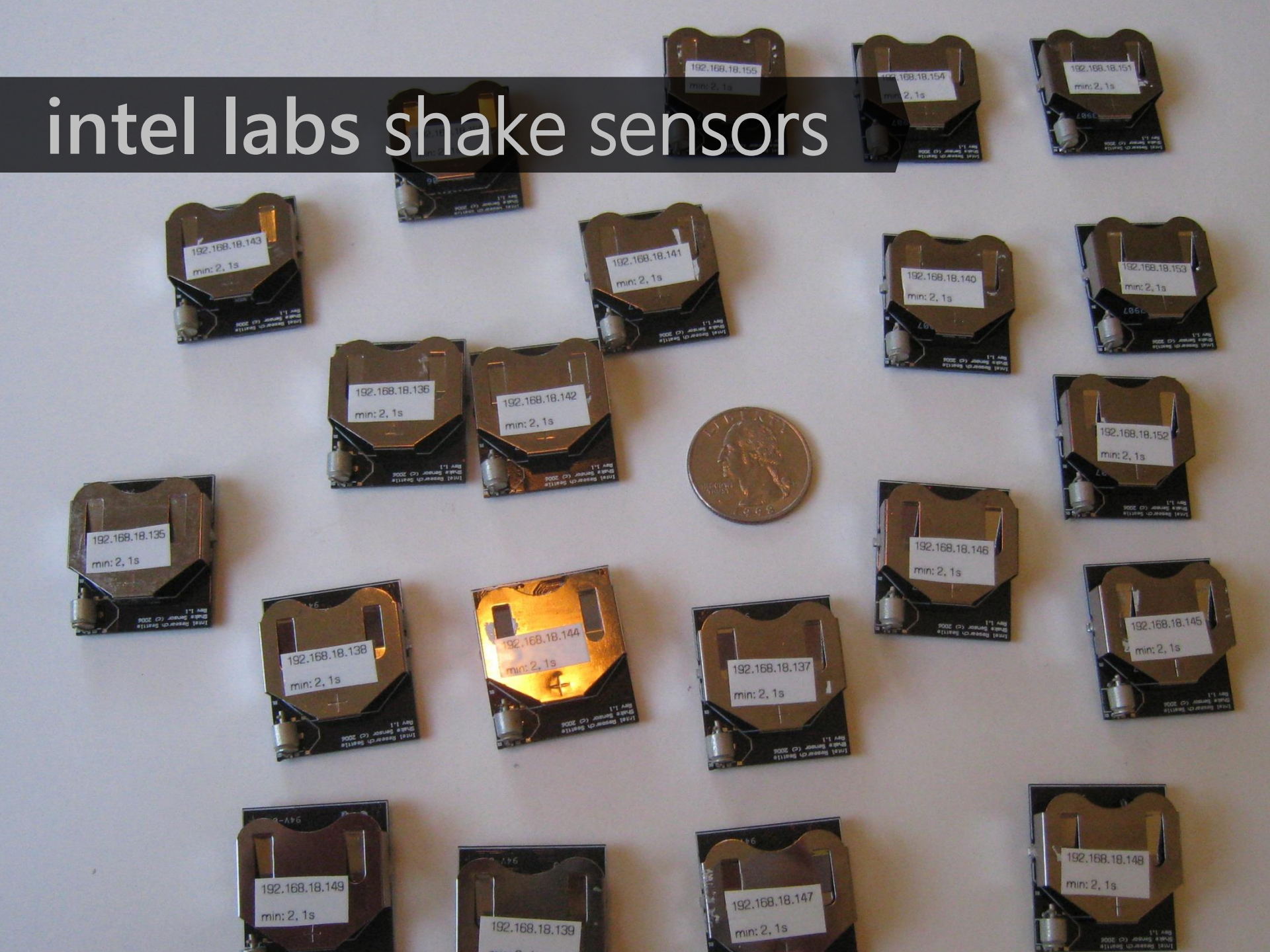
tracks the number of times
hot and cold are turned on/off

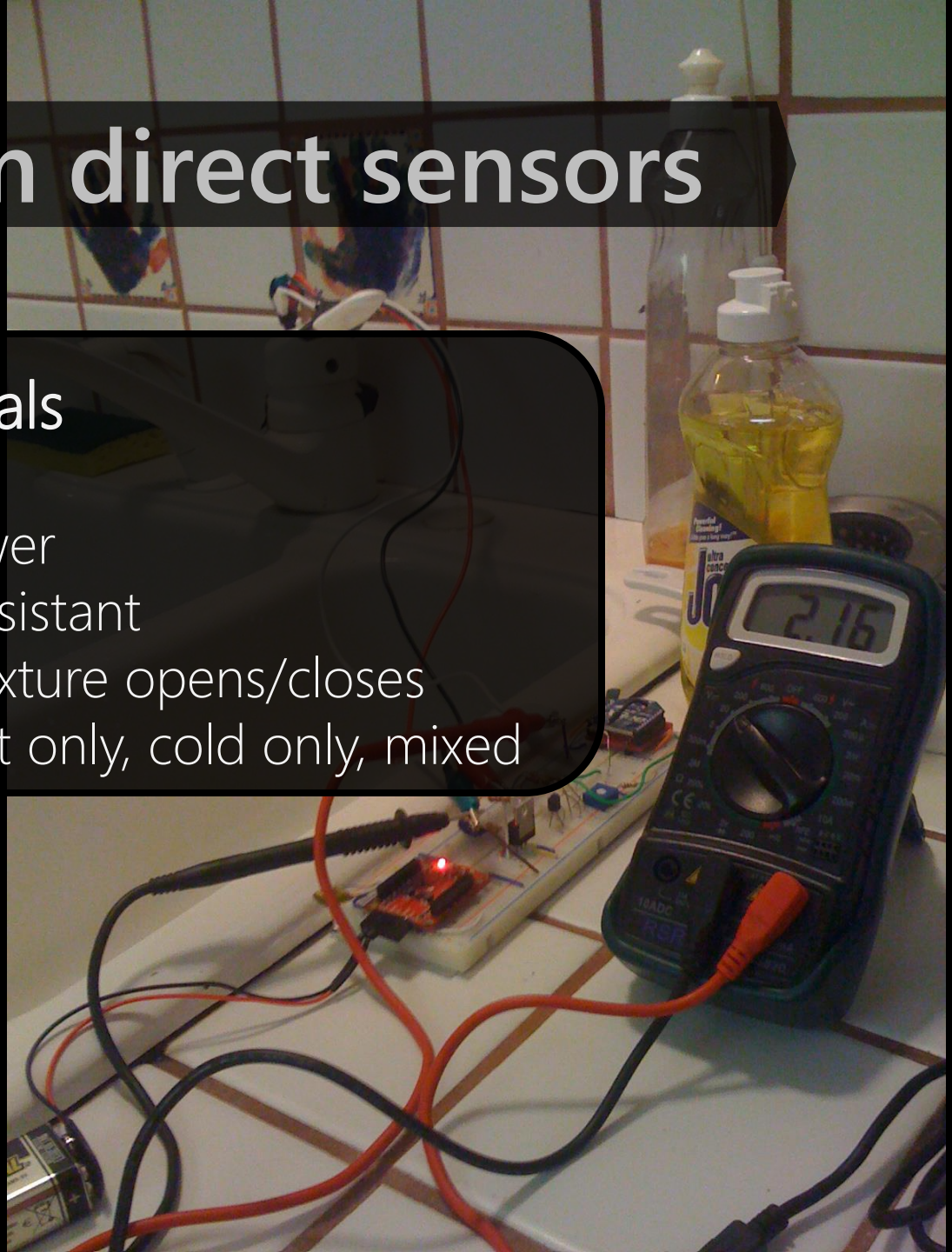
Movie Removed for Public Posting of Slides

intel labs shake sensors



our solution

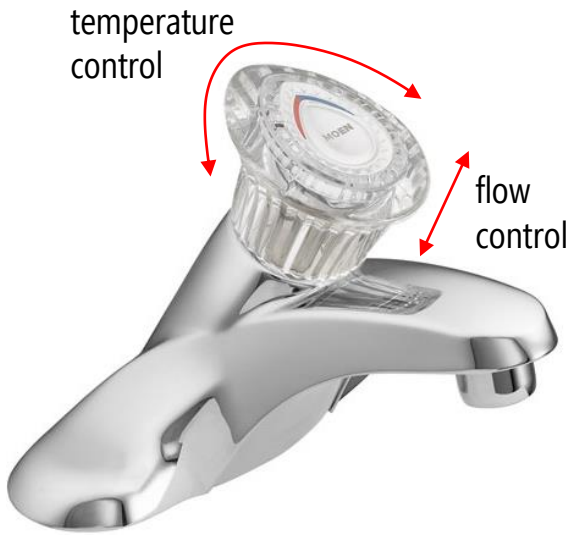
custom direct sensors



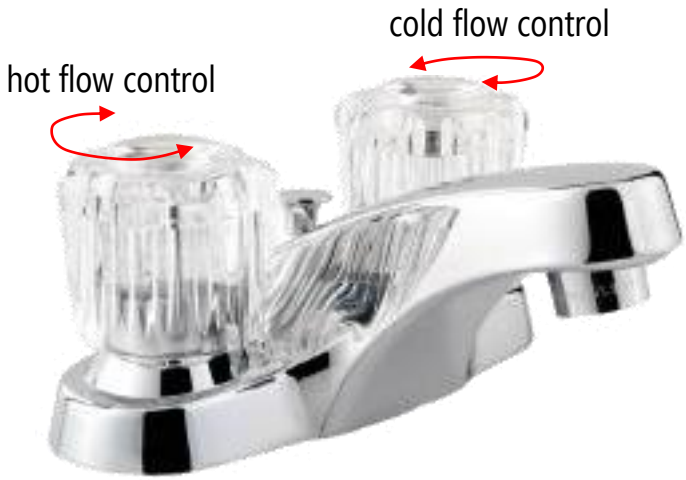
design goals

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

challenge: fixture diversity

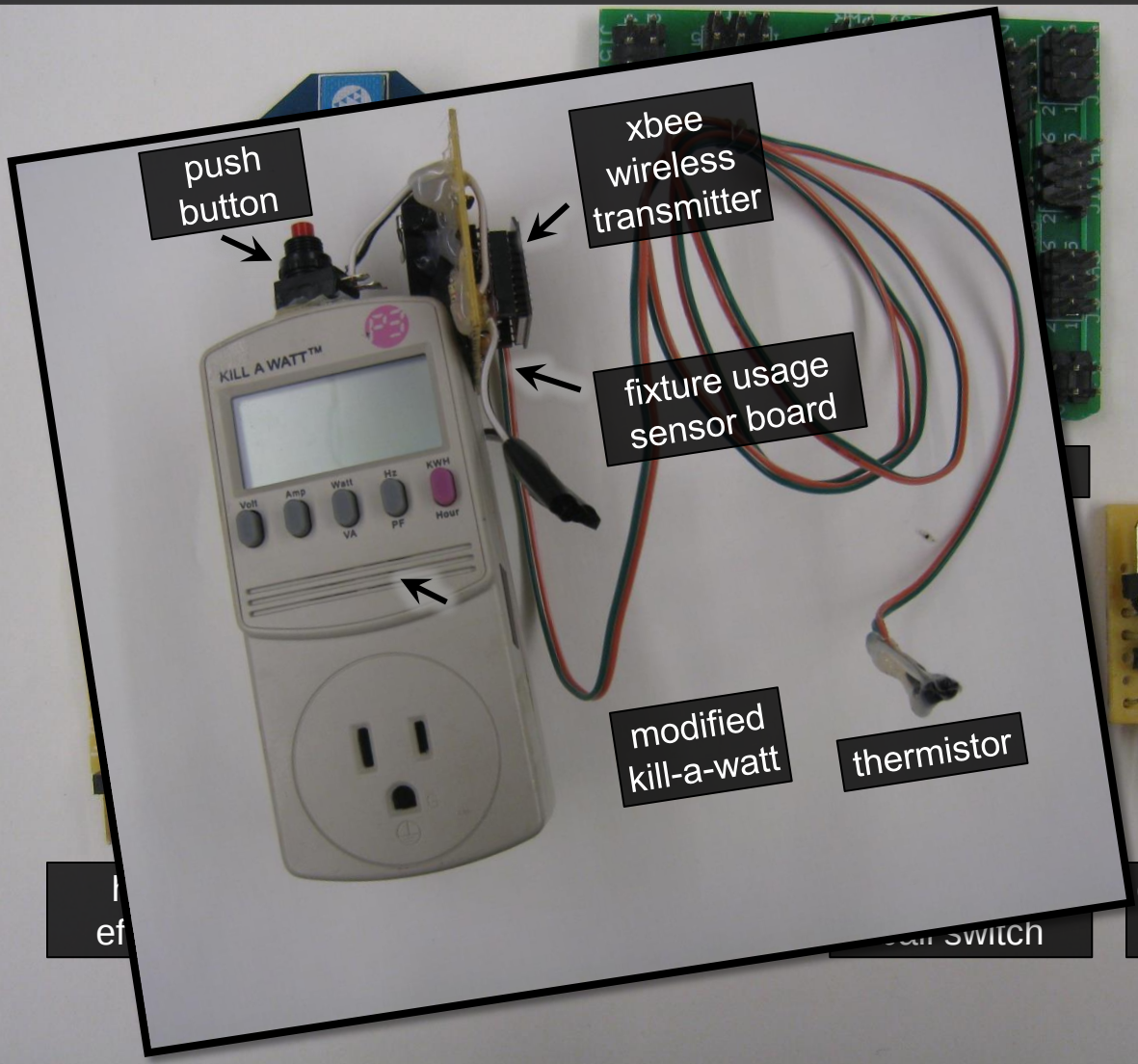


single handle faucet



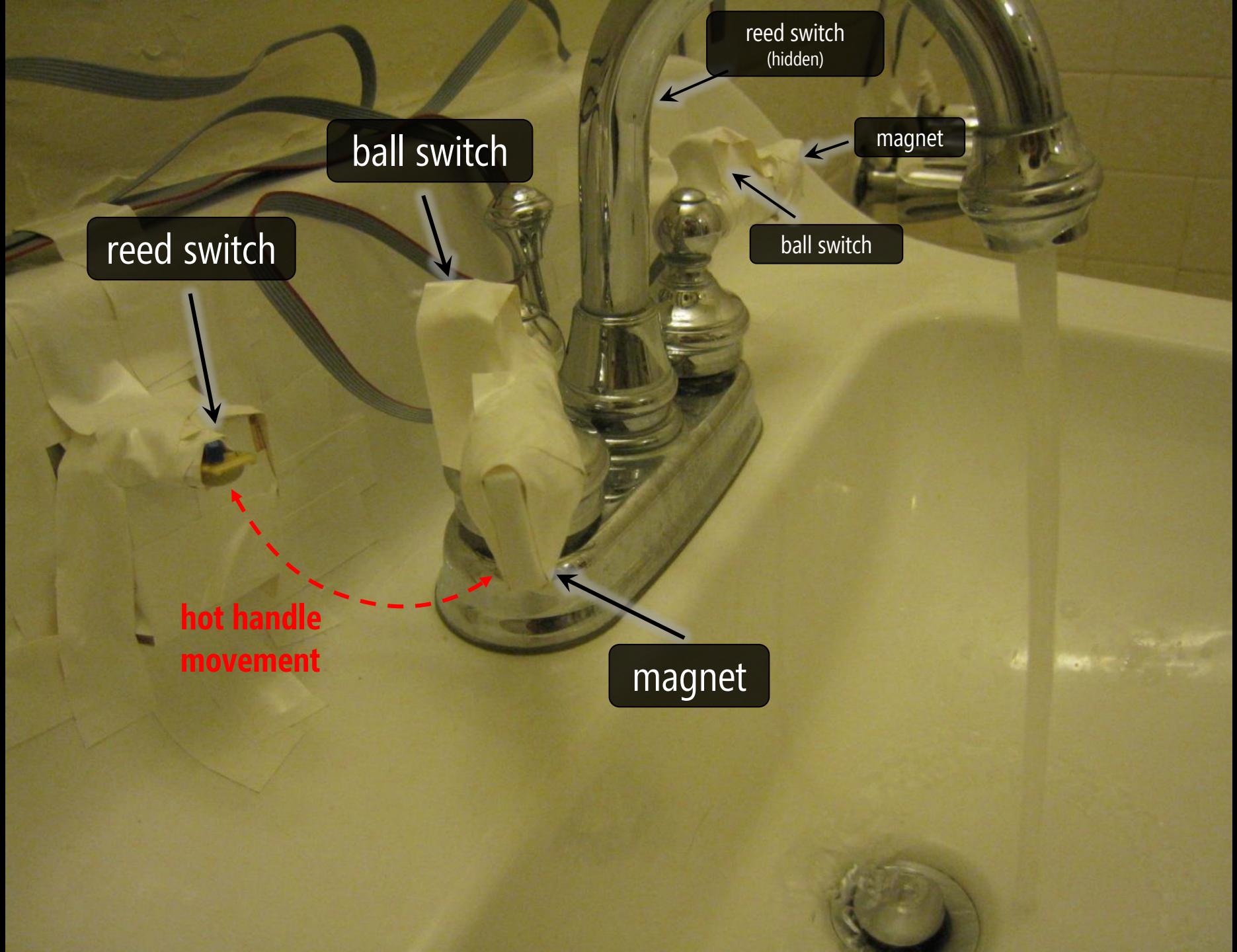
dual handle faucet

custom ground truth data collection system



omnidirectional ball switch

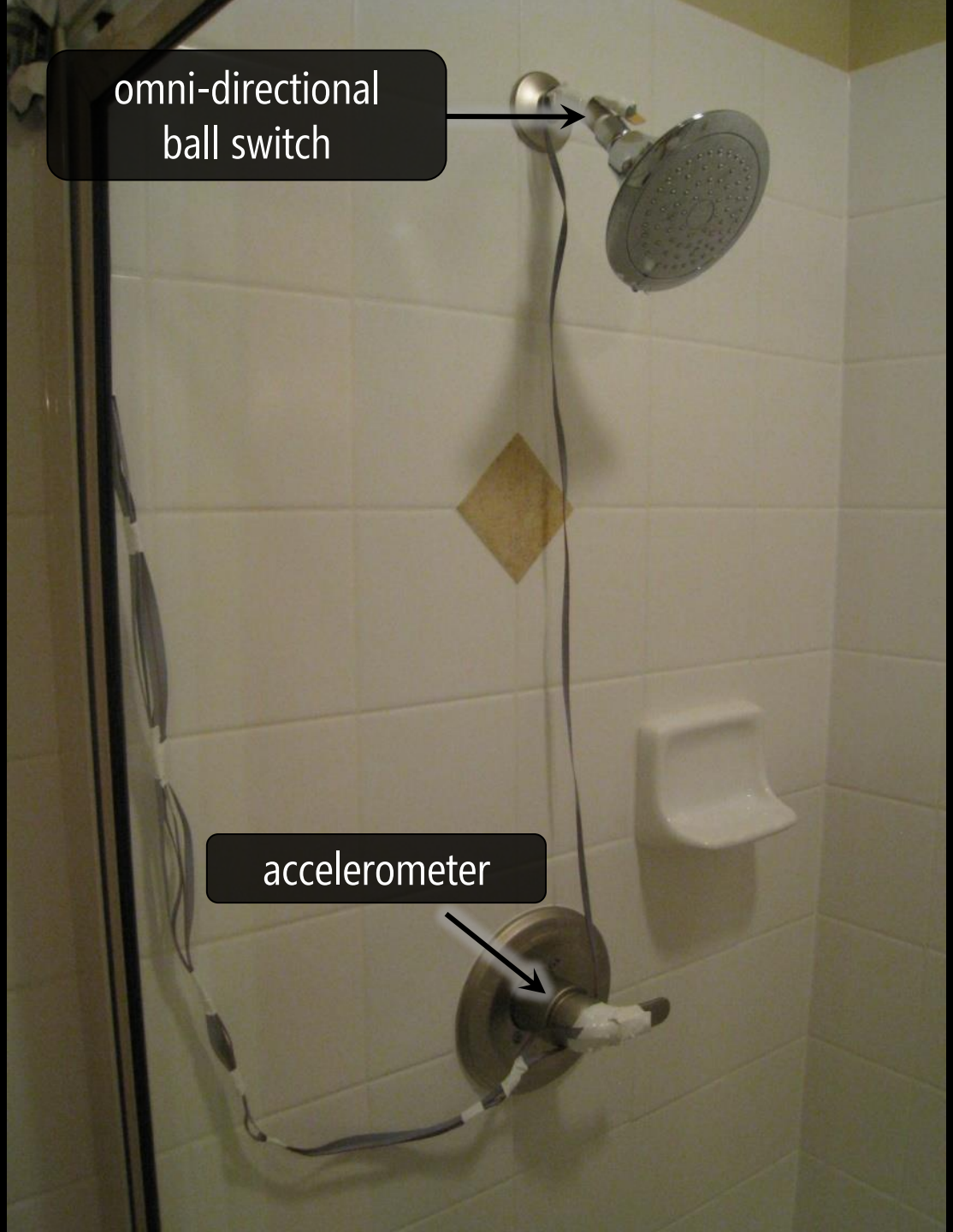
Movie Removed for Public Posting of Slides


reed switch
(hidden)
magnet
ball switch
ball switch
reed 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

magnet
reed switch
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

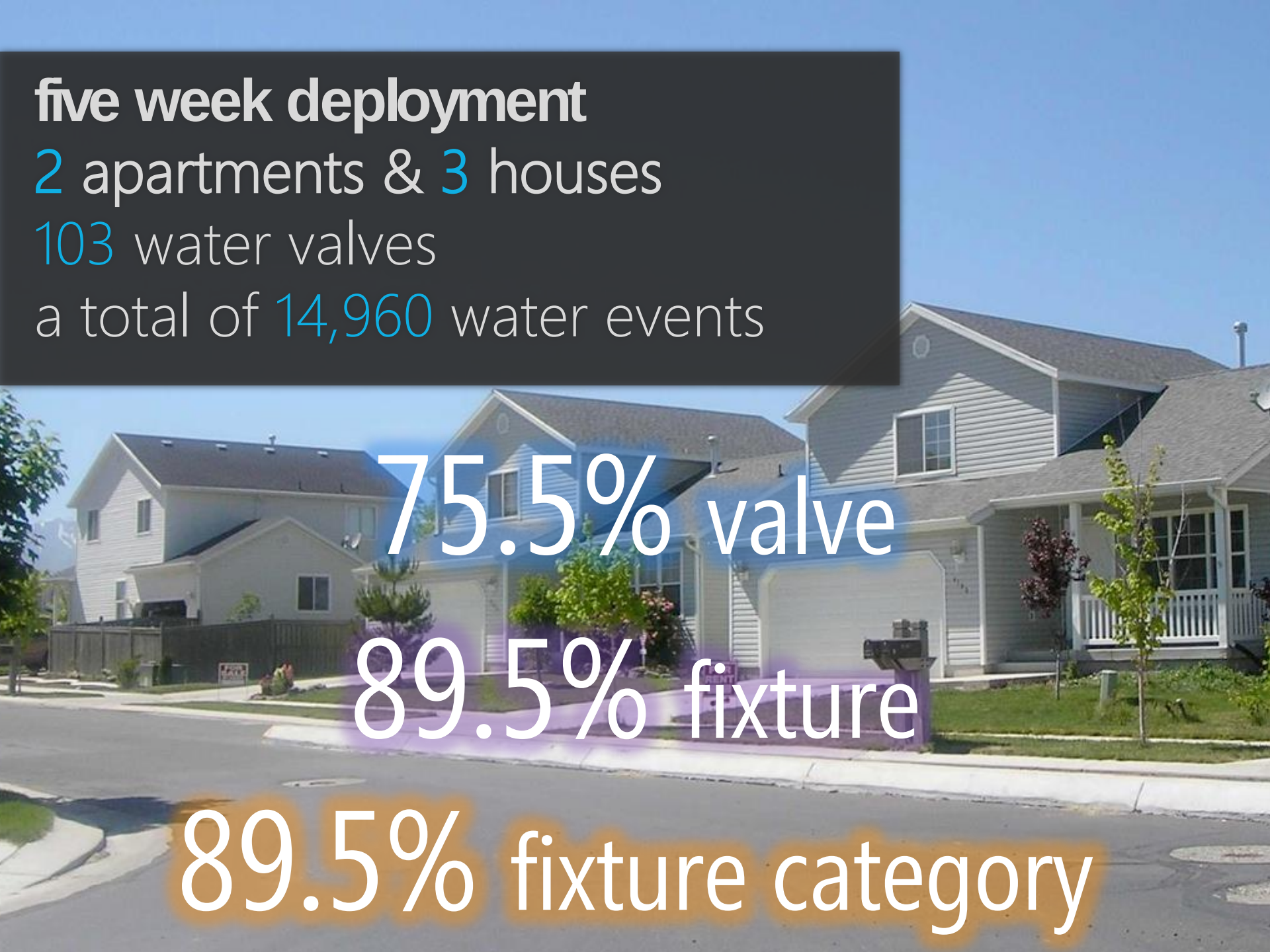
parent sensor board
xbee wireless transmitter
modified kill-a-watt
thermistor cable for drain pipe
(in red)
washing machine plug
(connects to kill-a-watt outlet)
PB32
XBee
WASH/SPIN SPEED
GENTLE SLOW
NORMAL SLOW
NORMAL FAST
TEMPERATURE
WARM COLD
HOT COLD
COLD COLD
WARM WARM
EXTRA RINSE
OFF
SET
COTTONS REGULAR
PERMANENT PRESS
DELICATES
9 Cycle 3 Speed Combinations
Heavy Duty Super Capacity

five week deployment

2 apartments & 3 houses

103 water valves

a total of 14,960 water events


five week deployment
2 apartments & 3 houses
103 water valves
a total of 14,960 water events
75.5% valve
89.5% fixture
89.5% fixture category

Thank You!

jonfroehlich@gmail.com
twitter @jonfroehlich

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

students

Jon Froehlich Campbell

Gabe Cohn

Sidhant Gupta

Eric Larson

Tim

faculty

Shwetak Patel Landay

James Fogarty

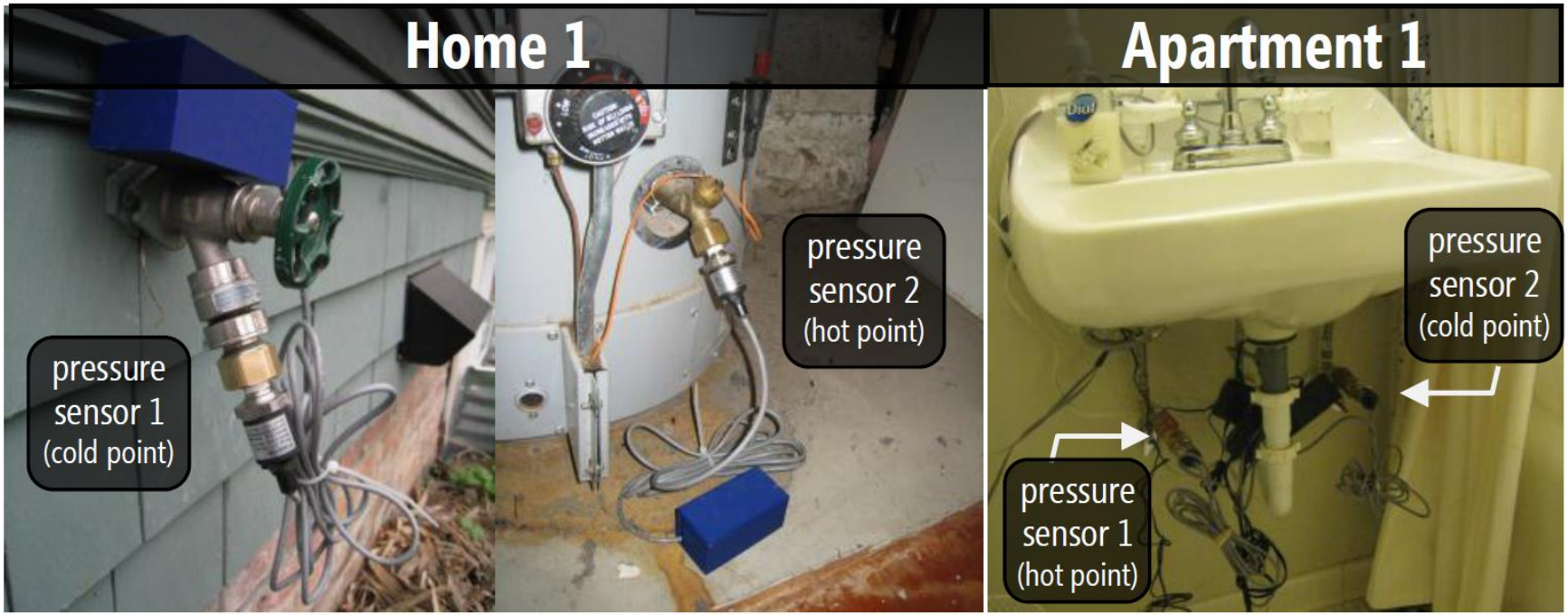
James

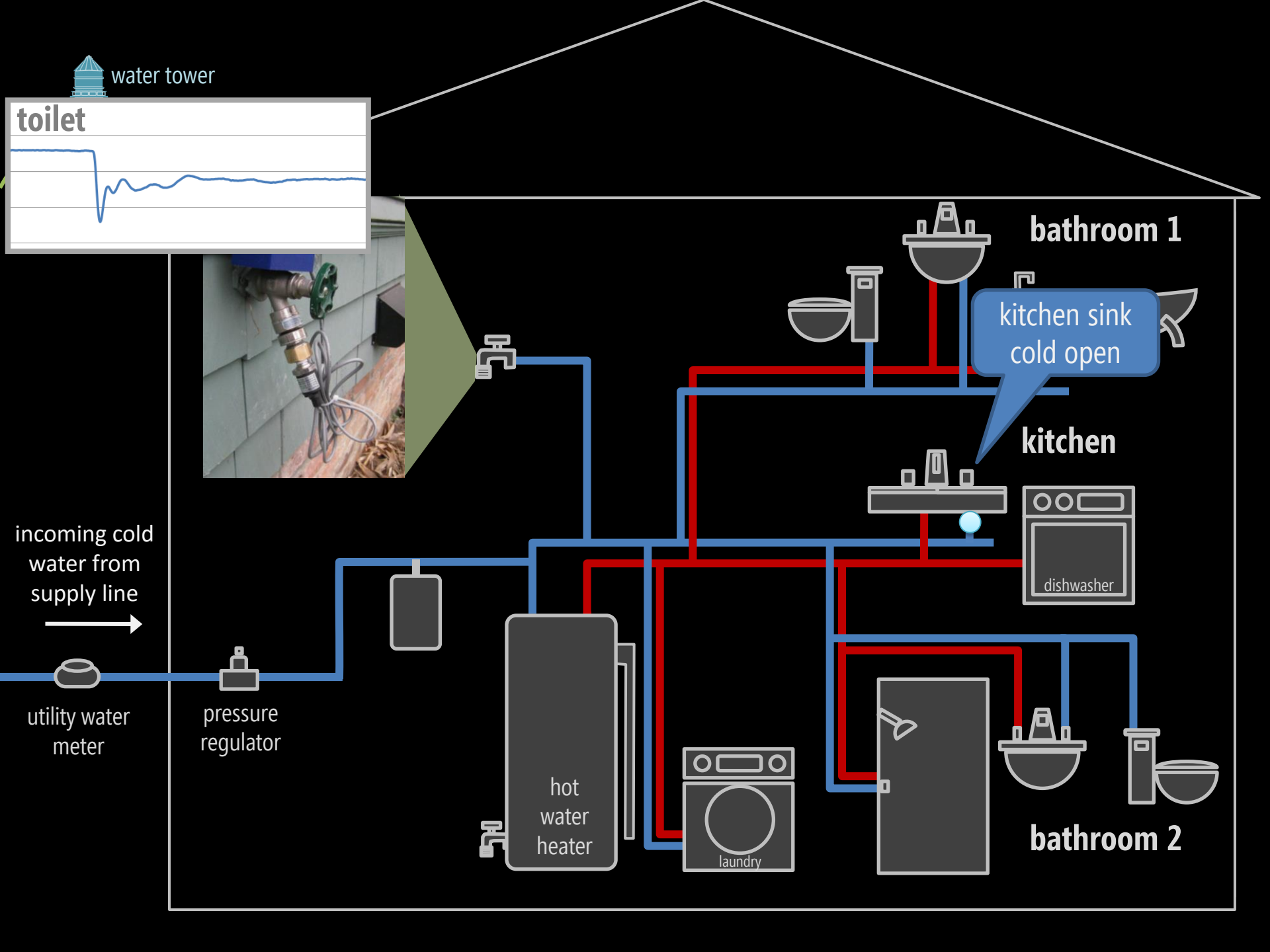
dub design: use: build:
university of washington

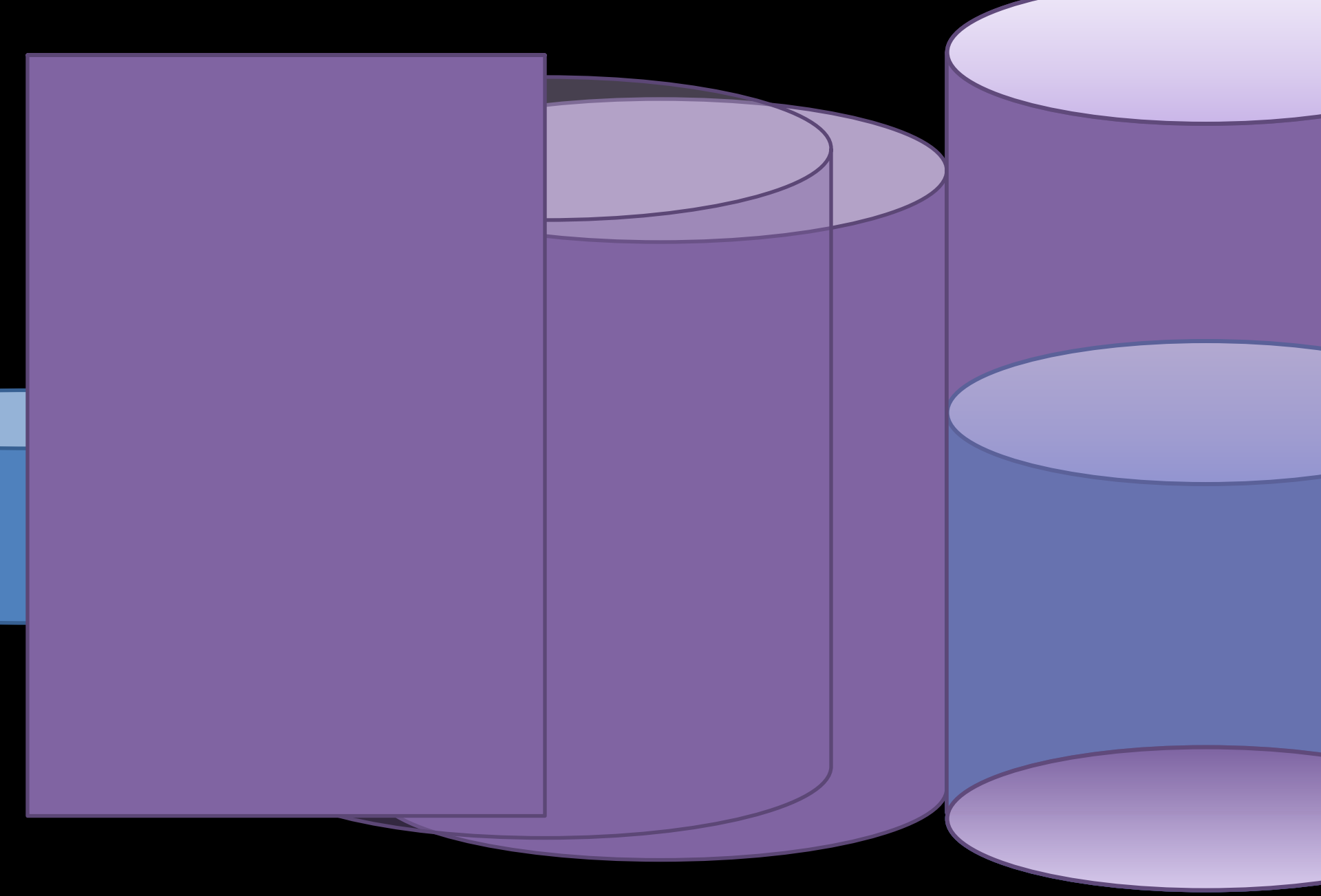
ubicomp lab
university of washington

sustain
sustainability research

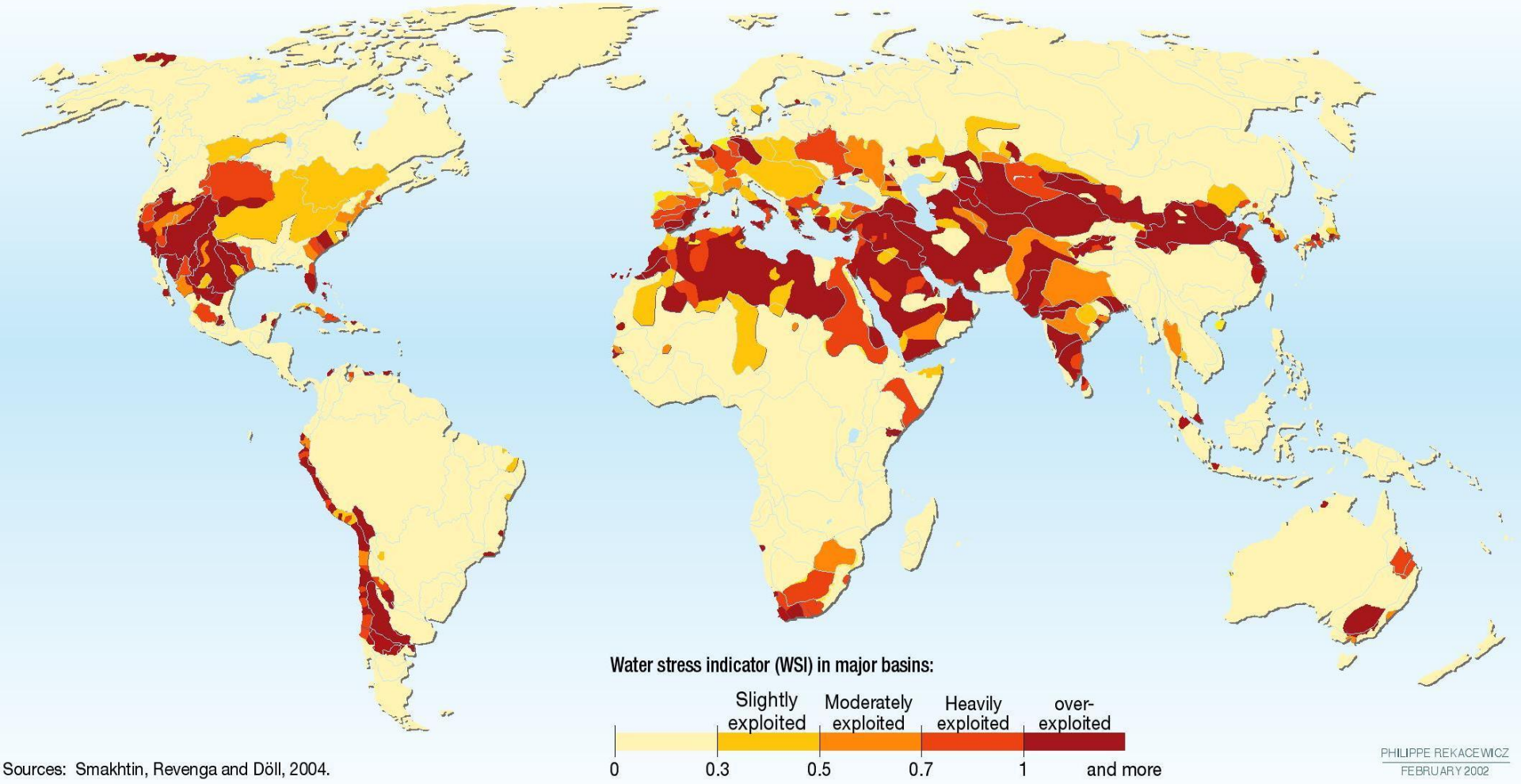
two pressure sensors per home




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



water scarcity



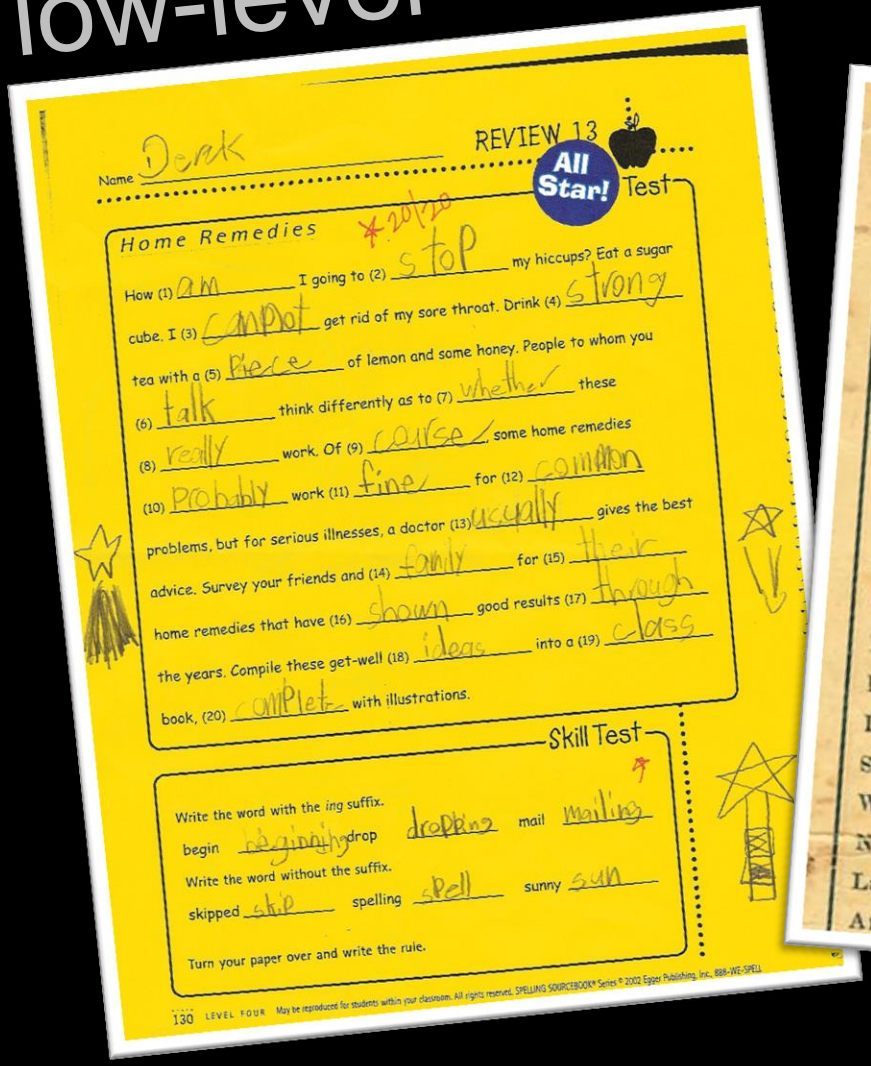
barcelona, spain

lake mead, nevada

feedback improves performance

low-level

high-level



Name Derk

REVIEW 13

All Star! Test

Home Remedies

How (1) am I going to (2) stop my hiccups? Eat a sugar cube. I (3) cannot 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) complet with illustrations.

Skill Test

Write the word with the *ing* suffix.

begin beginning drop dropping 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

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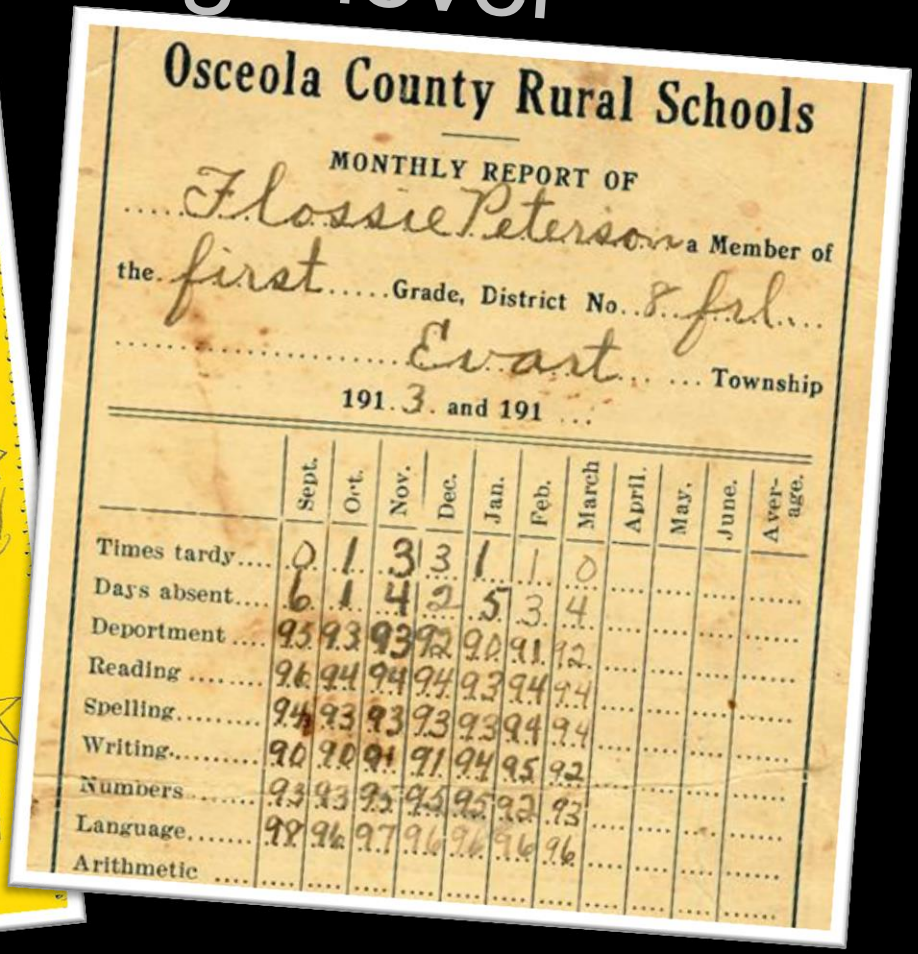

Osceola County Rural Schools

MONTHLY REPORT OF

Flossie Peterson a Member of the first Grade, District No. 8 frl.

Evart Township

191 3. and 191 ...

	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April.	May.	June.	Aver-age.
Times tardy	0	1	3	3	1	1	0				
Days absent	6	1	4	2	5	3	4				
Deportment	93	93	93	92	90	91	12				
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	92	93				
Language	92	96	97	96	96	96	96				
Arithmetic											

Becker, *J. of Applied Psychology 1978*

face washing