HYDROSENSE

Infrastructure-Mediated Single-Point Sensing of Whole-Home Water Activity

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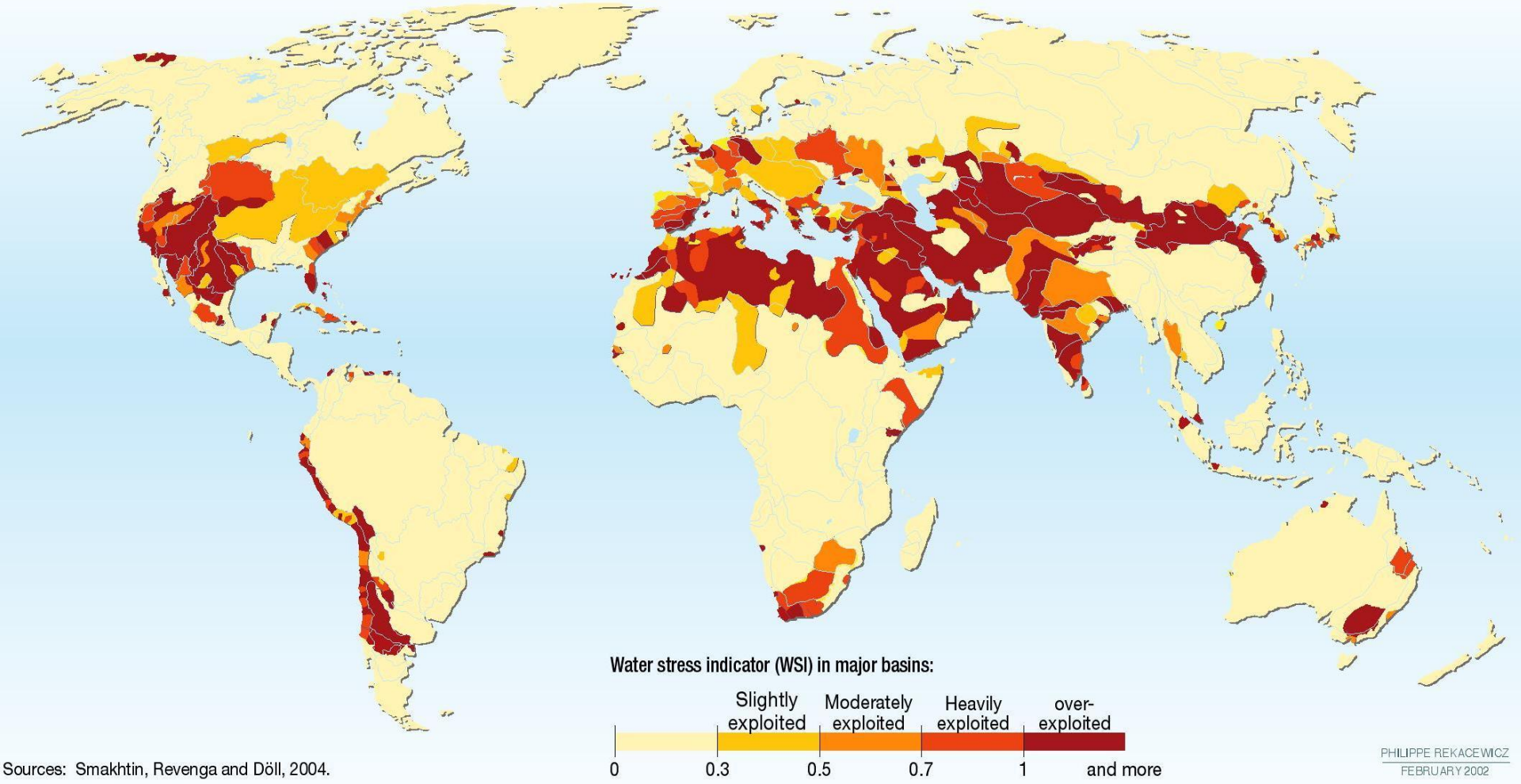
[3]Mechanical Engineering, [4]Community, Environment, and Planning

dub design: use: build:
univ. of washington

computer science and engineering

water scarcity



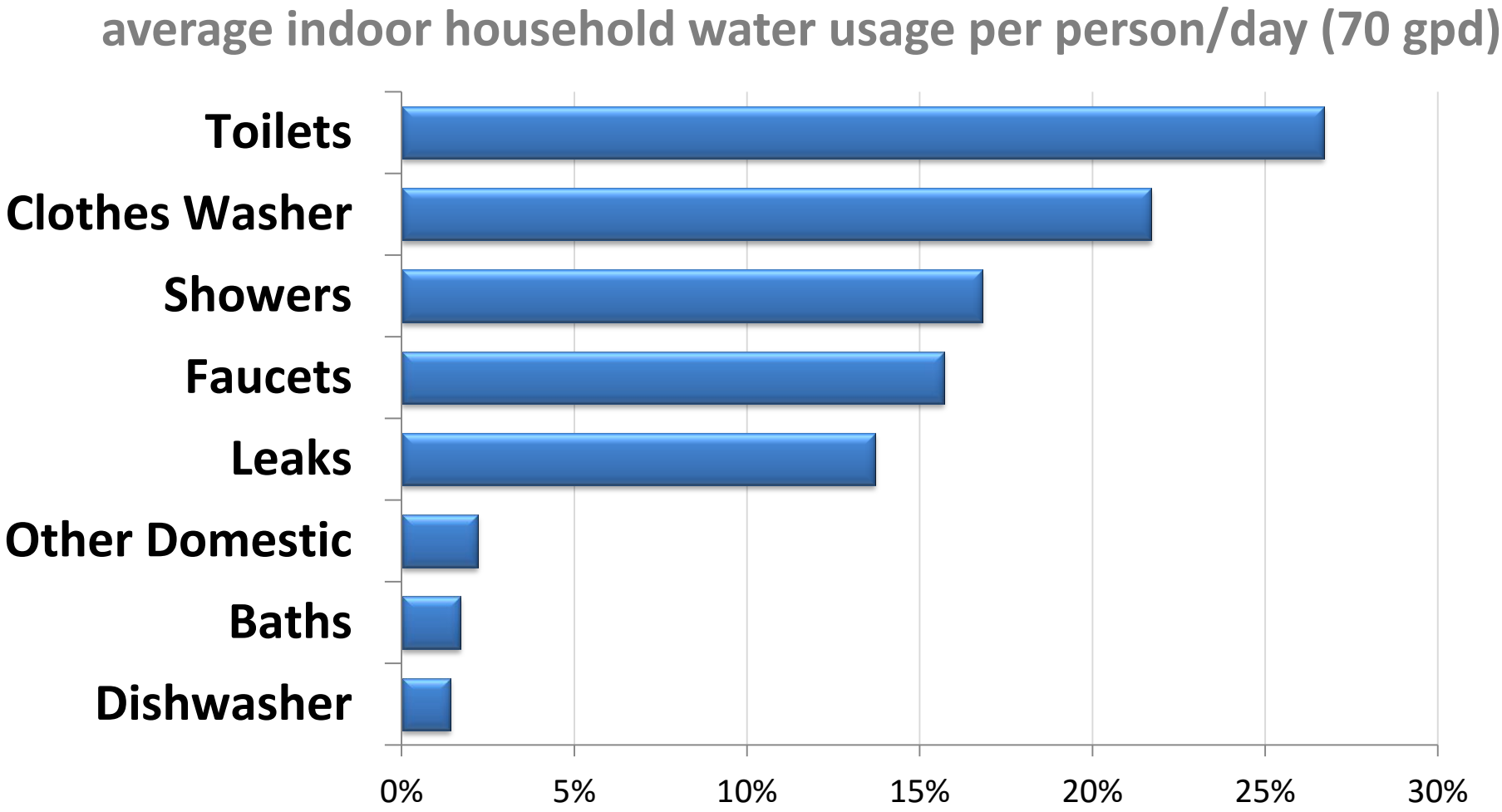
Sources: Smakhtin, Revenga and Döll, 2004.

PHILIPPE REKACEWICZ
FEBRUARY 2002


barcelona, spain


lake mead, nevada

what are the most consuming water activities in your home?



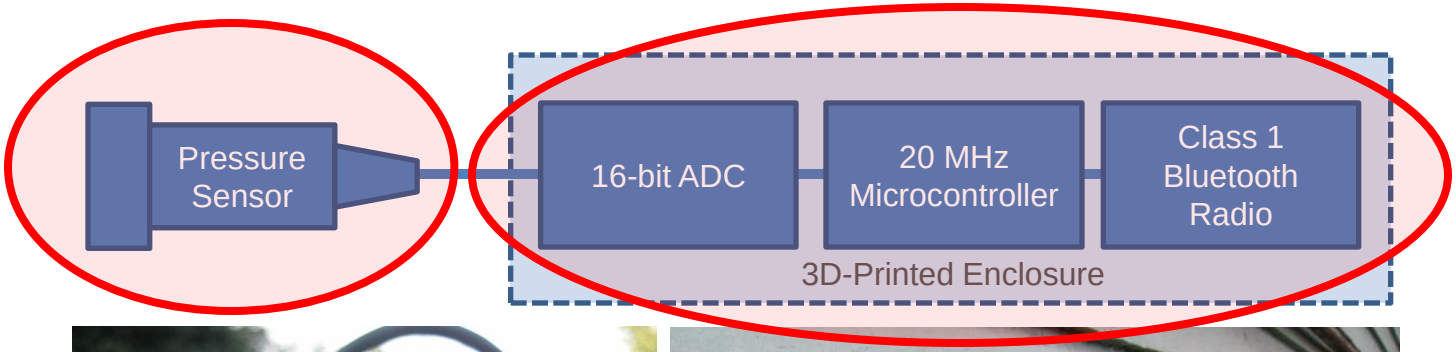
Vickers, 2001

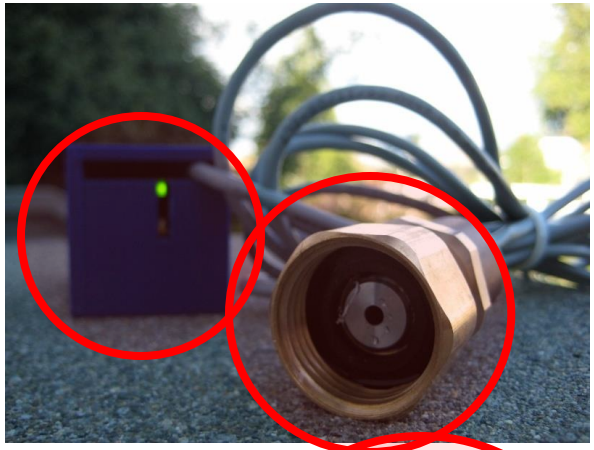
hydrosense

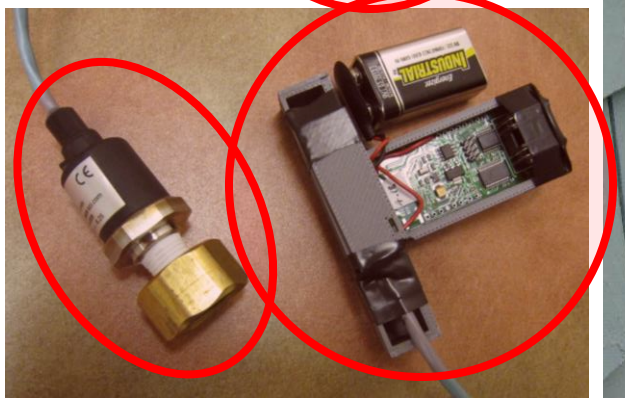
- single-point pressure-based sensor of water usage
- identifies water usage activity down to fixture level (e.g., toilet)
- provides estimates of flow at each fixture

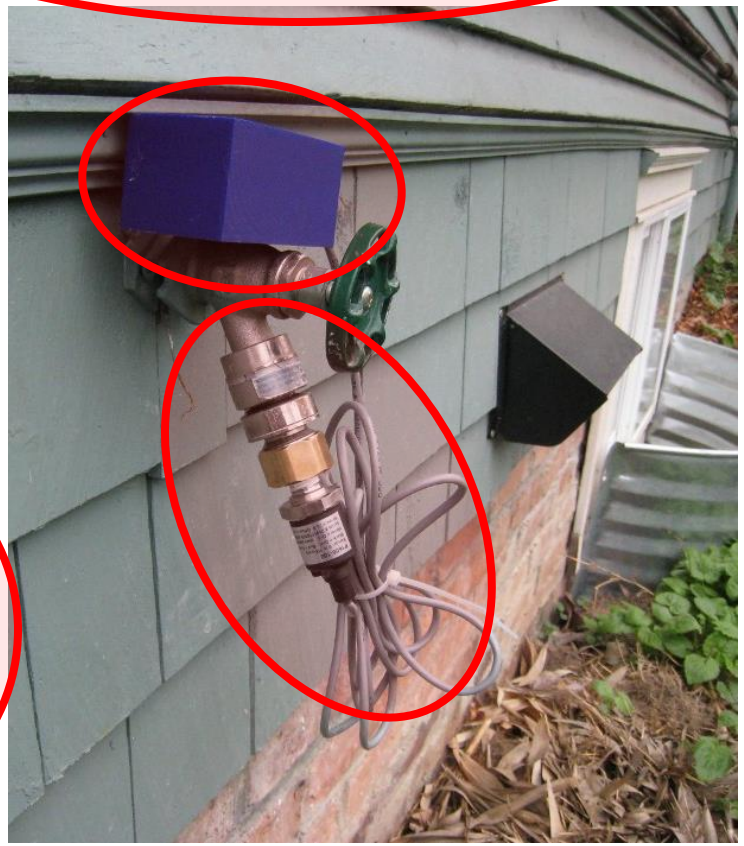
hydrosense

the hydrosensor prototype







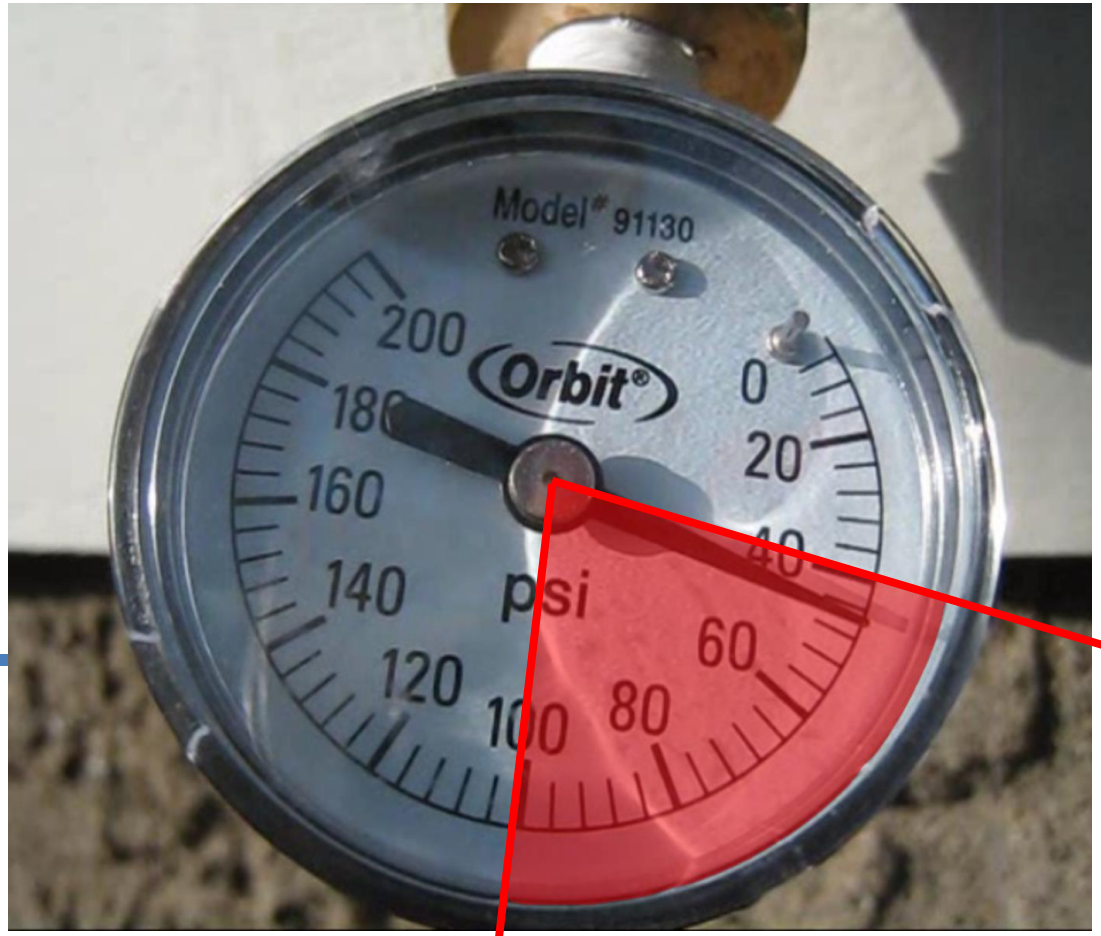


water tower

brief plumbing primer

water tower

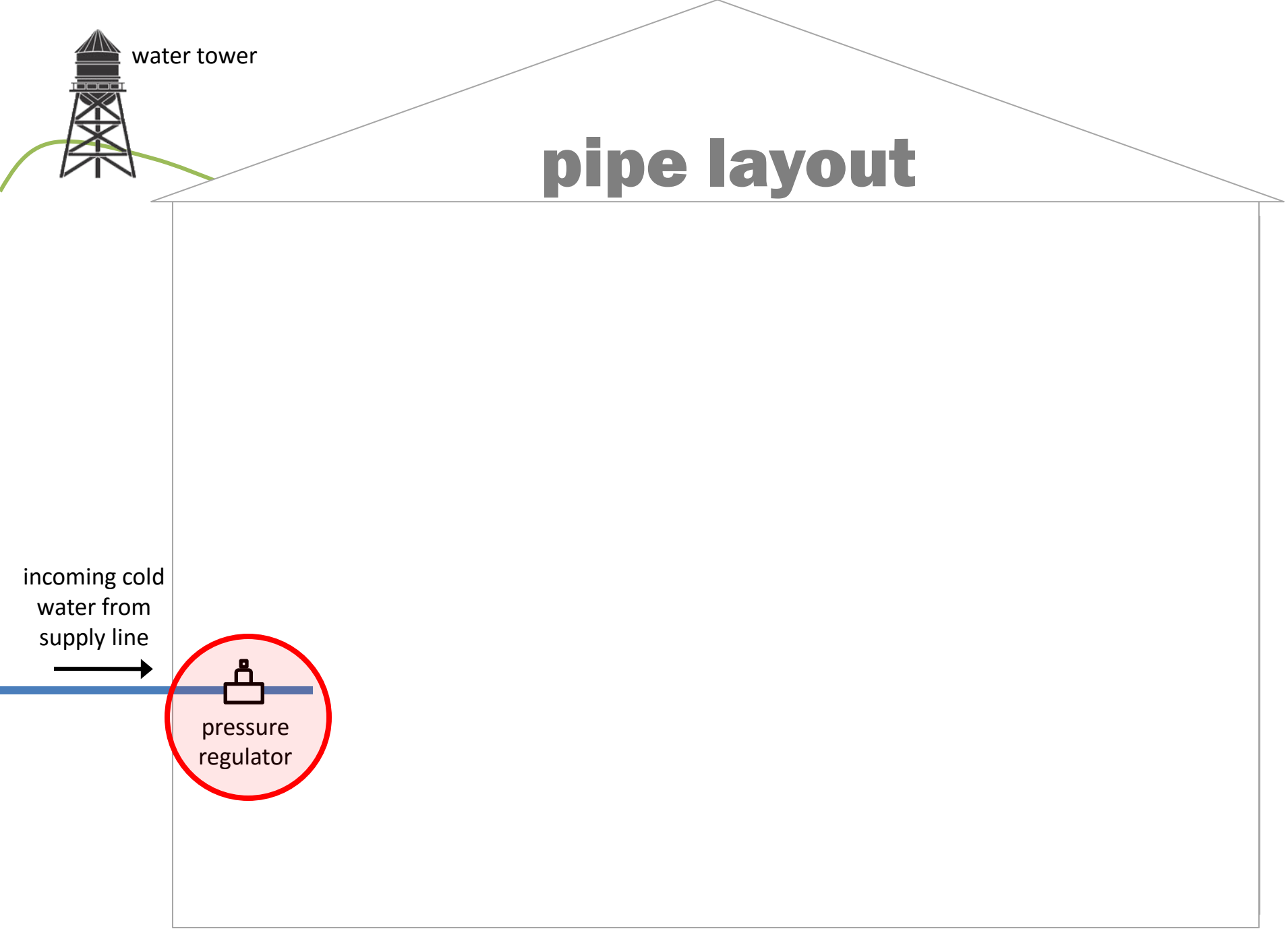
brief plumbing primer

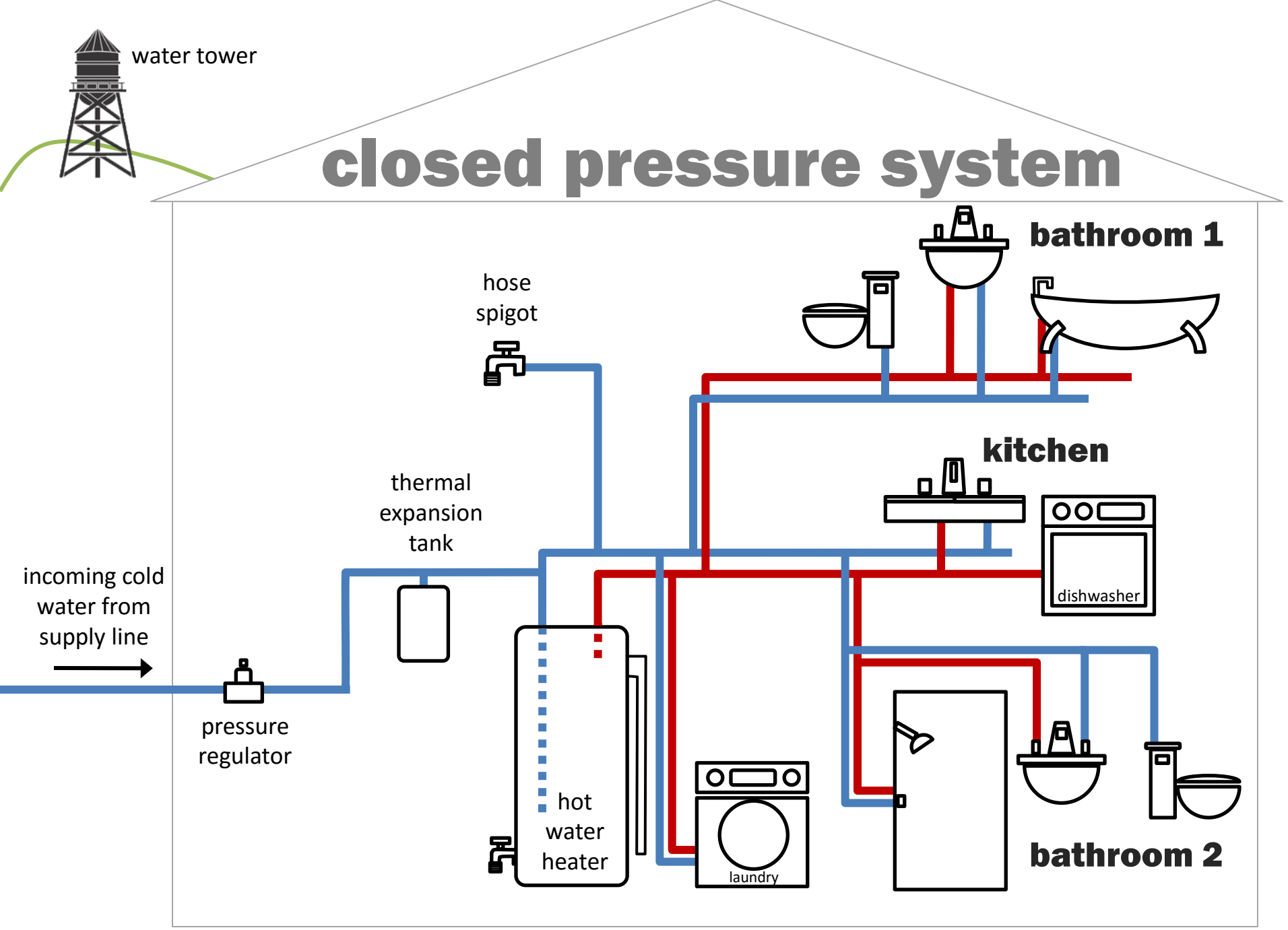


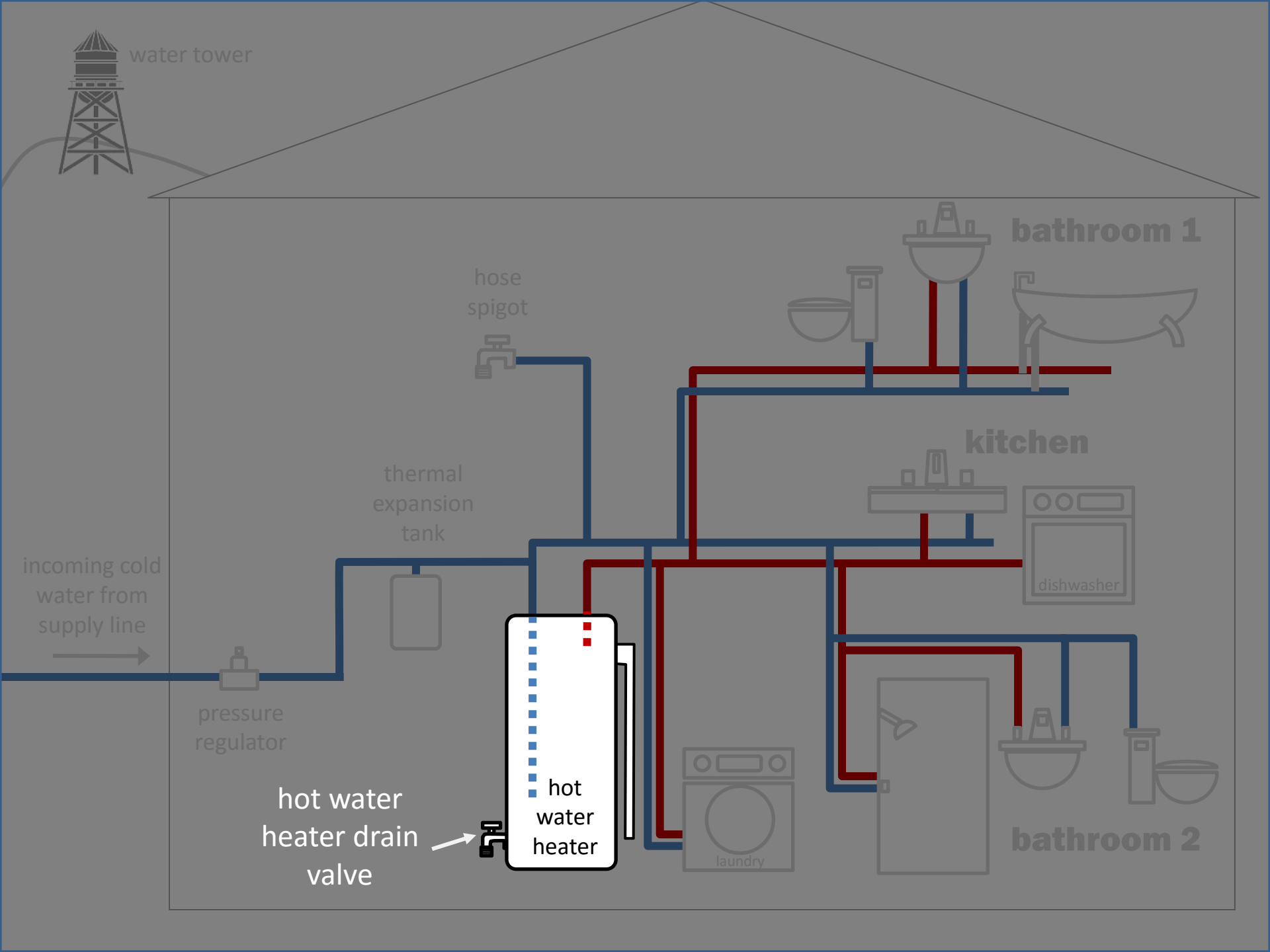
incoming cold water from supply line

40 psi

100 psi


water tower
pipe layout
incoming cold water from supply line
pressure regulator


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


water tower
bathroom 1
hose spigot
kitchen
thermal expansion tank
incoming cold water from supply line
dishwasher
pressure regulator
hot water heater
hot water heater drain valve
laundry
bathroom 2

some possible installation points

hose spigot

bathroom 1

kitchen

thermal expansion tank

incoming cold water from supply line

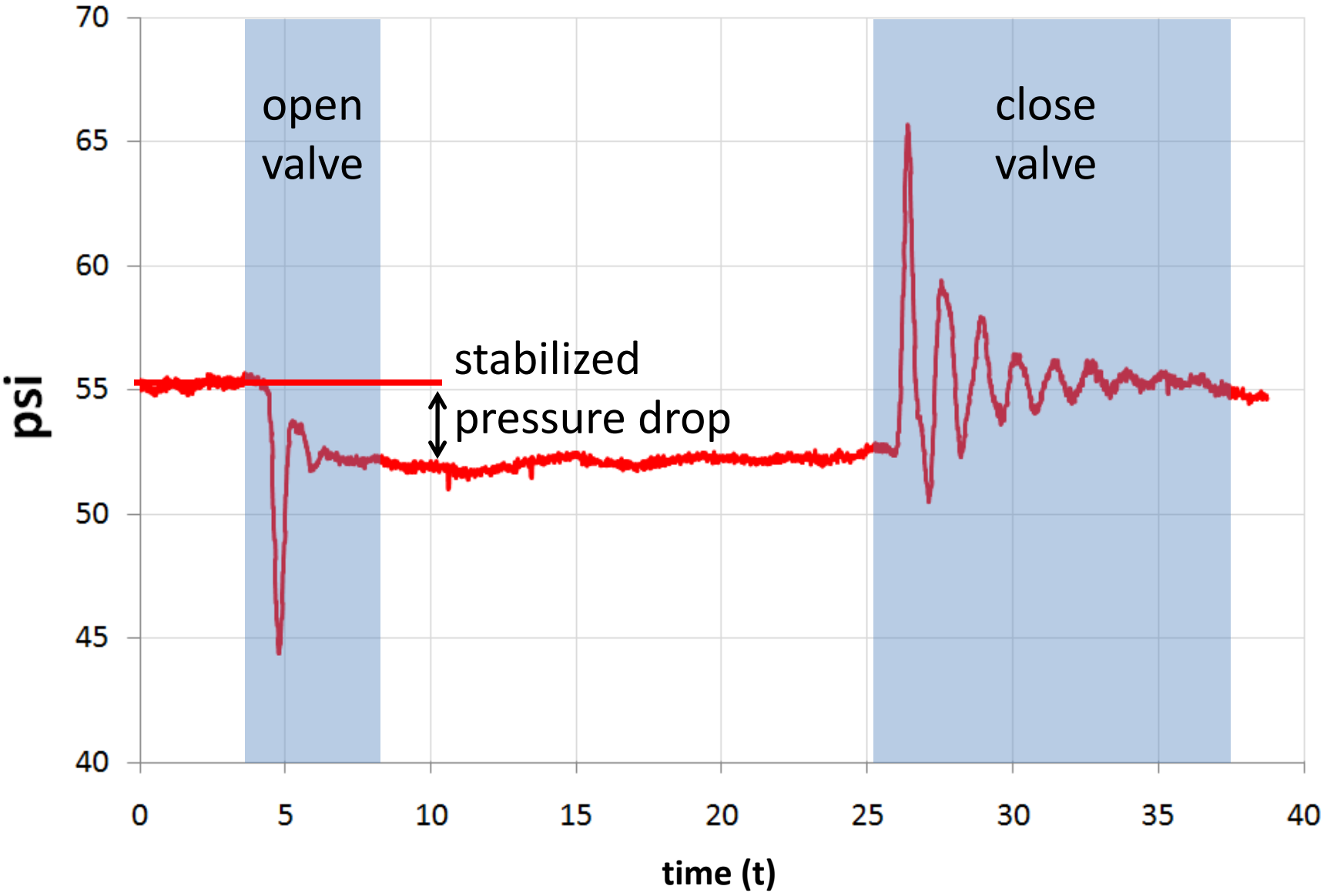
hot water heater

dishwasher

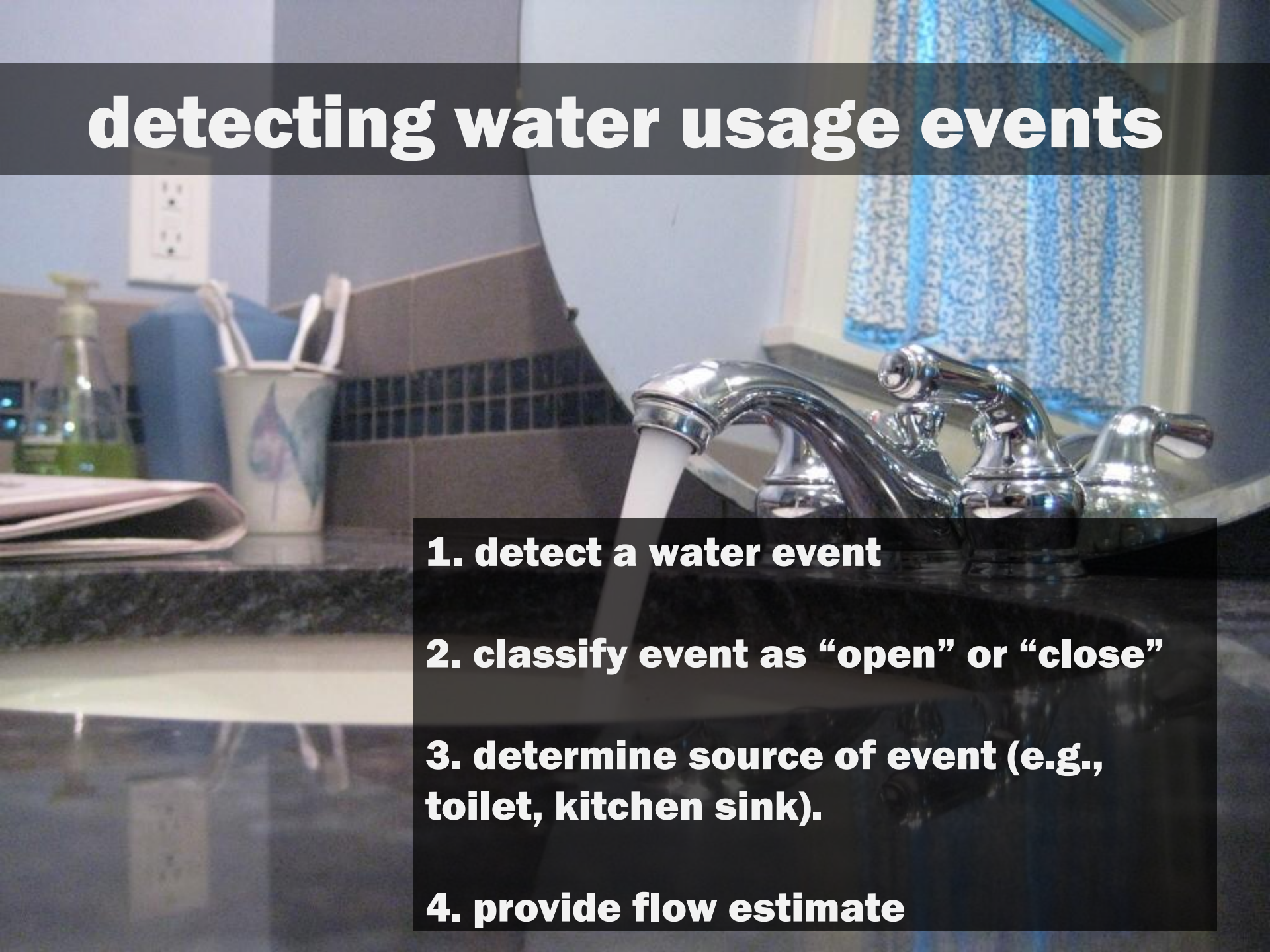
laundry

bathroom 2

raw bathroom sink signal



detecting water usage events



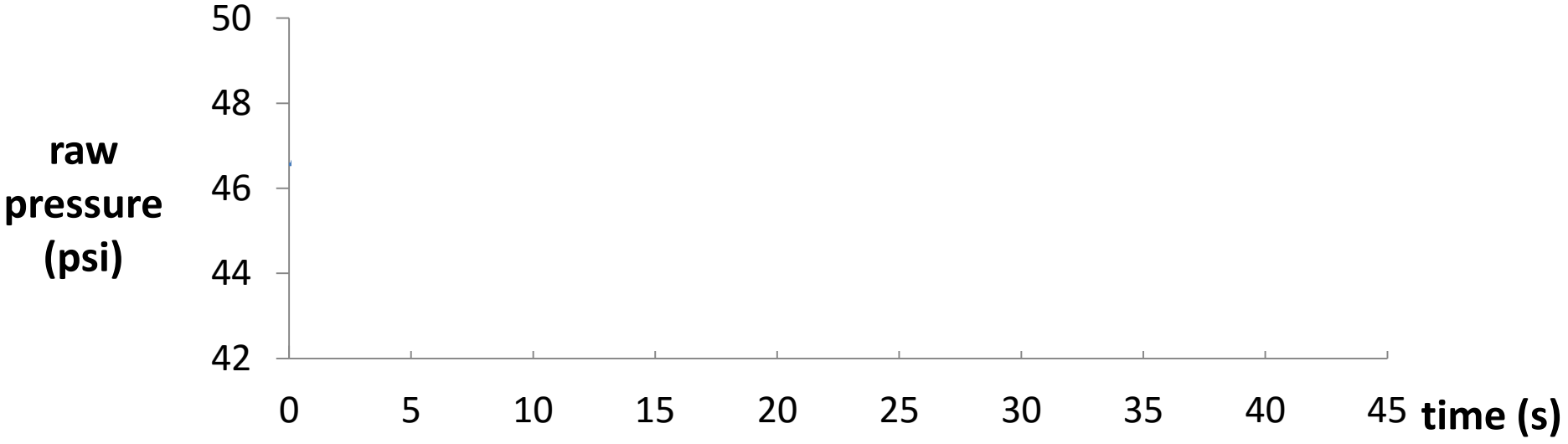
1. detect a water event

2. classify event as “open” or “close”

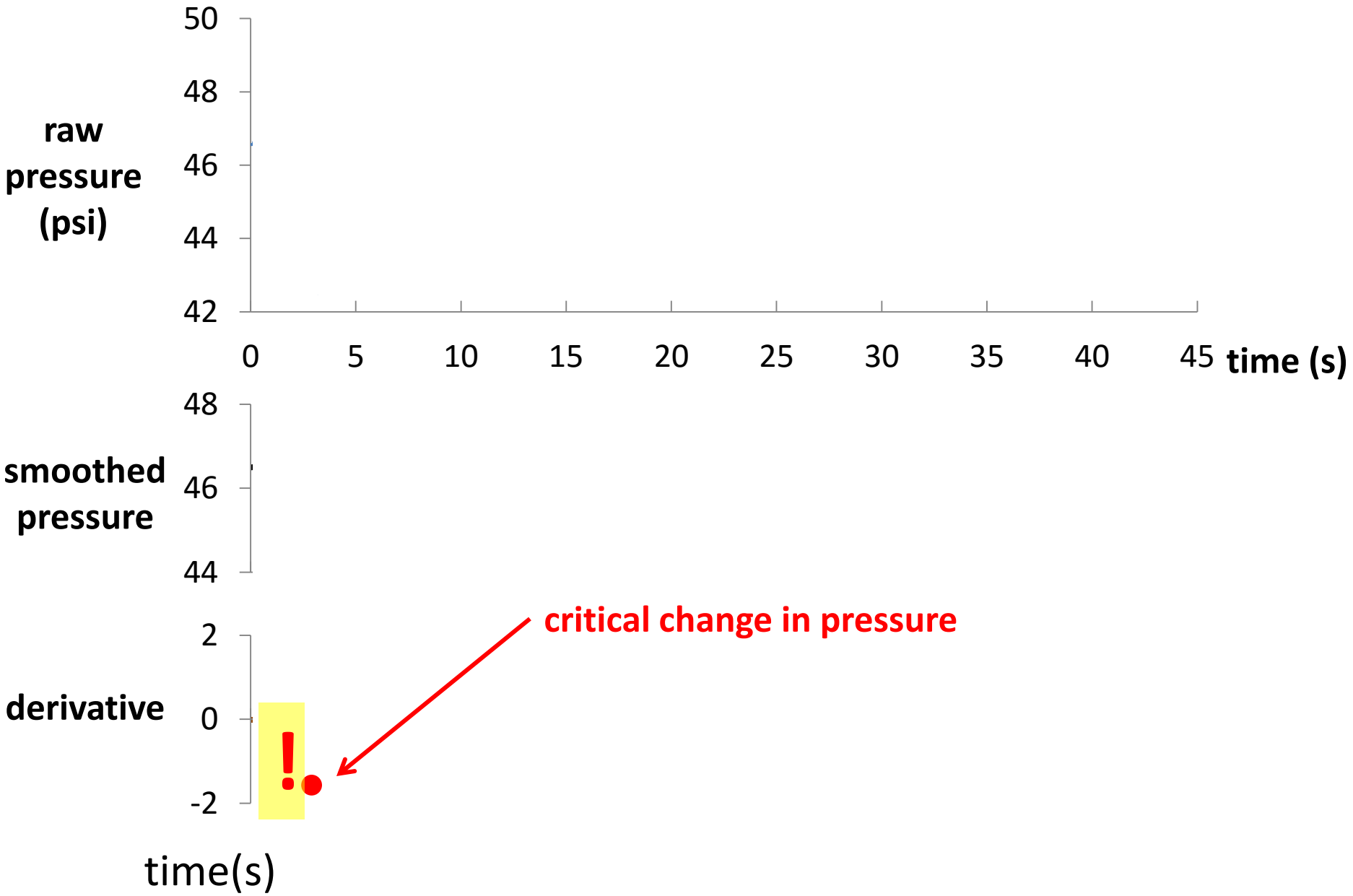
3. determine source of event (e.g., toilet, kitchen sink).

4. provide flow estimate

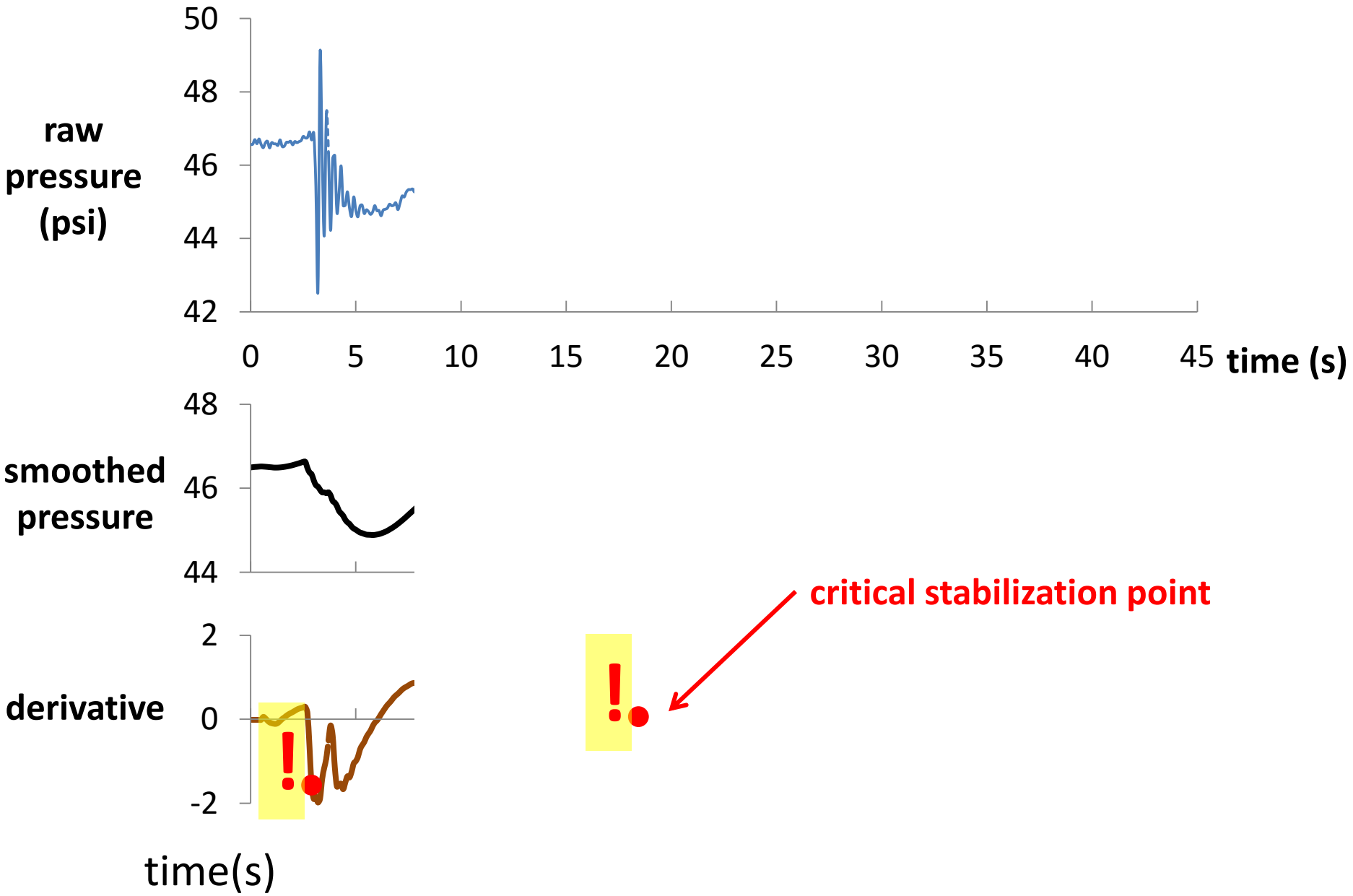
event detection



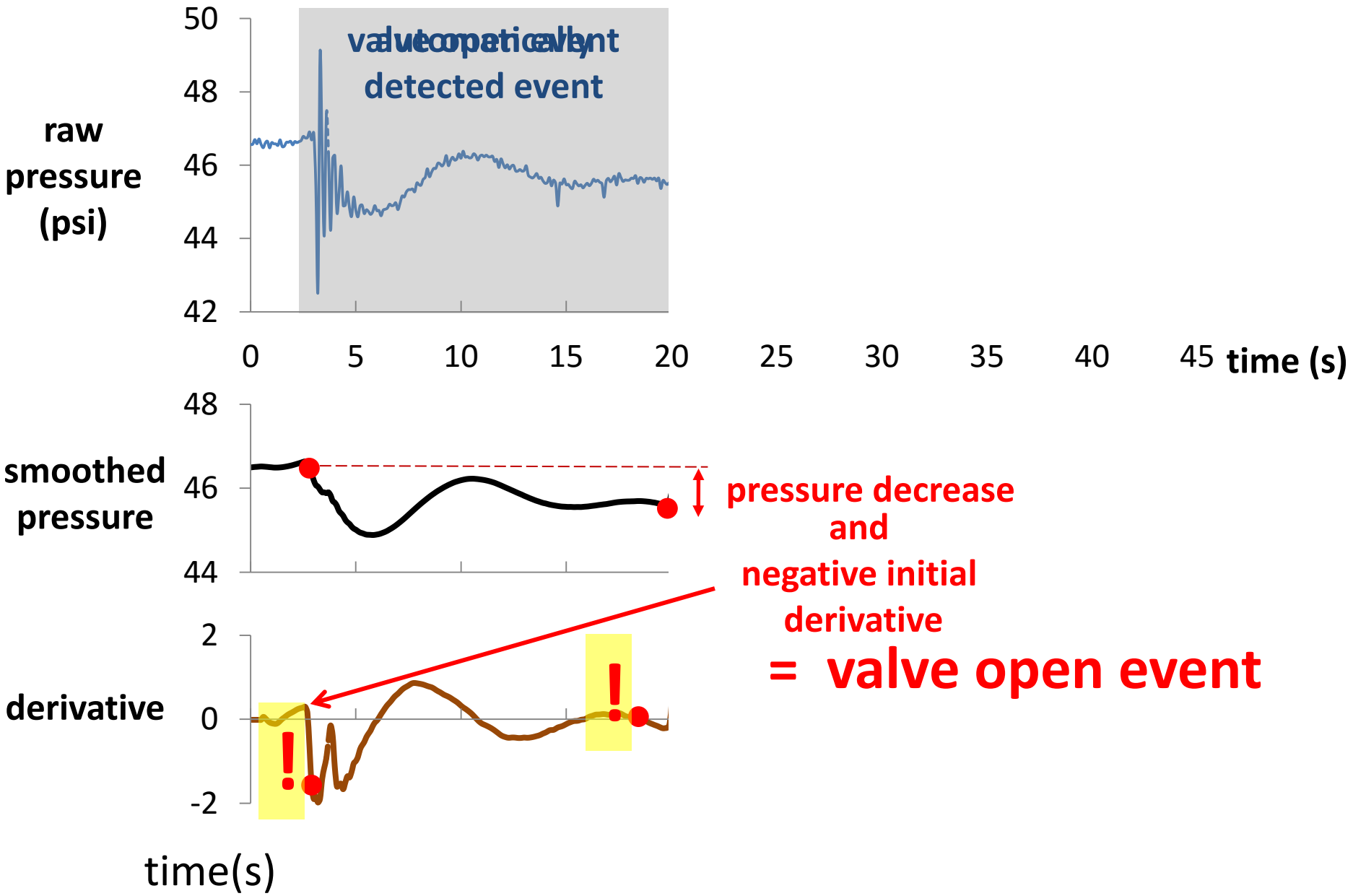
event detection



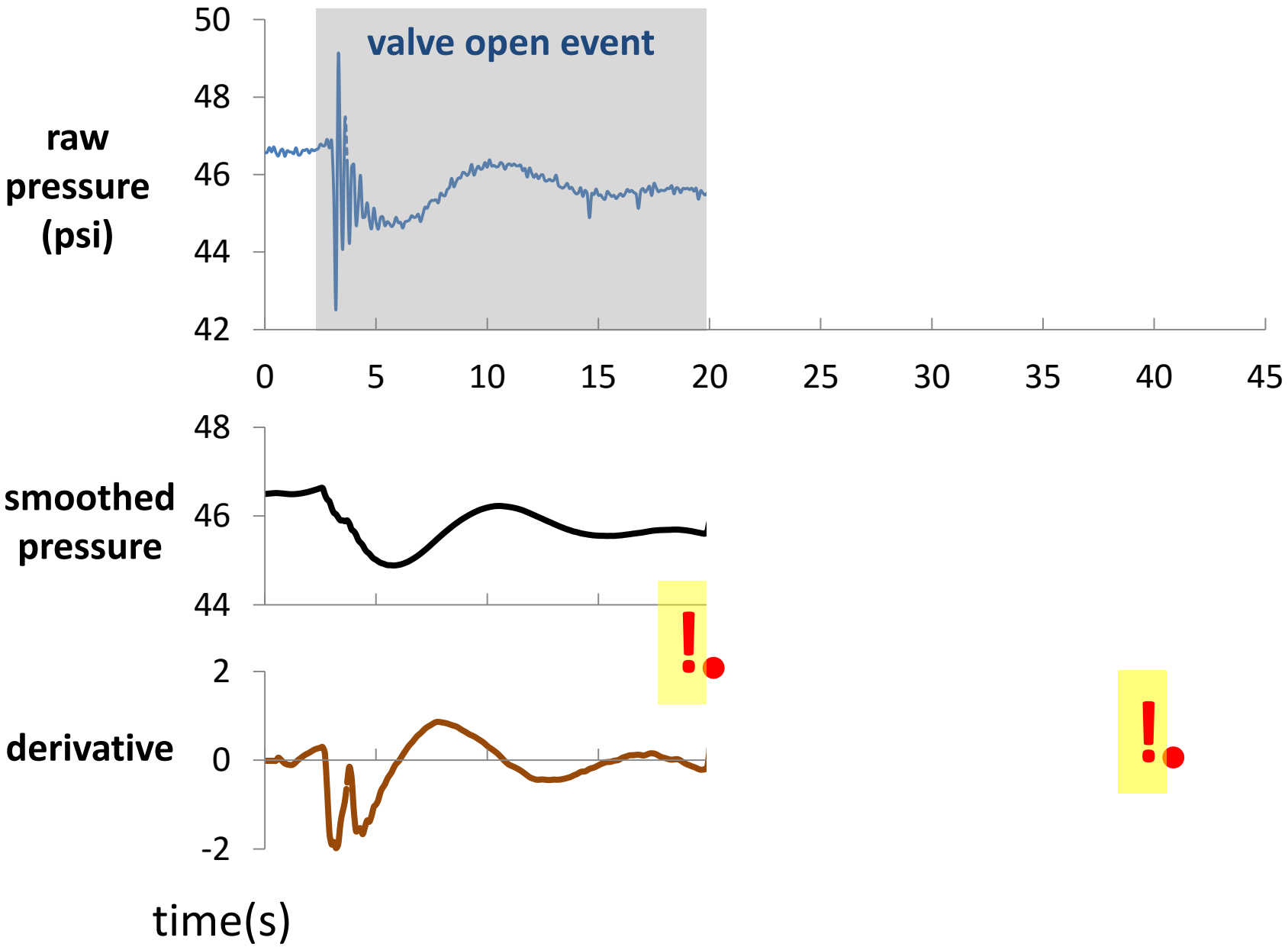
event detection



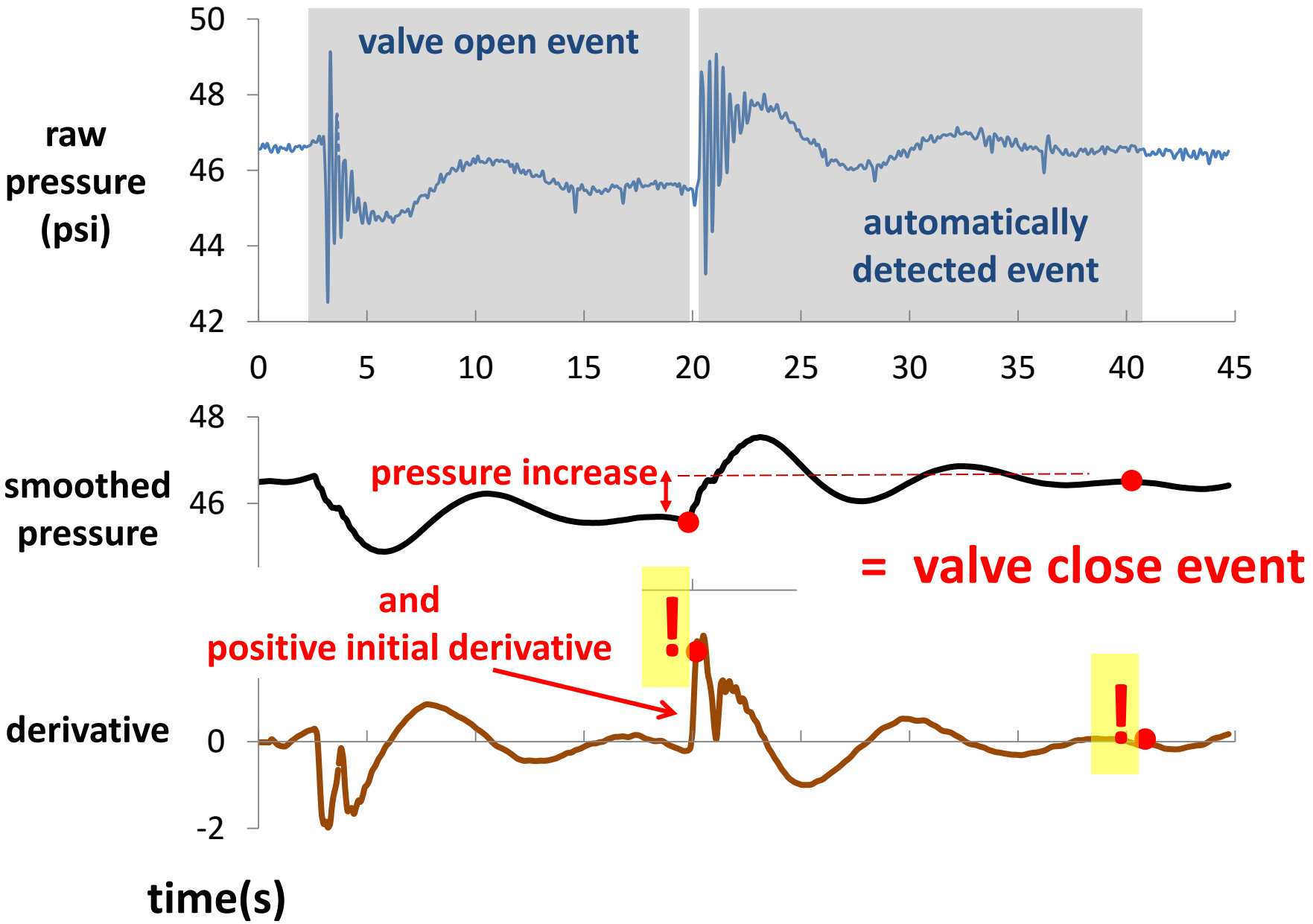
event detection



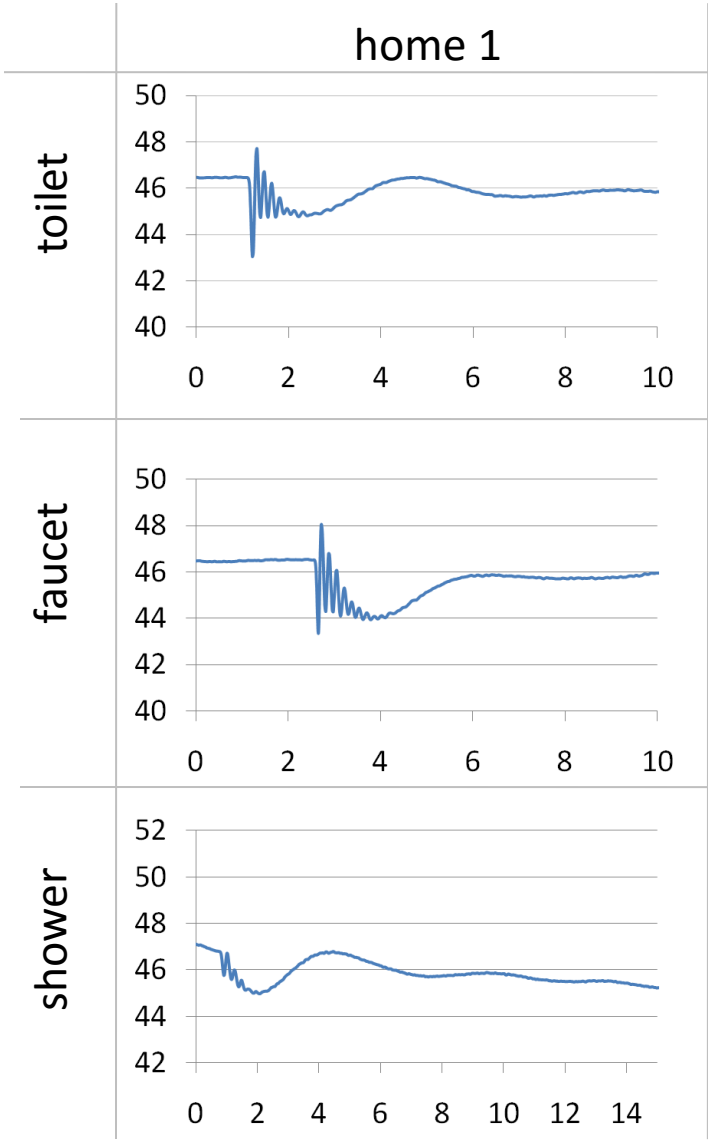
event detection



event detection



example open events

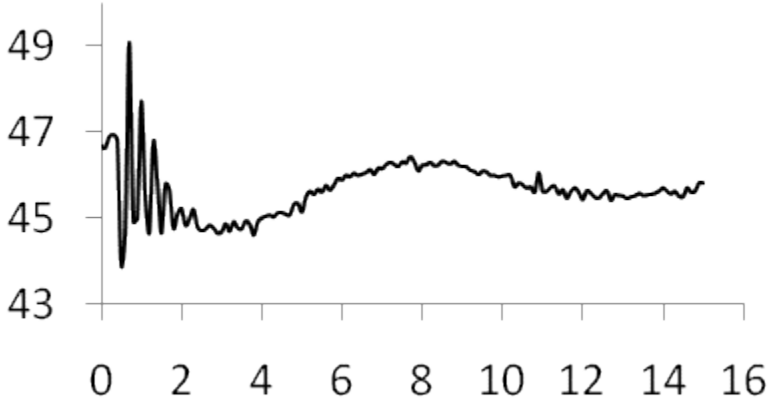


signature dependent on:

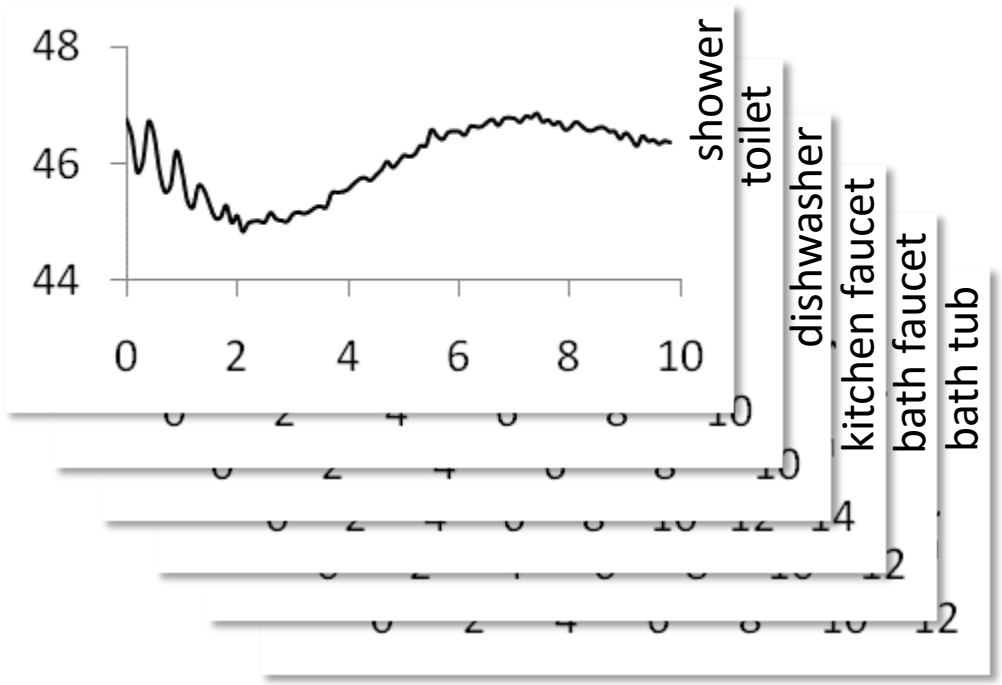
- **fixture type**
- **valve type**
- **valve location in home**

fixture classification

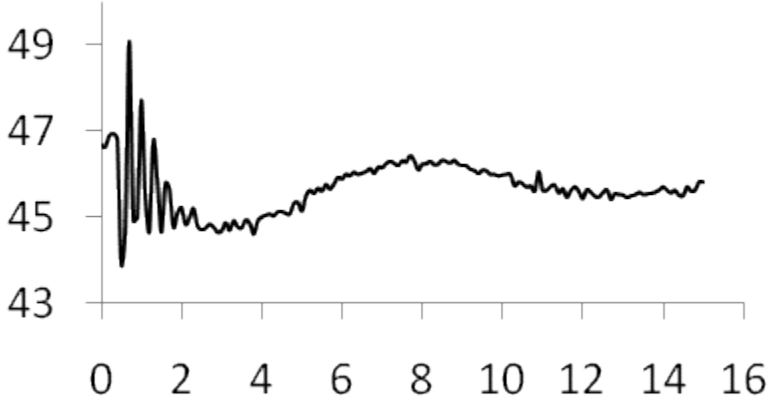
unclassified open event



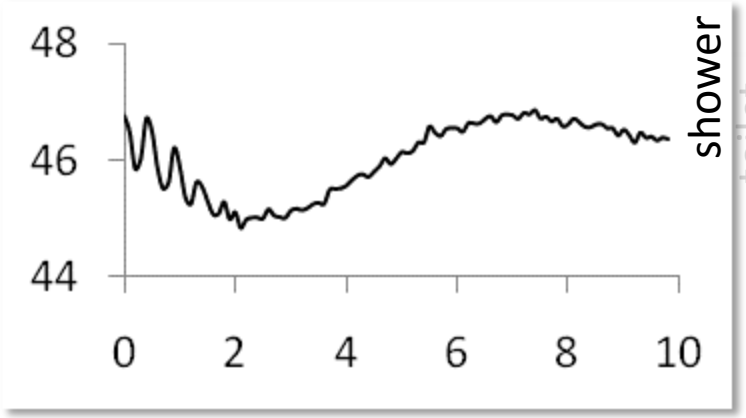
open event library

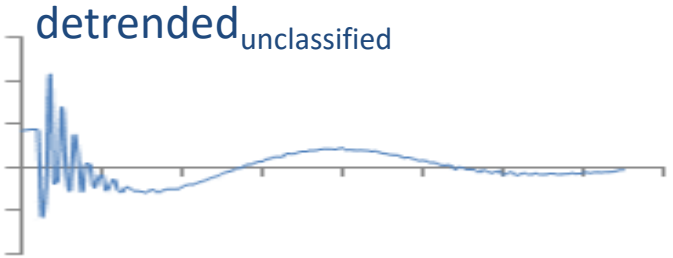


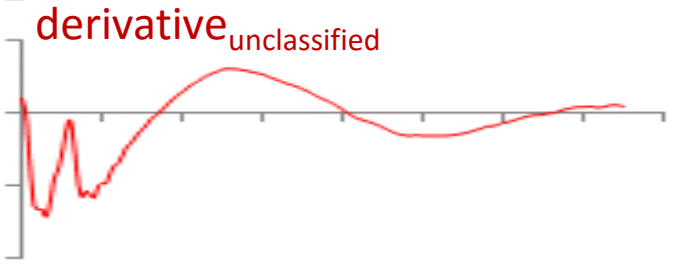
unclassified open event

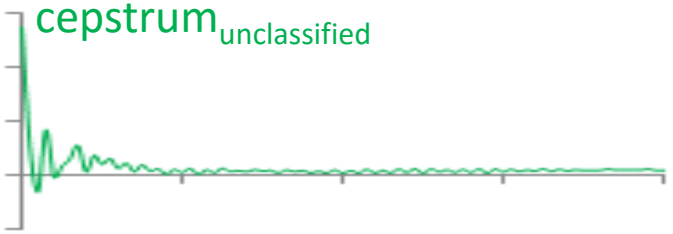


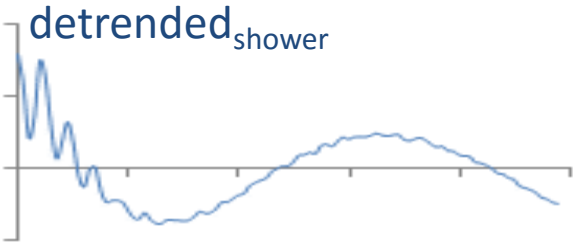
open event library

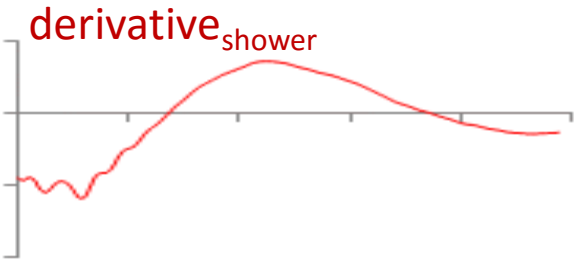


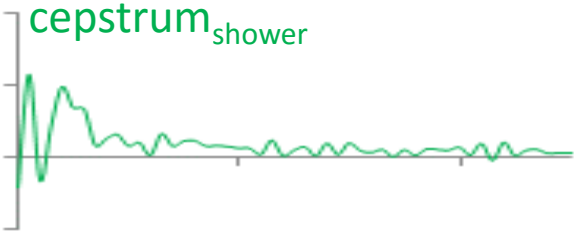


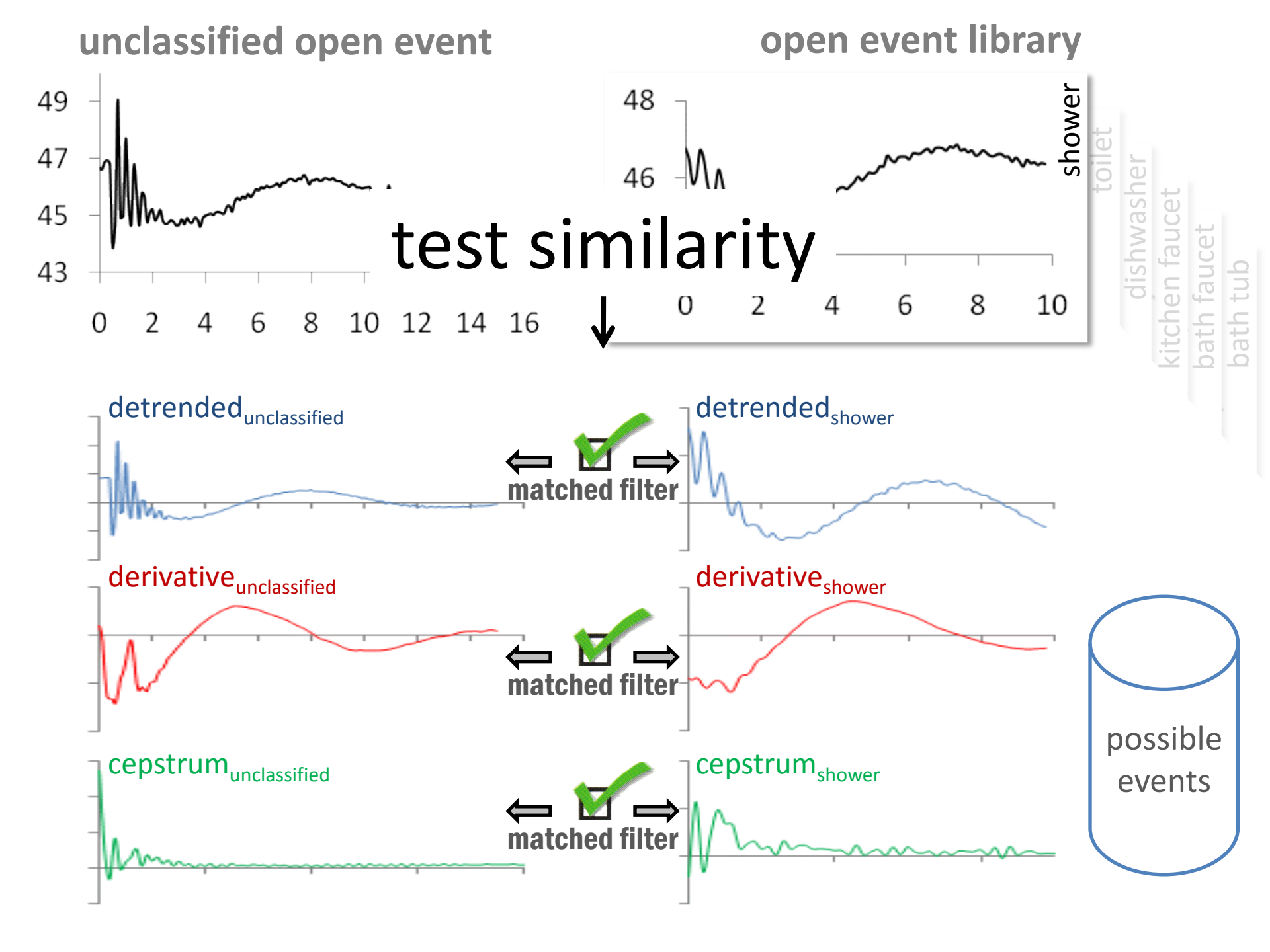




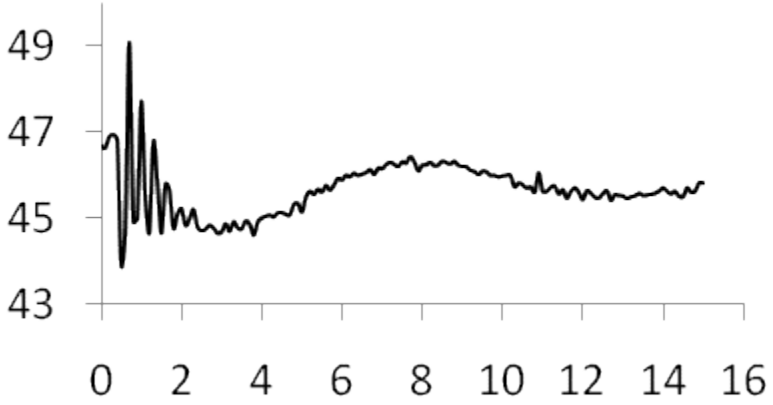




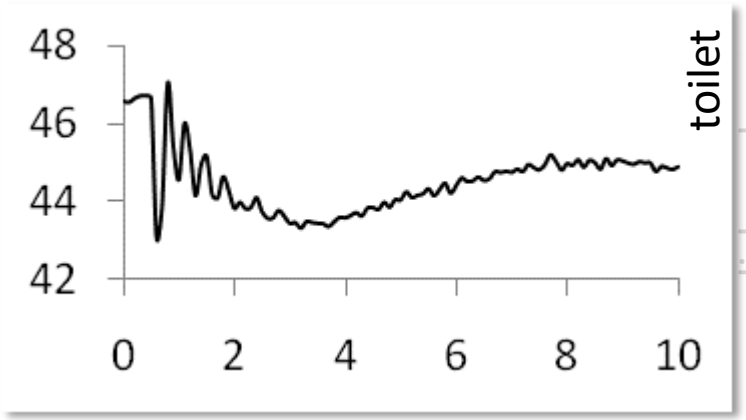


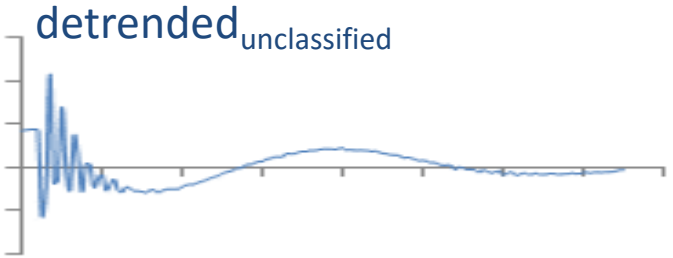

unclassified open event
open event library
49
47
45
43
0 2 4 6 8 10 12 14 16
48
46
shower
toilet
dishwasher
kitchen faucet
bath faucet
bath tub
0 2 4 6 8 10
test similarity
detrended unclassified
detrended shower
matched filter
derivative unclassified
derivative shower
matched filter
cepstrum unclassified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

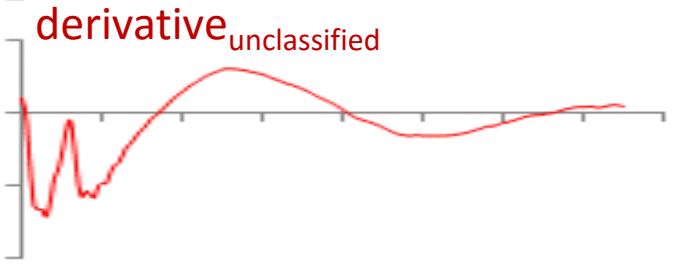
unclassified open event

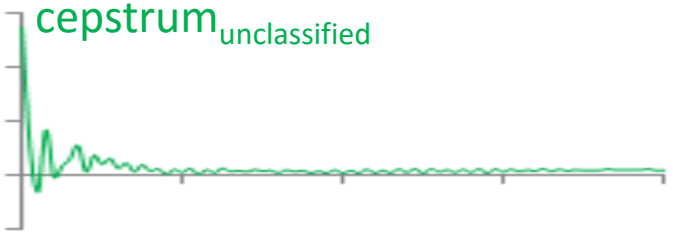


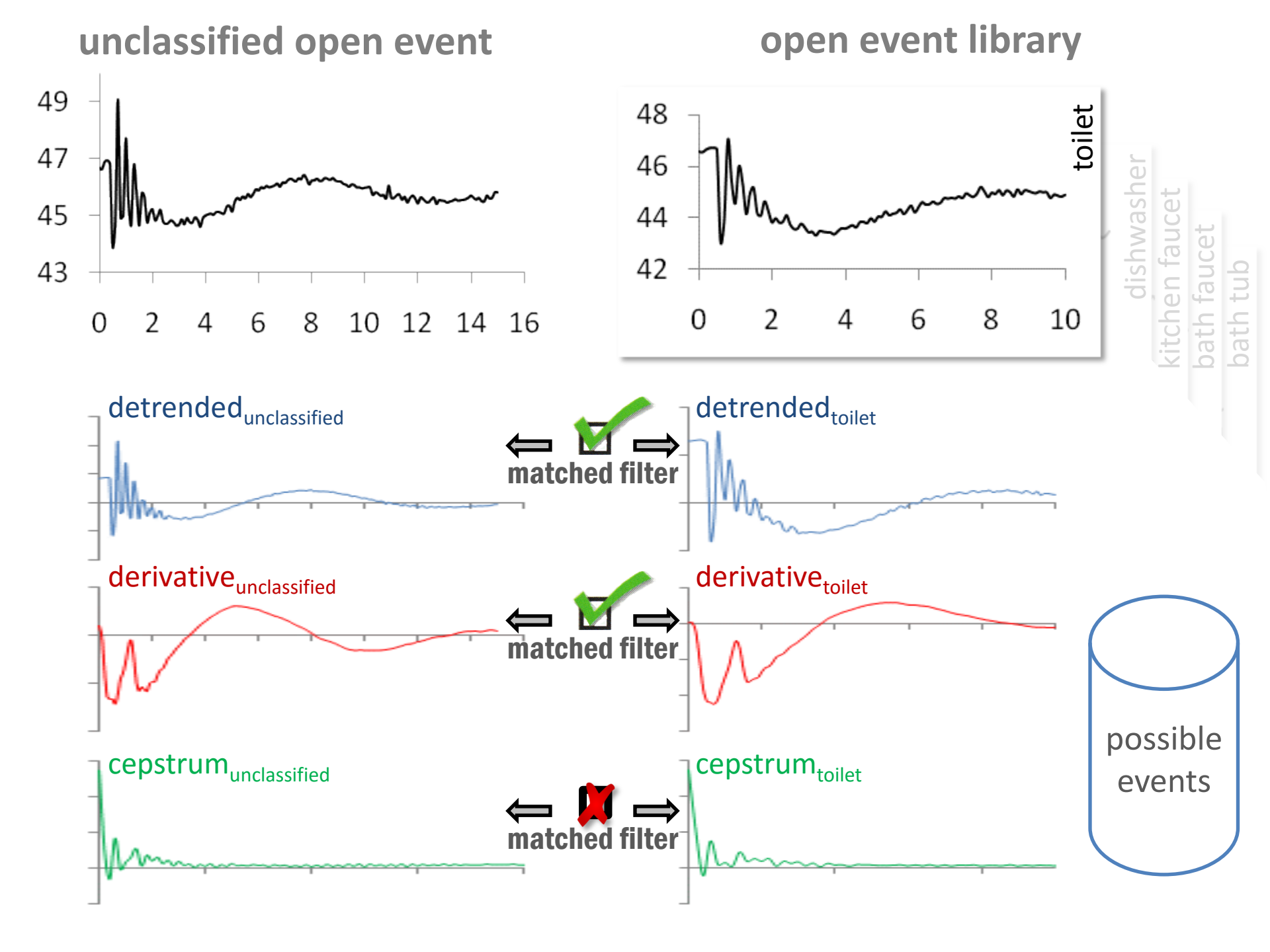
open event library



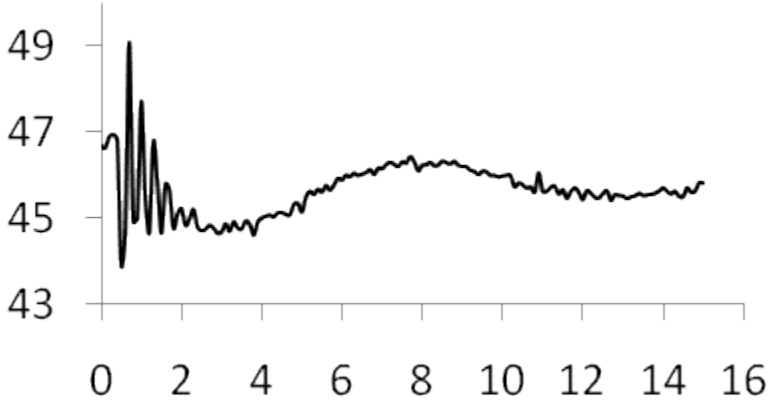


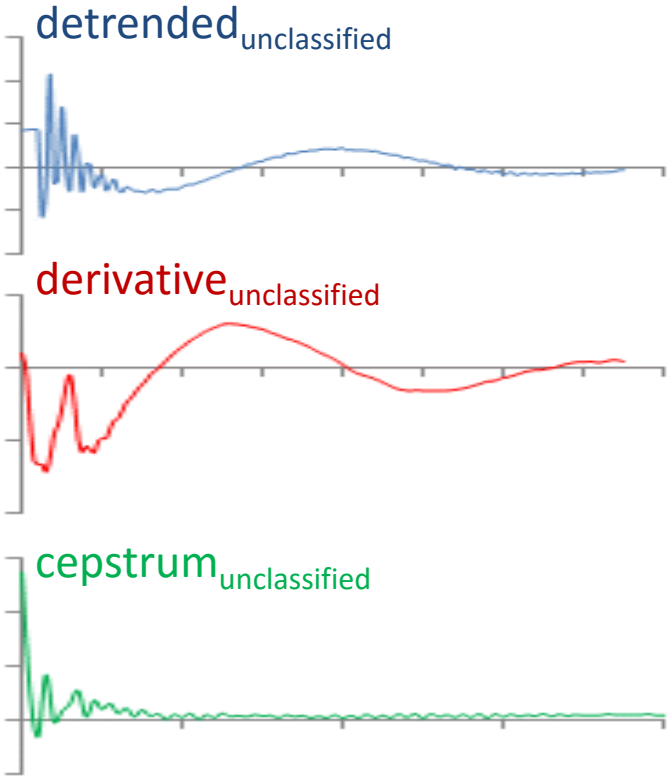





unclassified open event
open event library
49
47
45
43
0 2 4 6 8 10 12 14 16
48
46
44
42
0 2 4 6 8 10
toilet
dishwasher
kitchen faucet
bath faucet
bath tub
detrended unclassified
matched filter
detrended toilet
derivative unclassified
matched filter
derivative toilet
cepstrum unclassified
matched filter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

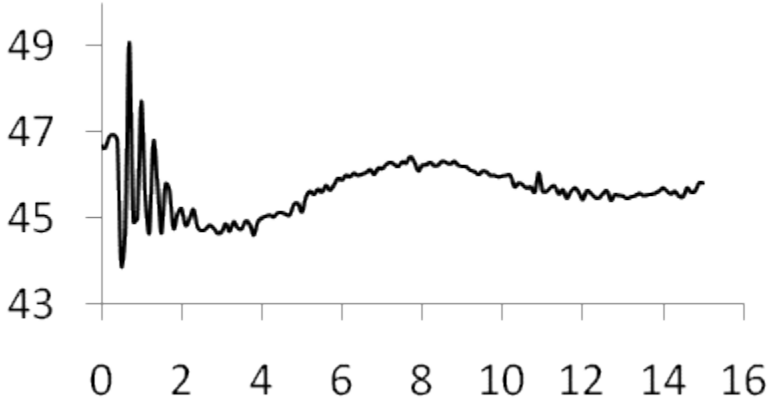
unclassified open event

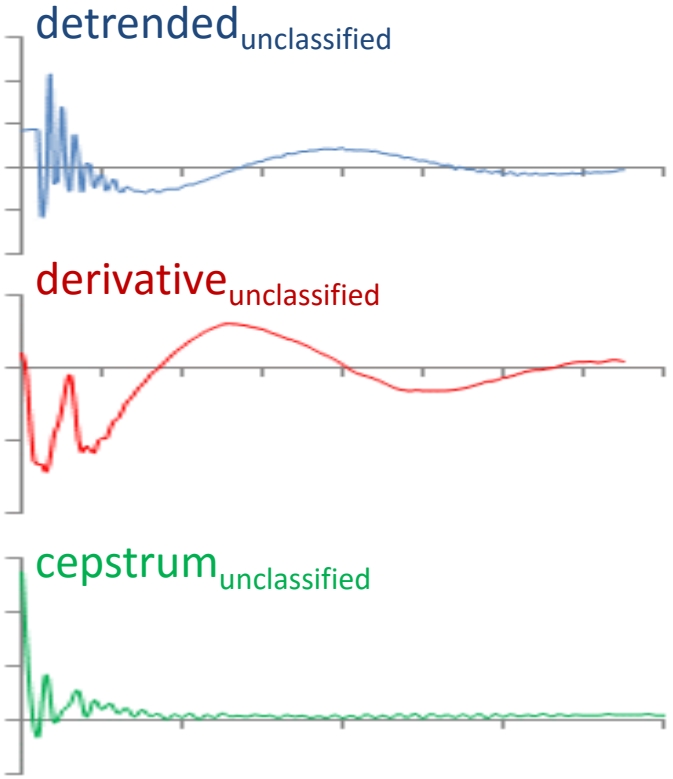




open event library

unclassified open event





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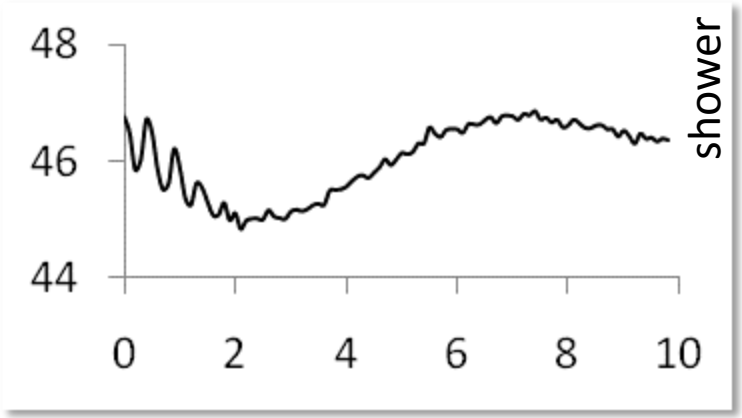

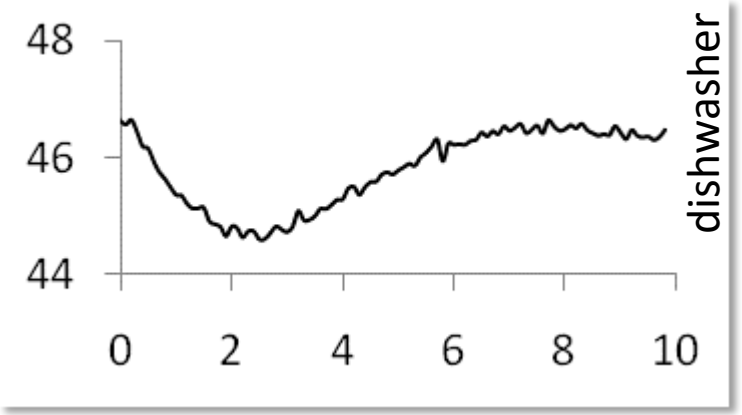

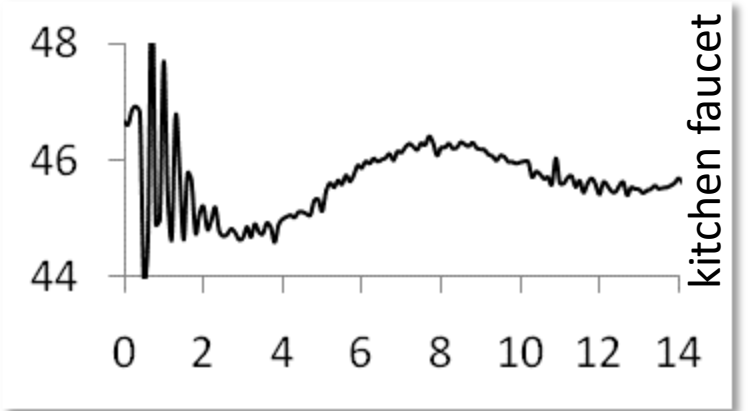

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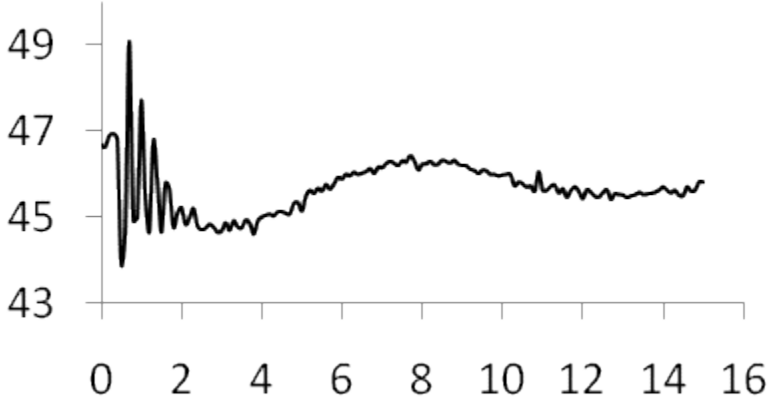

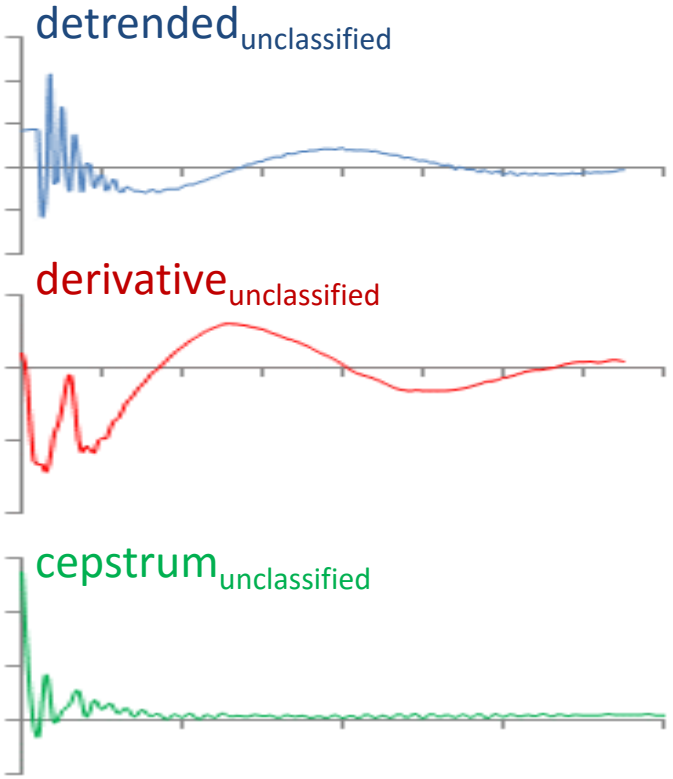

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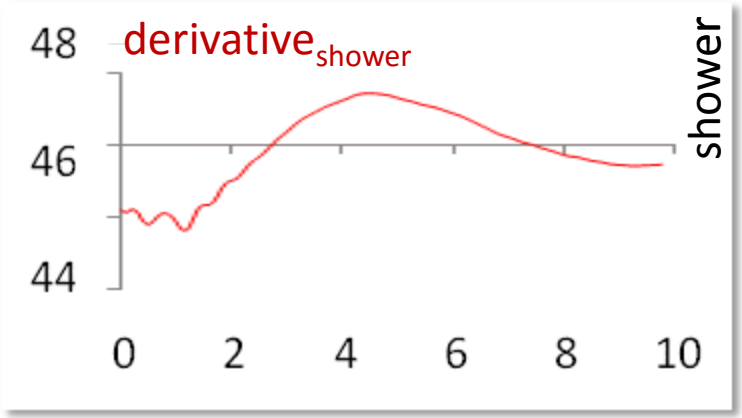

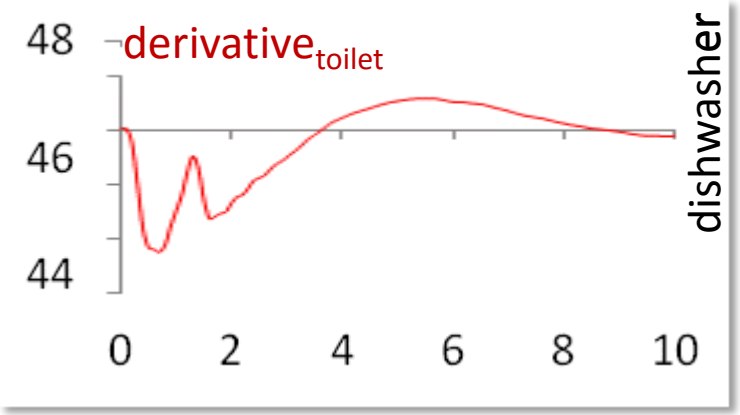

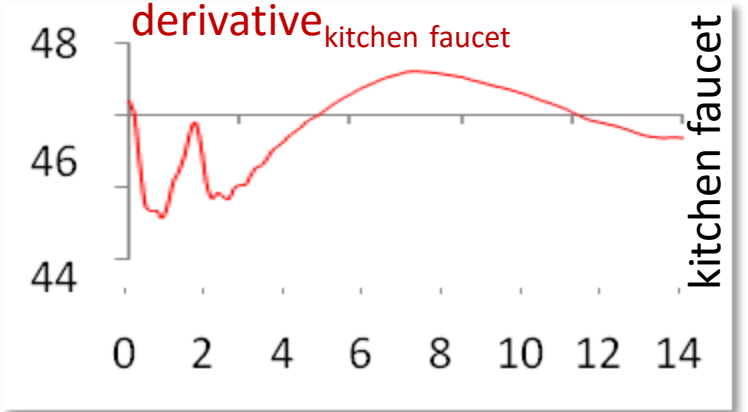

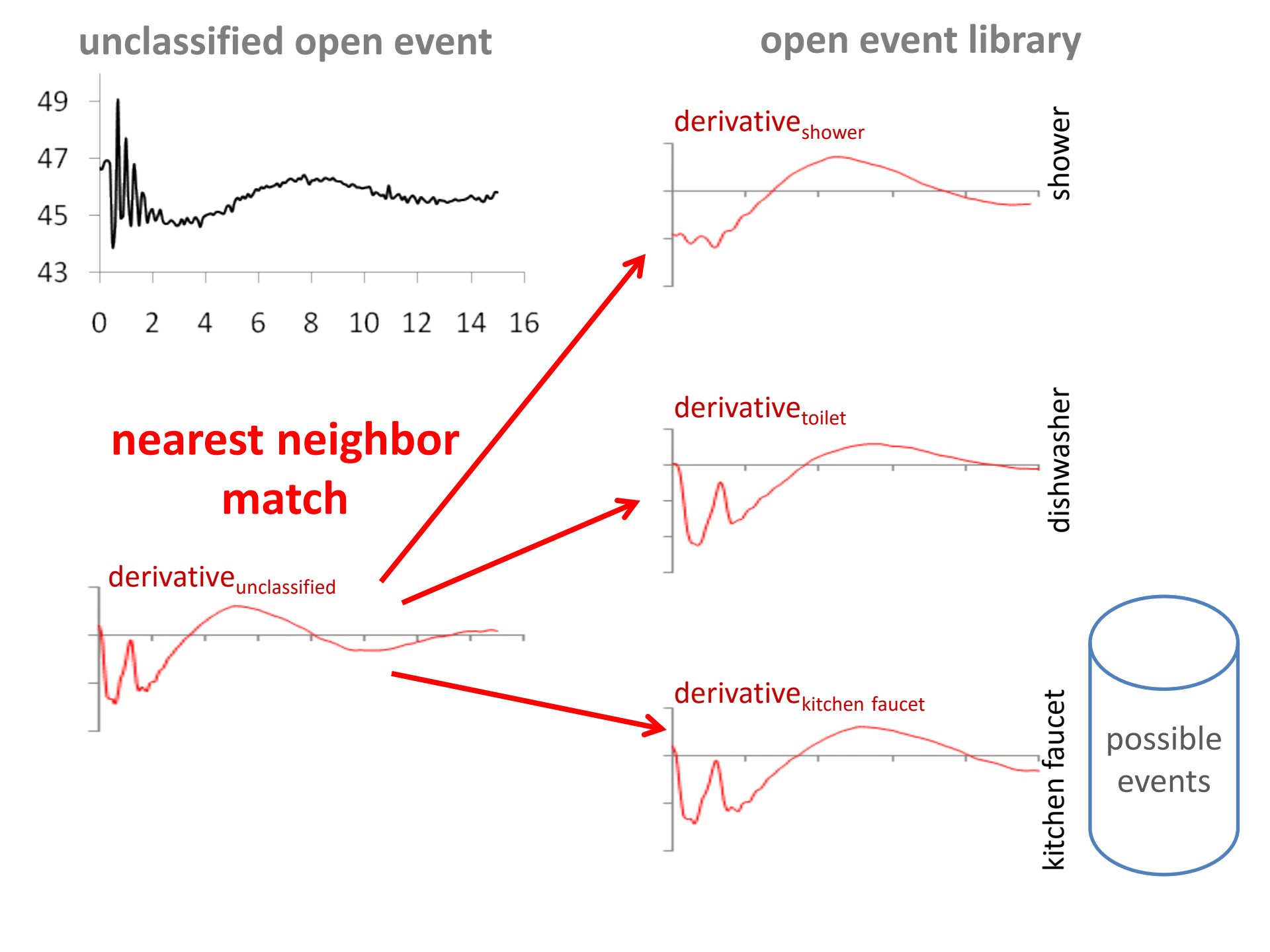
unclassified open event
open event library
49
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45
43
0
2
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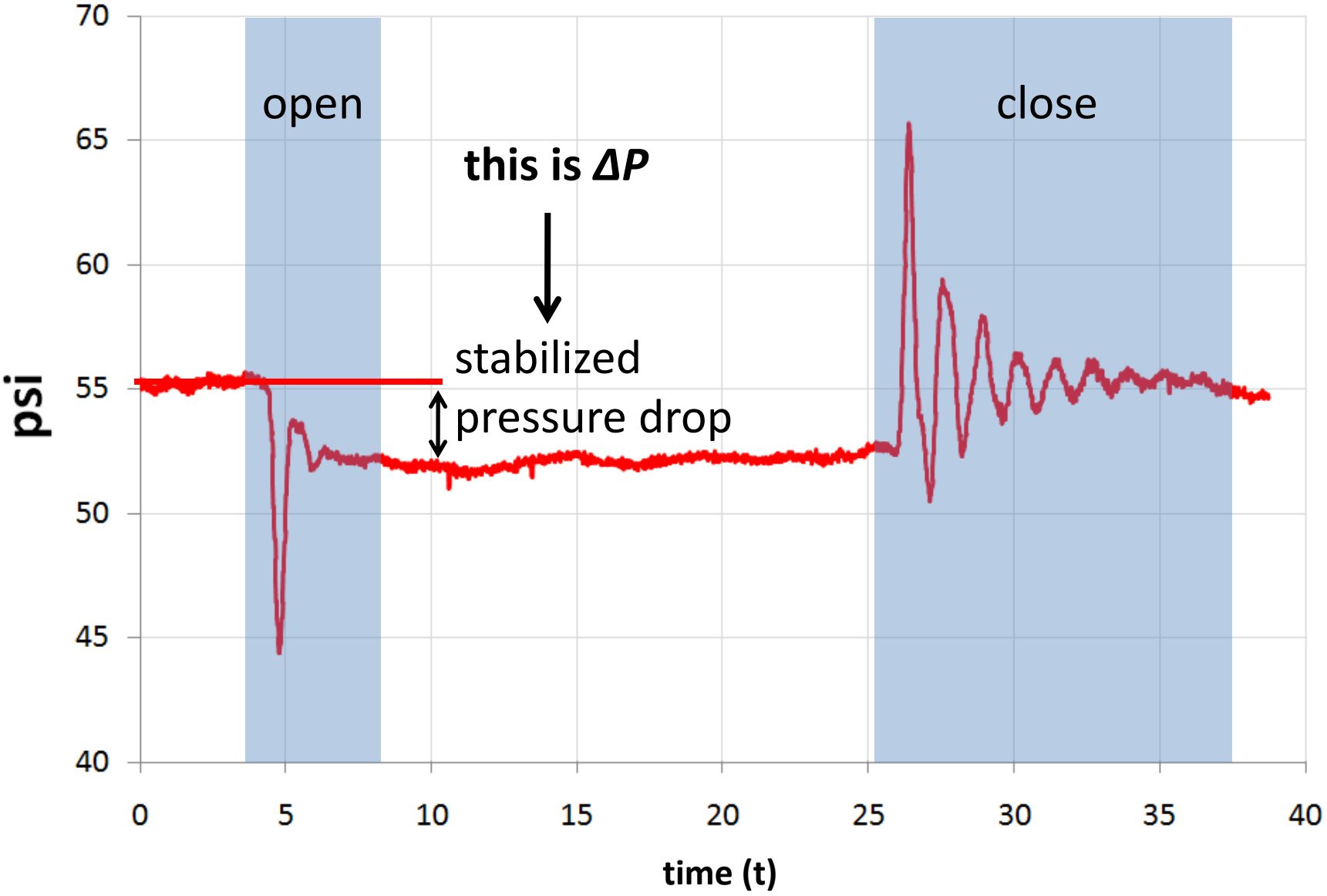
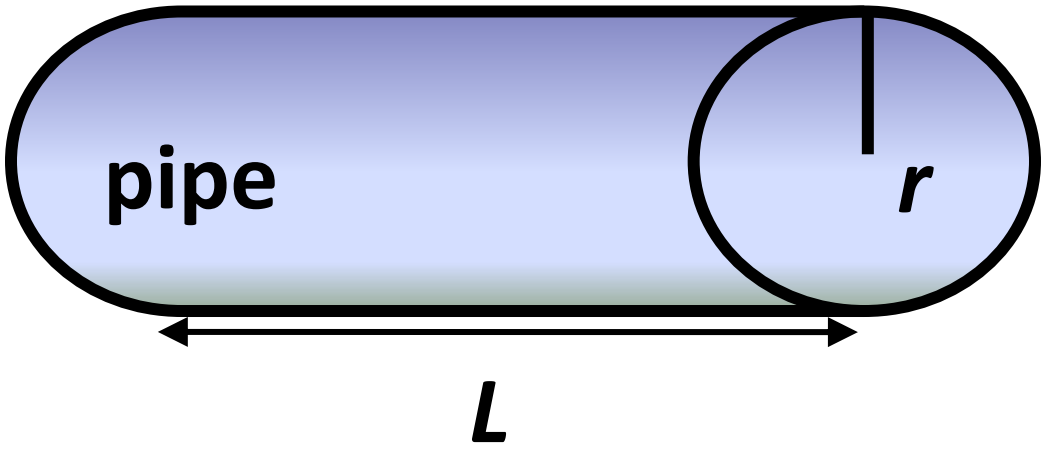
6
8
10
12
14
16
derivative shower
shower
derivative toilet
dishwasher
nearest neighbor match
derivative unclassified
derivative kitchen faucet
kitchen faucet
possible events

raw bathroom sink signal



using ∆pressure to estimate flow



ΔP = change in pressure
L = length of pipe
r = radius of pipe
μ = viscosity of liquid
Q = volumetric flow rate

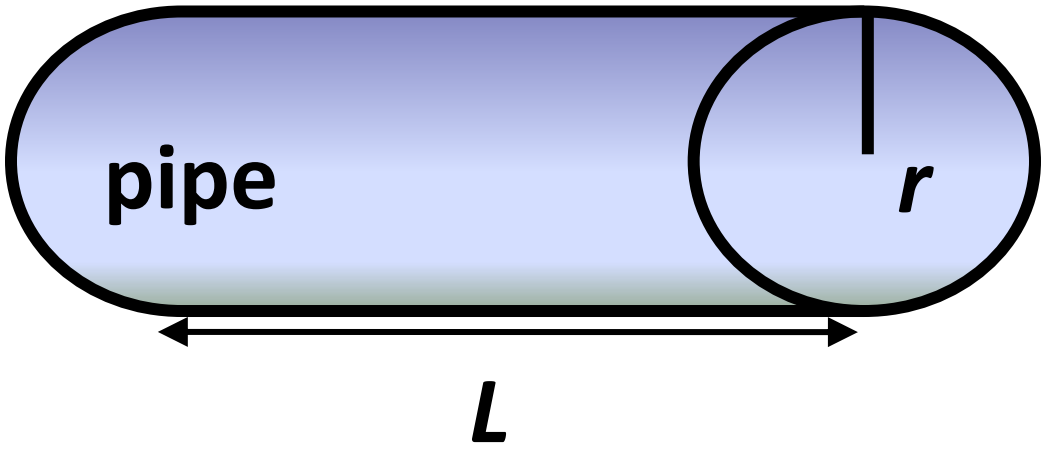
poiseuille's law:

$$Q = \frac{\Delta P \, \pi \, r^4}{8 \, \mu \, L}$$

fluid resistance formula:

$$R_f = \frac{\Delta P}{Q}$$

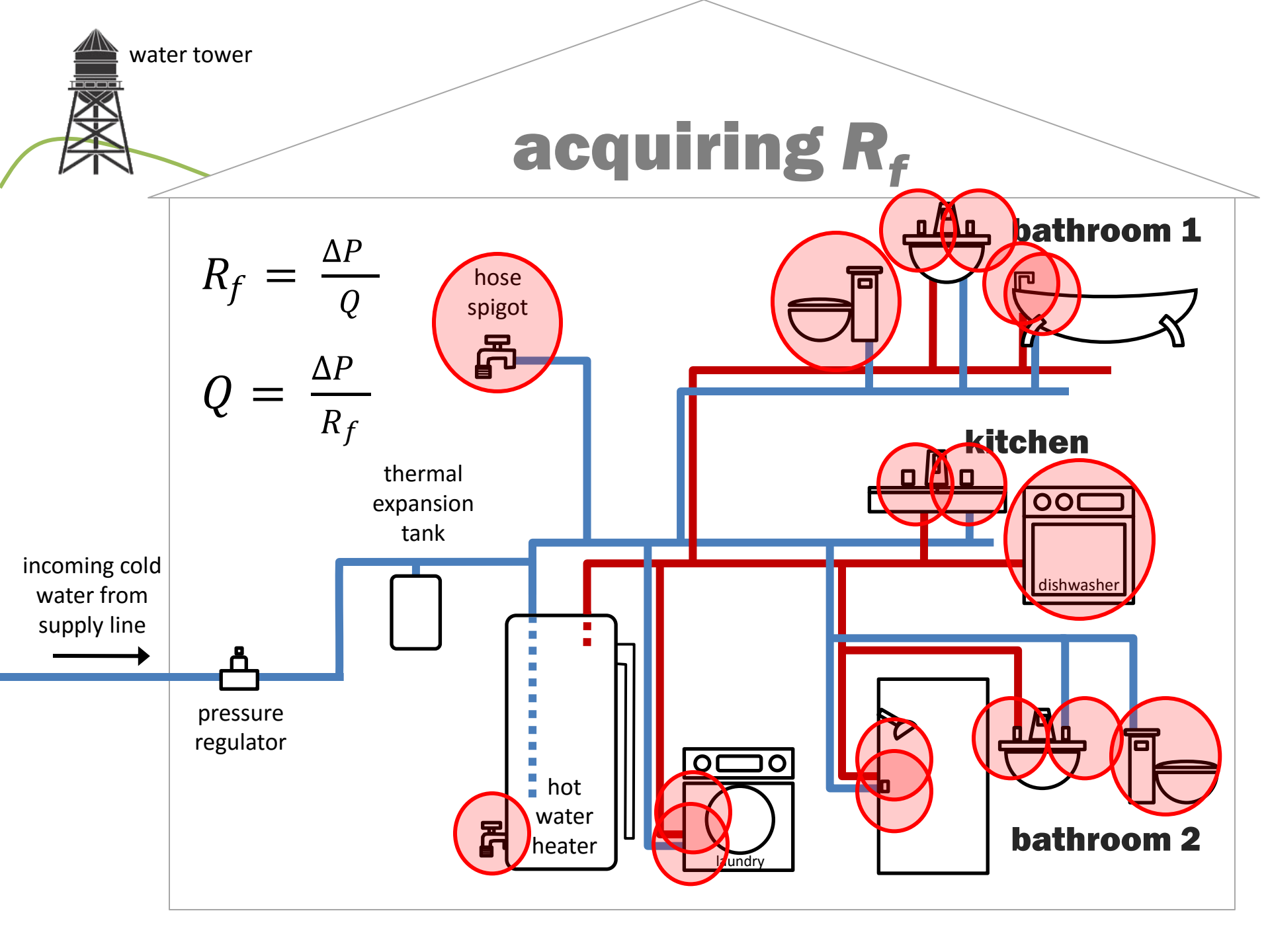
using ∆pressure to estimate flow



ΔP = change in pressure
L = length of pipe
r = radius of pipe
μ = viscosity of liquid
Q = volumetric flow rate

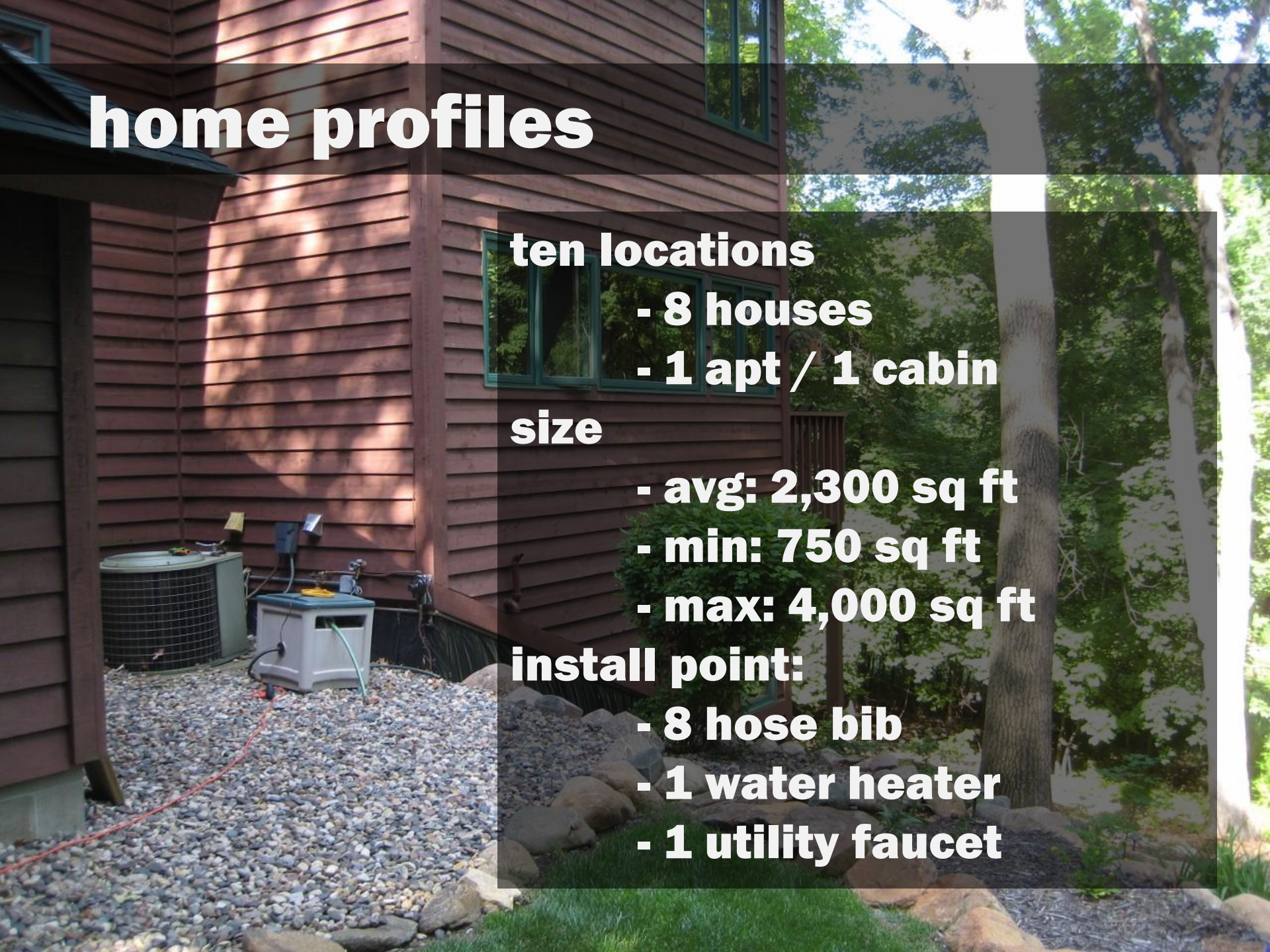
$$Q = \frac{\Delta P}{R_f}$$

acquiring R_f




in-home data collection

home profiles



ten locations

- 8 houses
- 1 apt / 1 cabin

size

- avg: 2,300 sq ft
- min: 750 sq ft
- max: 4,000 sq ft

install point:

- 8 hose bib
- 1 water heater
- 1 utility faucet

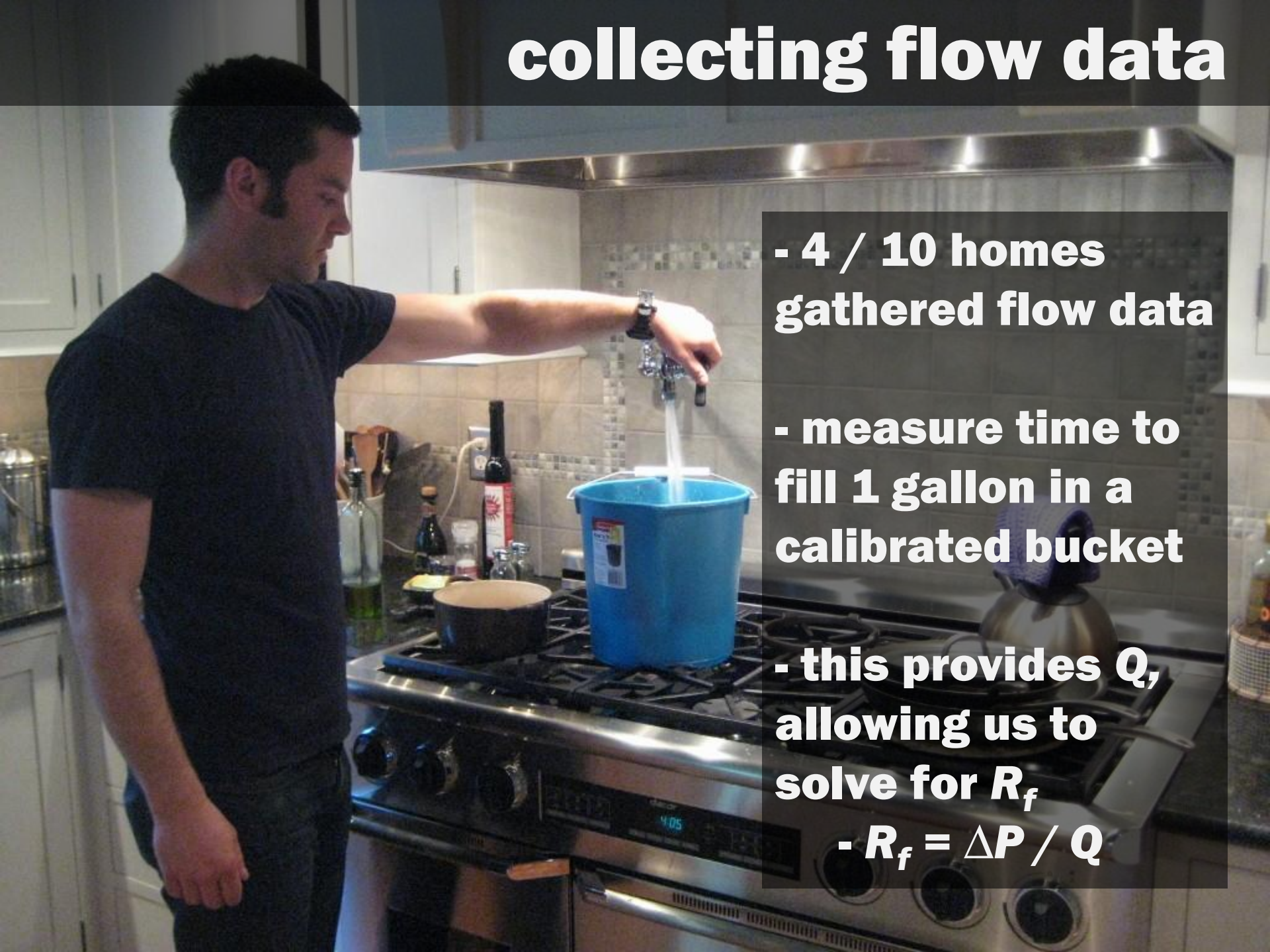
experimental protocol

- controlled experiments
  - 2 researchers per site

- 5 trials per valve
  - e.g., 5 cold / 5 hot for bathroom sink

- for each trial, valve open for 5 seconds, then closed

collecting flow data



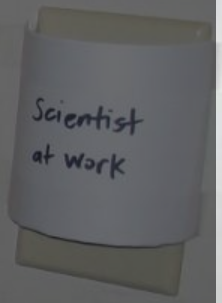
- 4 / 10 homes gathered flow data

- measure time to fill 1 gallon in a calibrated bucket

- this provides Q, allowing us to solve for R_f
  - $R_f = \Delta P / Q$

data collection stats

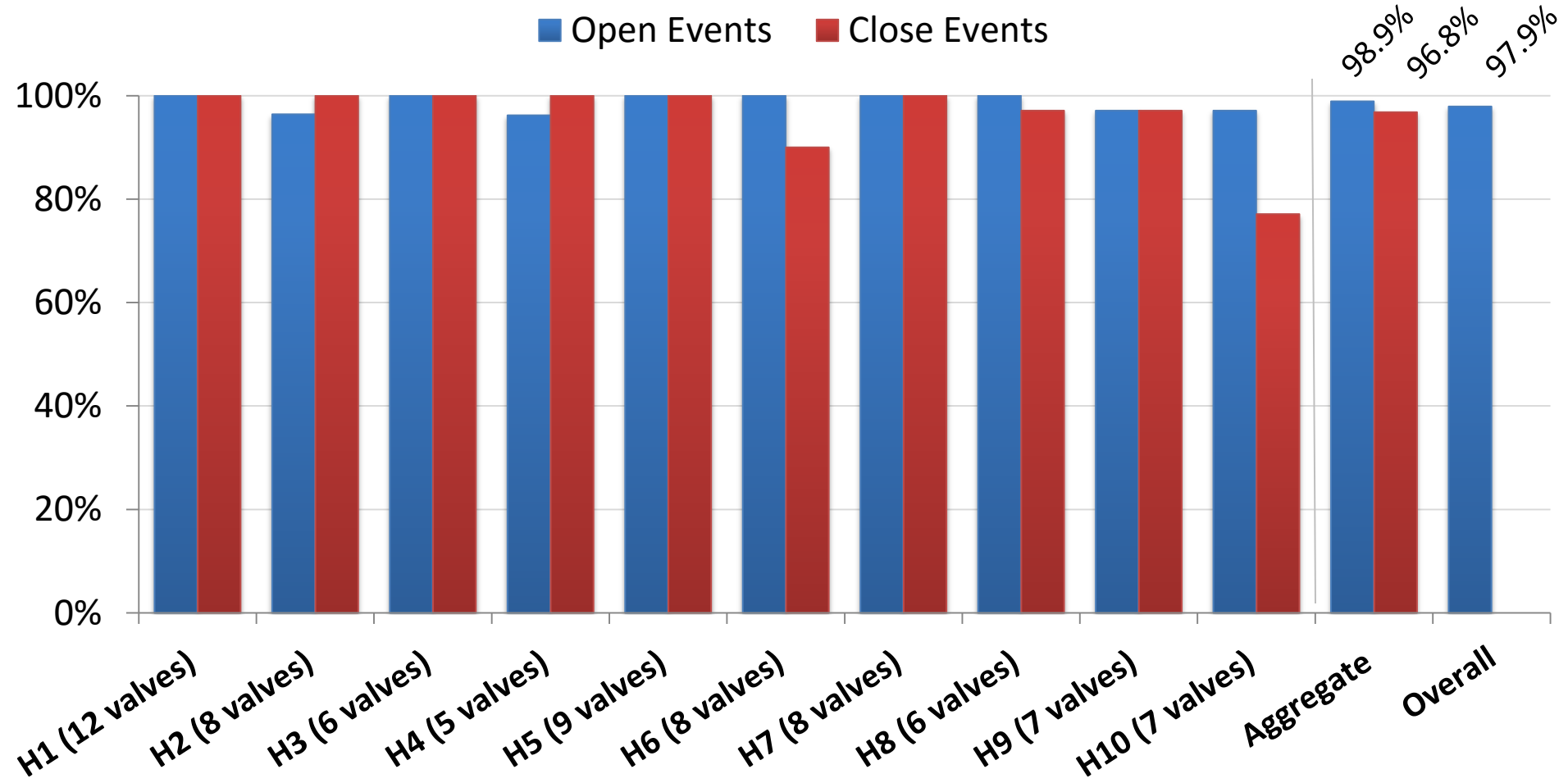
- ten locations
- 706 trials
- 155 flow rate trials
- 84 total fixtures tested



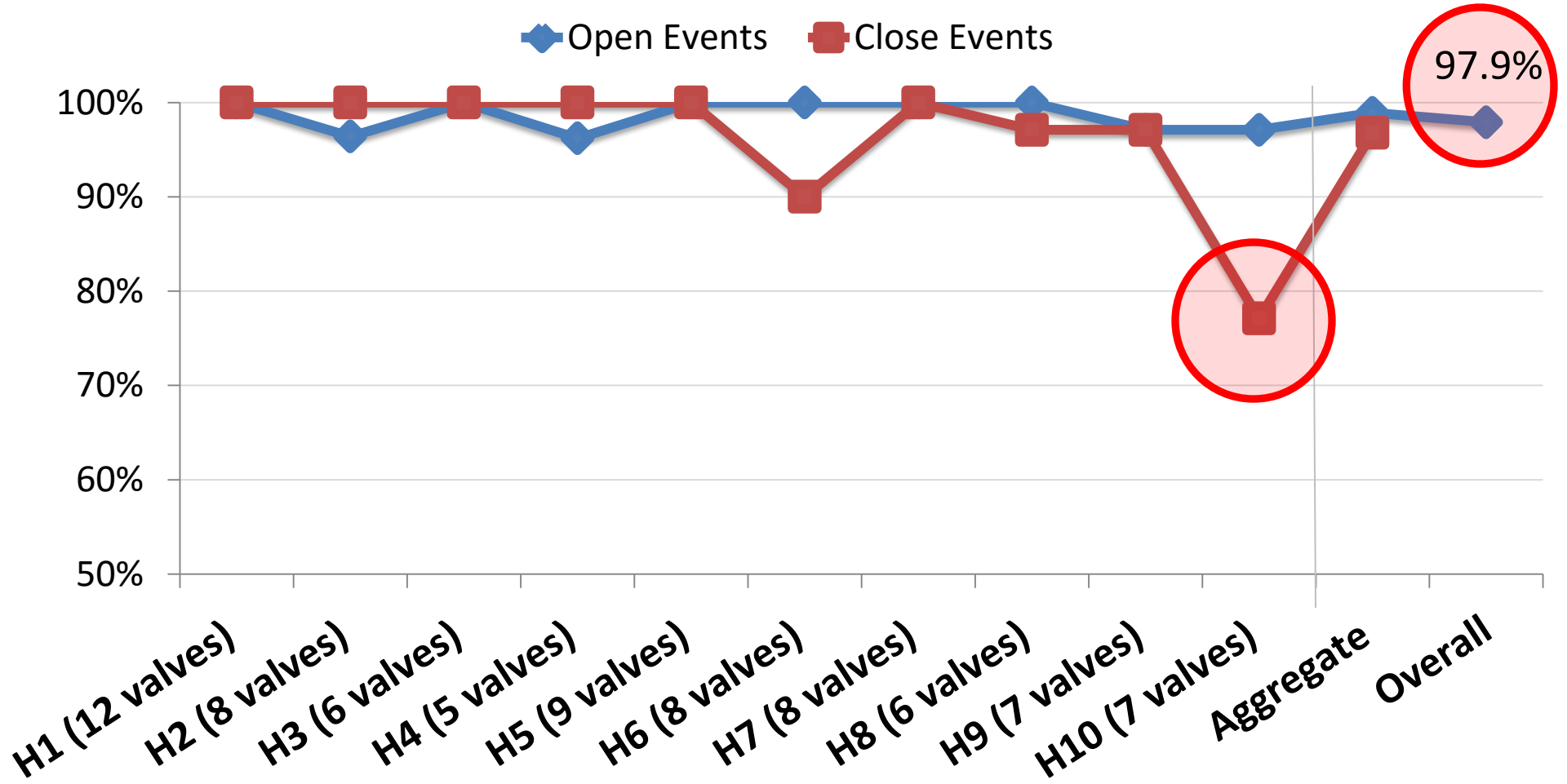
classification results across homes

- cross validation experiment
- learn similarity thresholds from test data
- classify each event per home using a leave-one out method

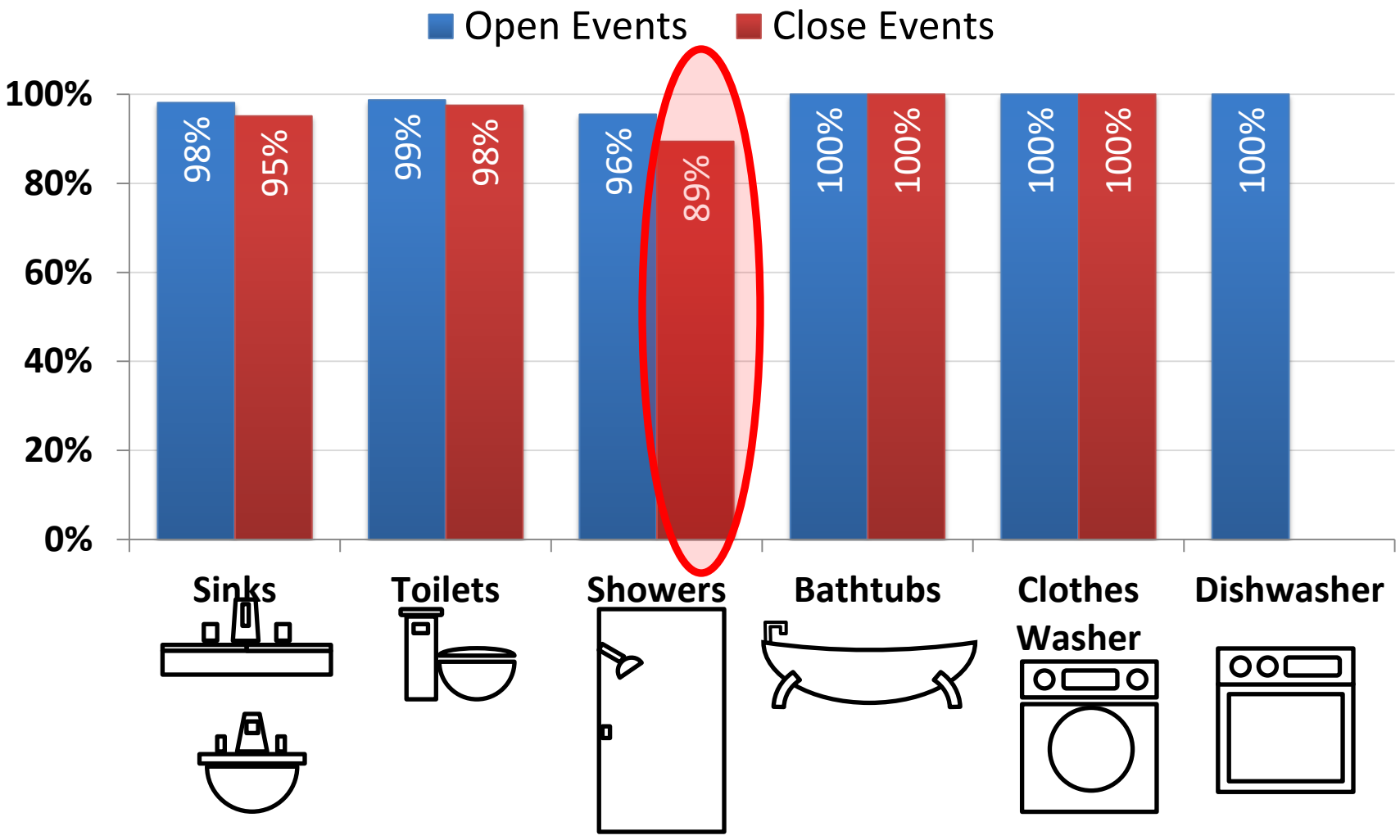
fixture classification results across homes



fixture classification results across homes



fixture classification results across fixtures



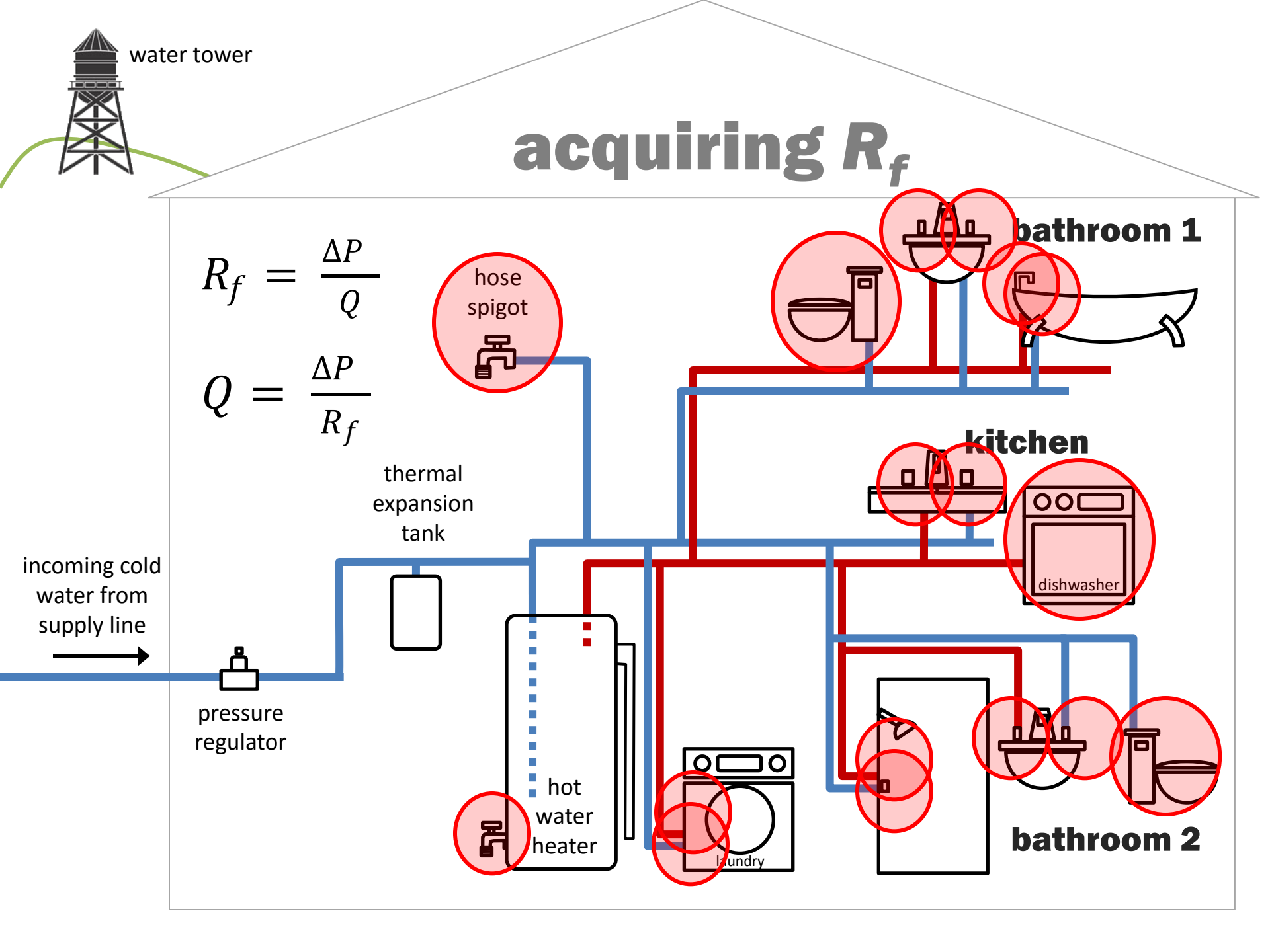
flow estim

Home	Avg Erro (GPM)			
H1 (7 valves)	0.17			
H4 (6 valves)	0.19			
H5 (8 valves)	0.13		4.5	5.5
H7 (8 valves)	0.67	1.47	22.2	46.0

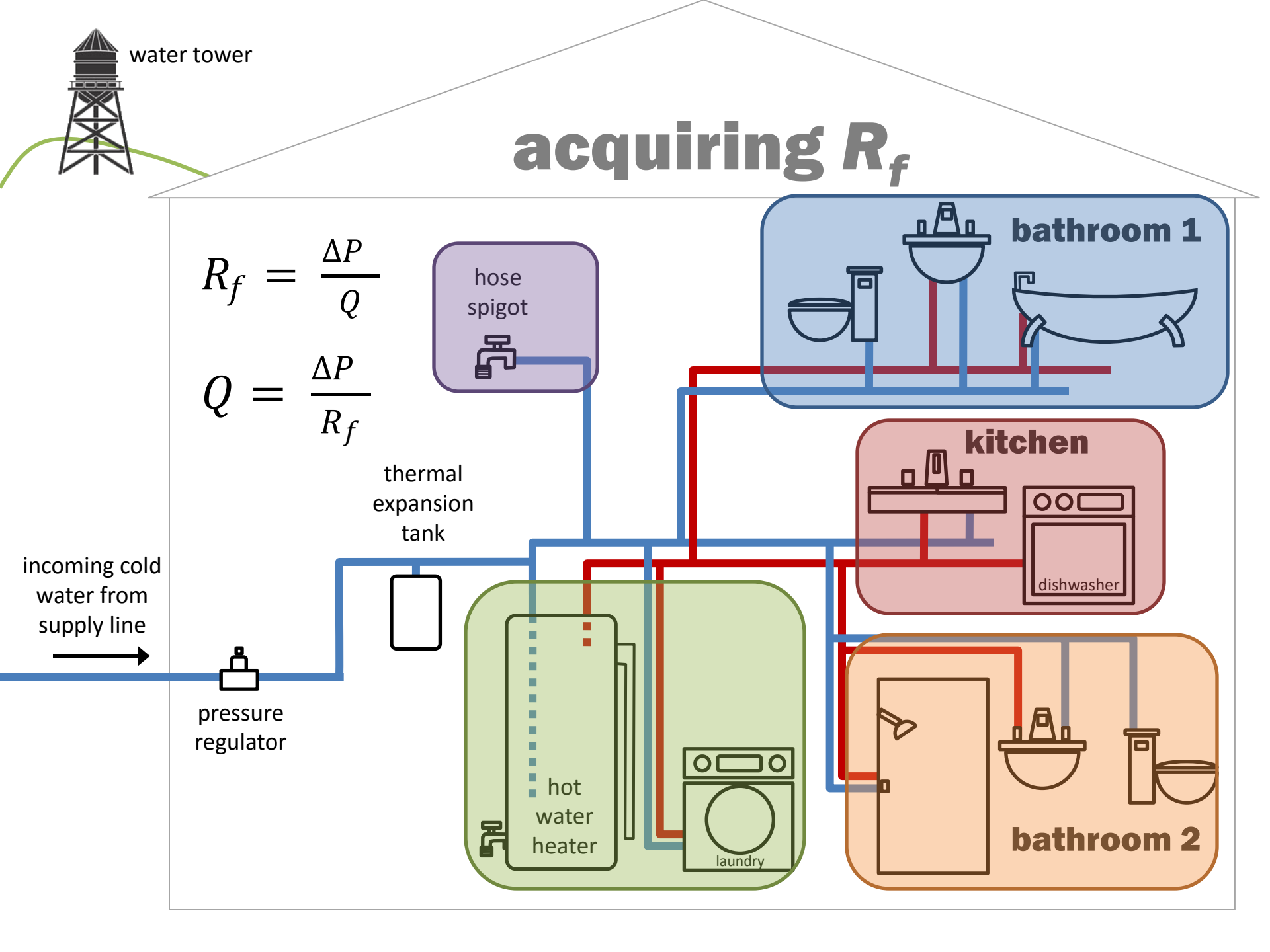
flow estimation results

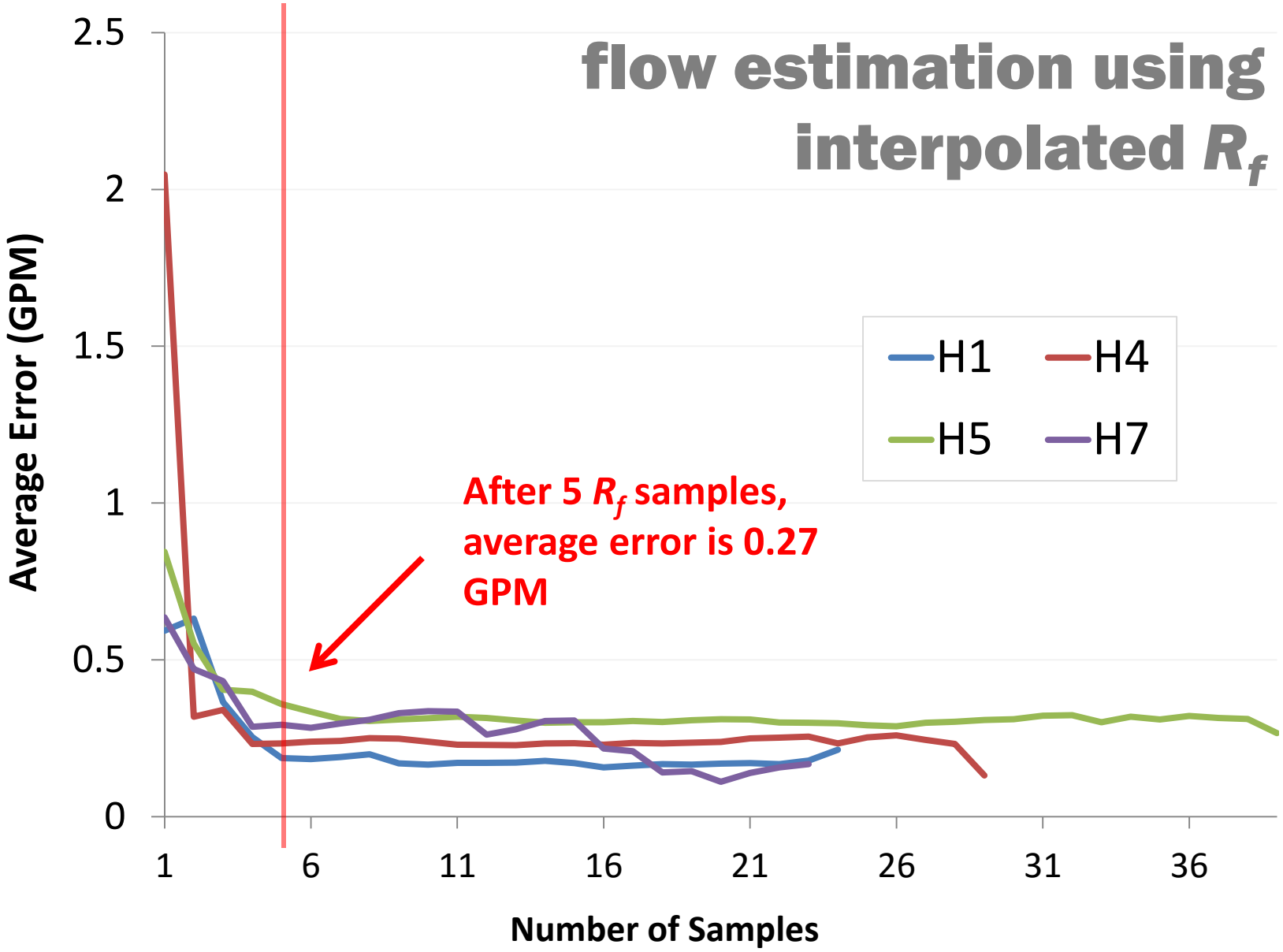
Home	Avg Error (GPM)	Stdev Error (GPM)	Avg Error (%)	Stdev Error (%)
H1 (7 valves)	0.17	0.13	7.3	6.7
H4 (6 valves)	0.19	0.17	5.6	5.3
H5 (8 valves)	0.13	0.11	4.5	5.5
H7 (4 valves)	0.15	0.18	4.5	3.8

acquiring R_f

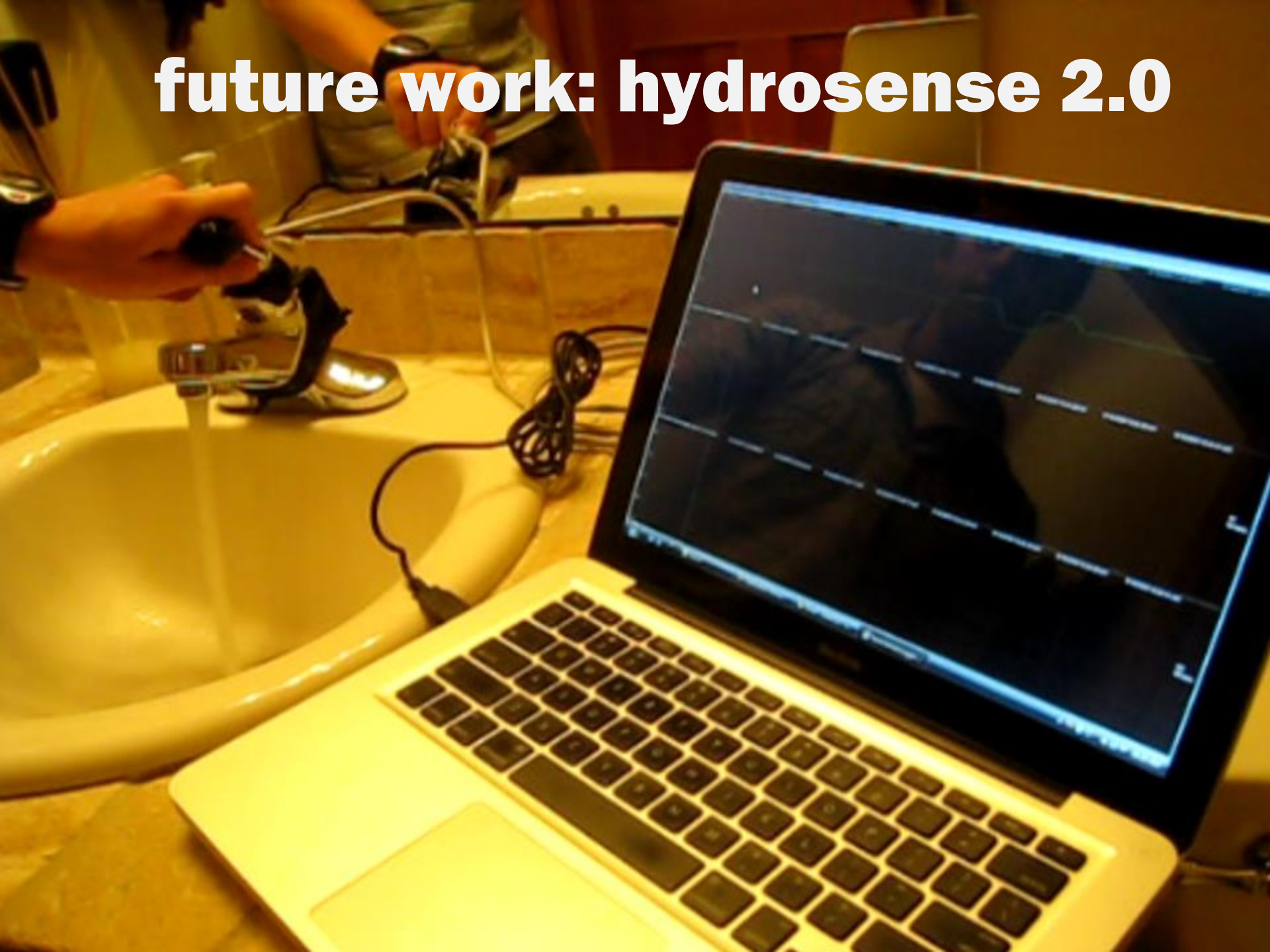


acquiring R_f

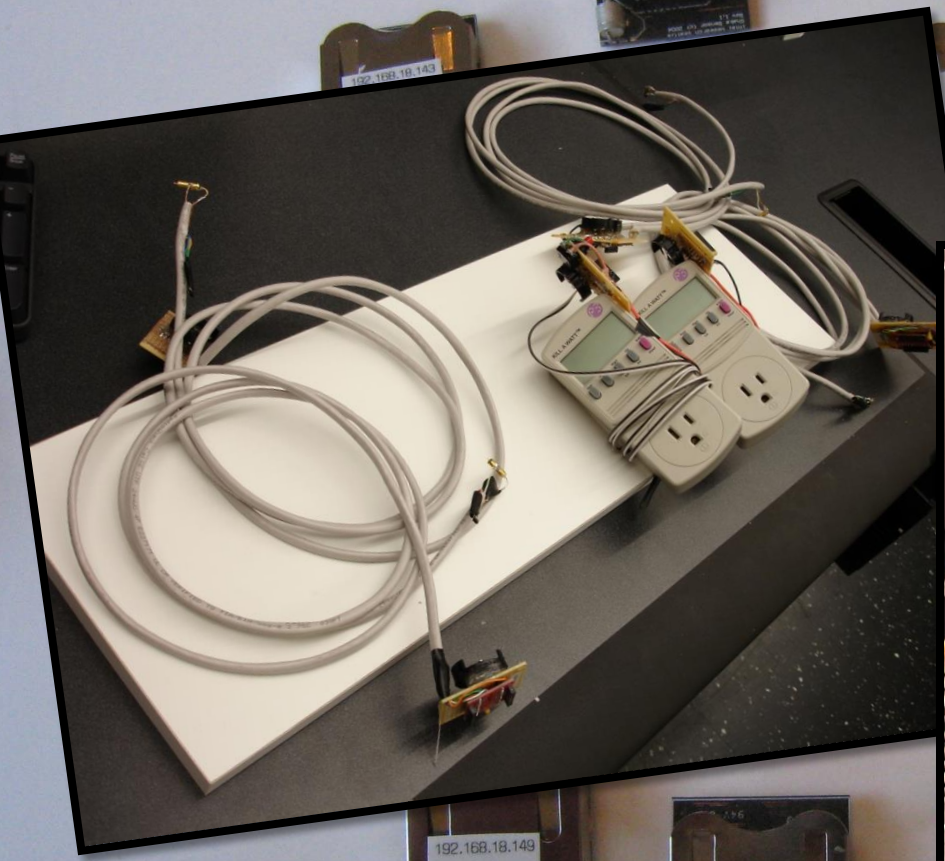


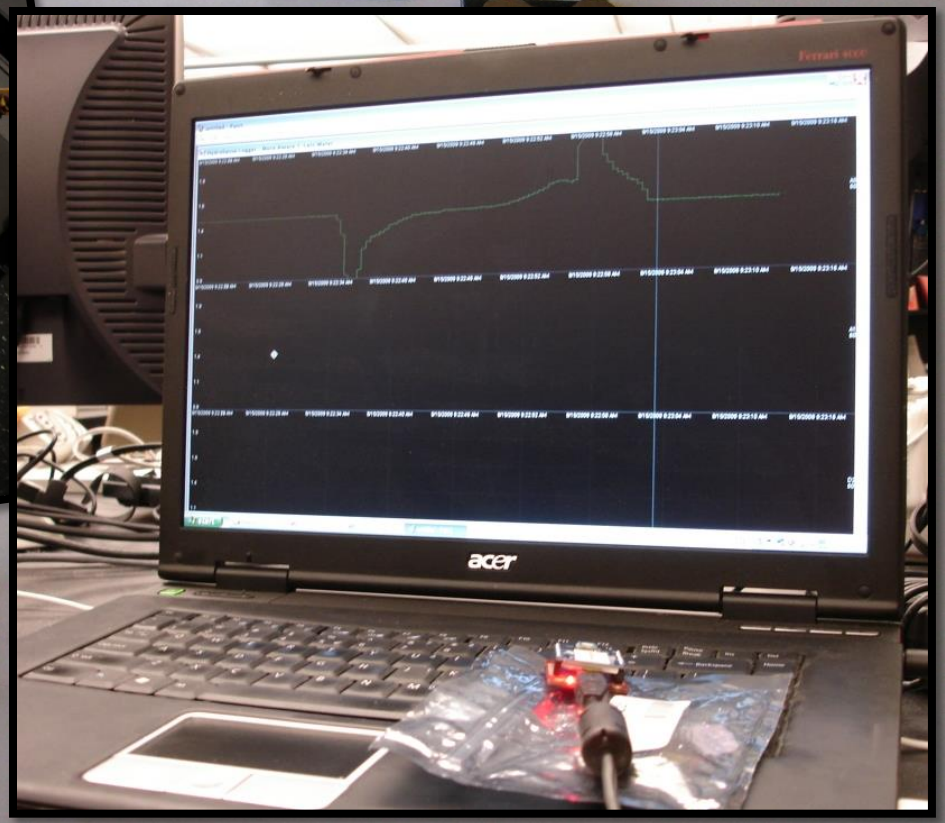

flow estimation using interpolated R_f
Average Error (GPM)
2.5
2
1.5
1
0.5
0
1
6
11
16
21
26
31
36
Number of Samples
H1
H4
H5
H7
After 5 R_f samples, average error is 0.27 GPM

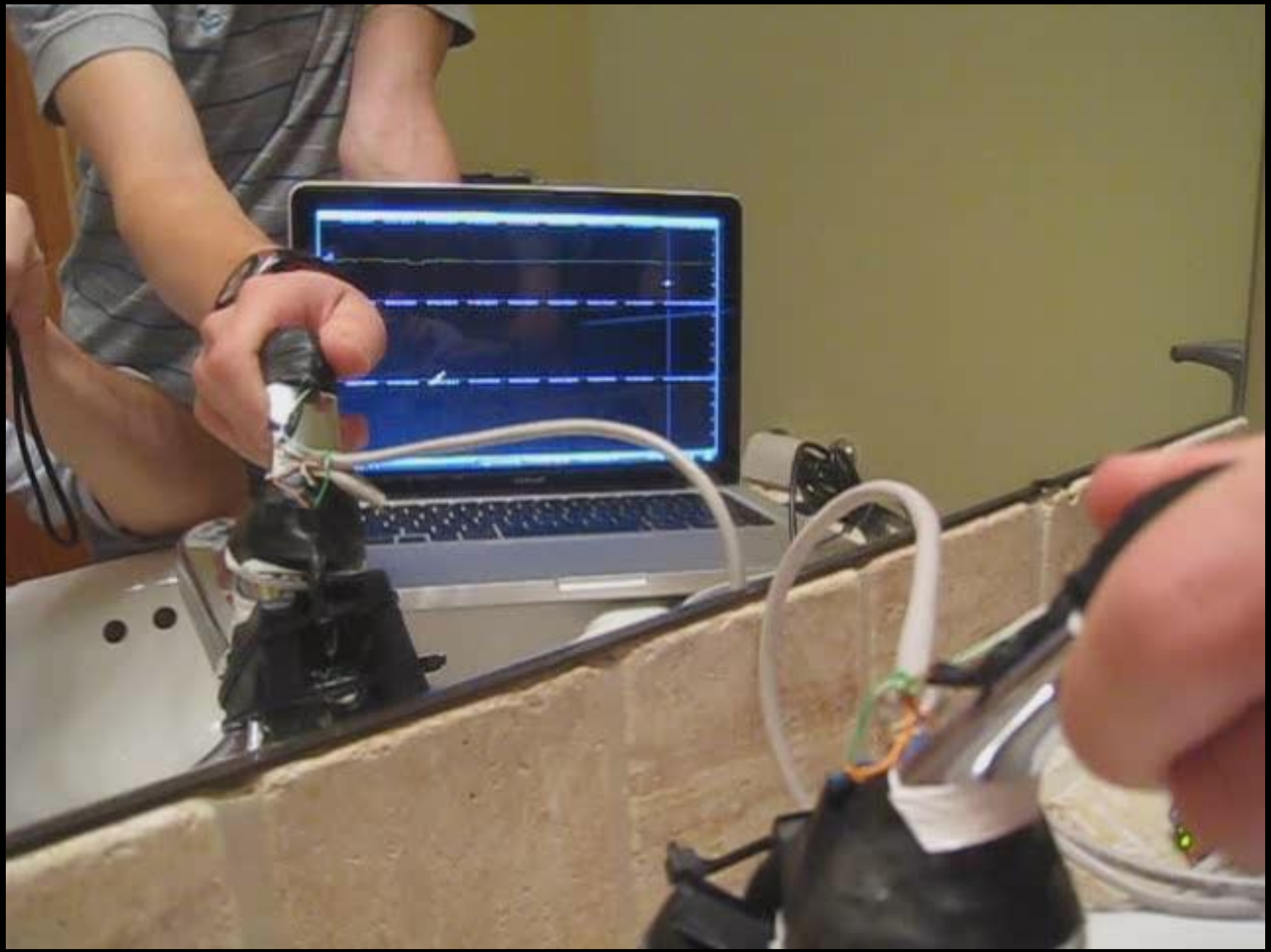
future work: hydrosense 2.0



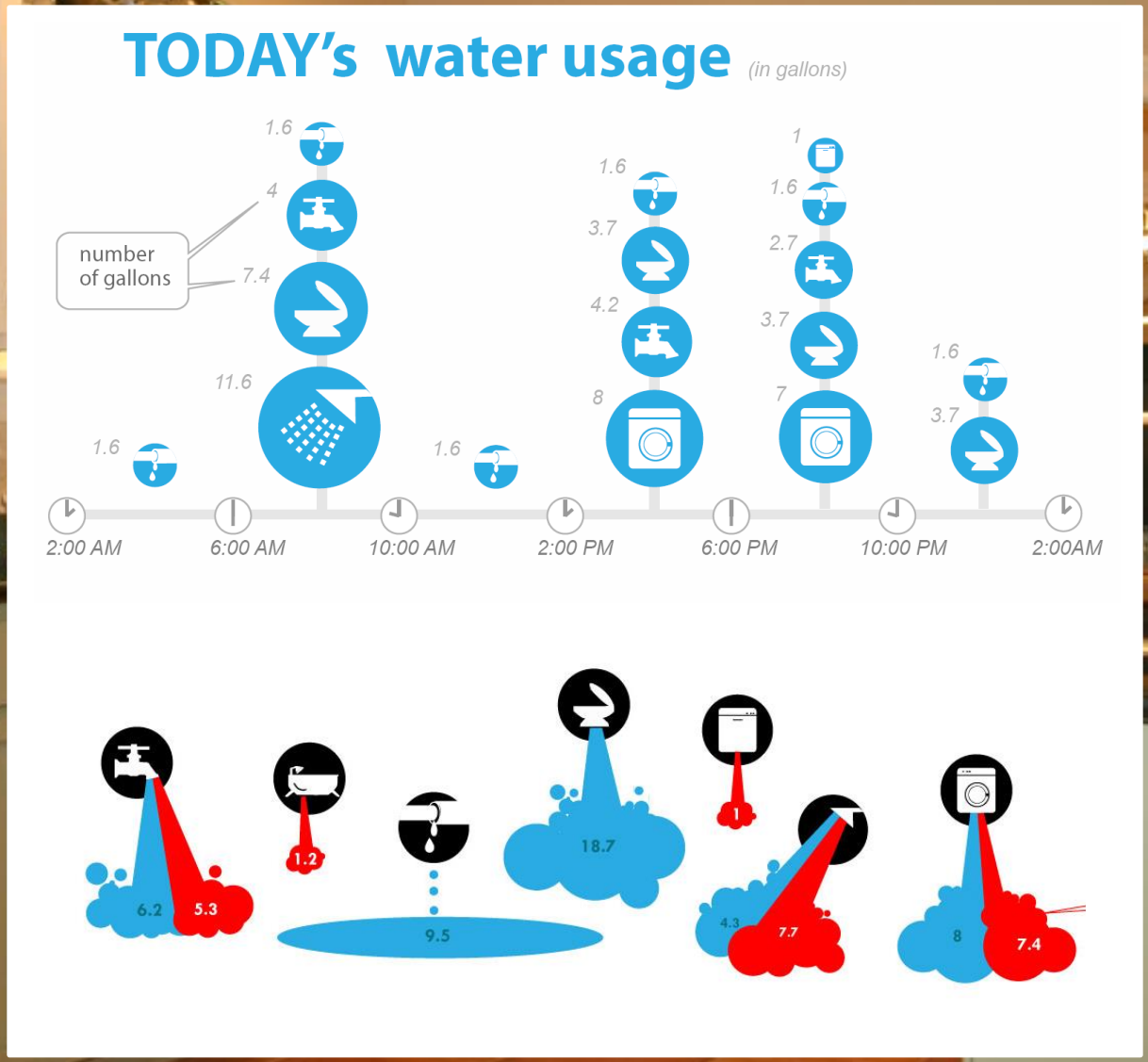
longitudinal data collection



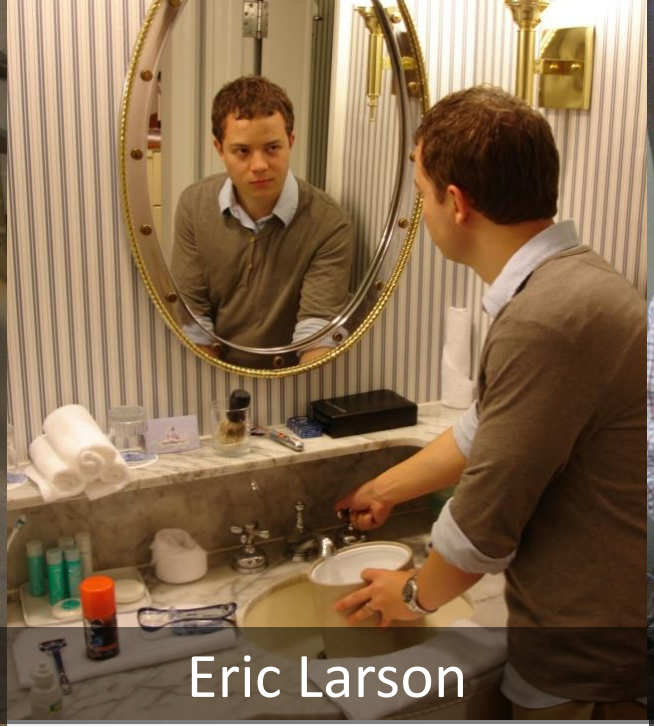




water feedback interfaces



Jon Froehlich


Eric Larson


Tim Campbell


Conor Haggerty


James Fogarty


Shwetak Patel

HYDROSENSE

Infrastructure-Mediated Single-Point Sensing of Whole-Home Water Activity

Jon Froehlich[1], Eric Larson[2], Tim Campbell[3], Conor Haggerty[4], James Fogarty[1], Shwetak N. Patel[1,2]

[1]Computer Science & Engineering, [2]Electrical Engineering,
[3]Mechanical Engineering, [4]Community, Environment, and Planning

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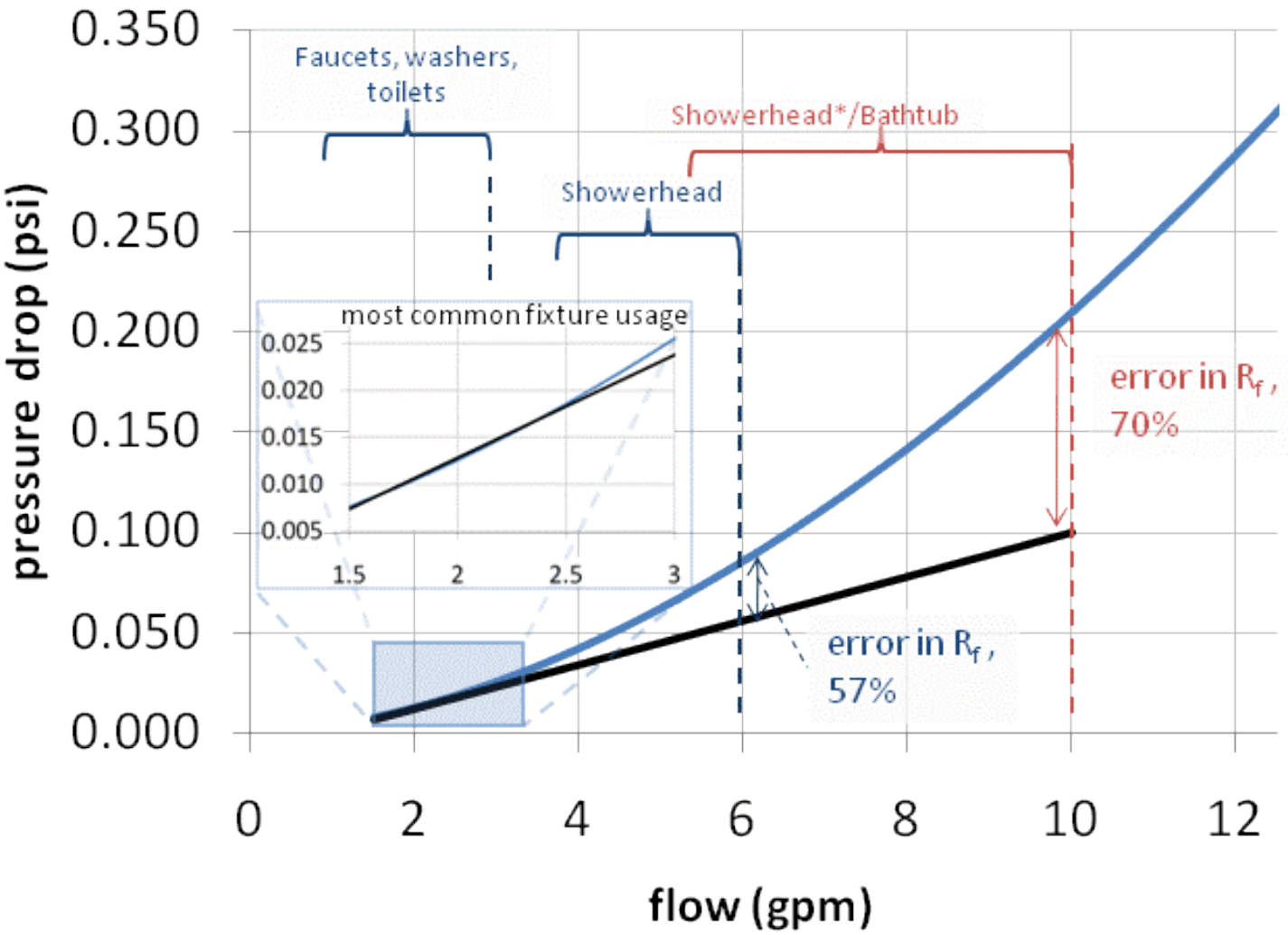
dub design: use: build:
univ. of washington

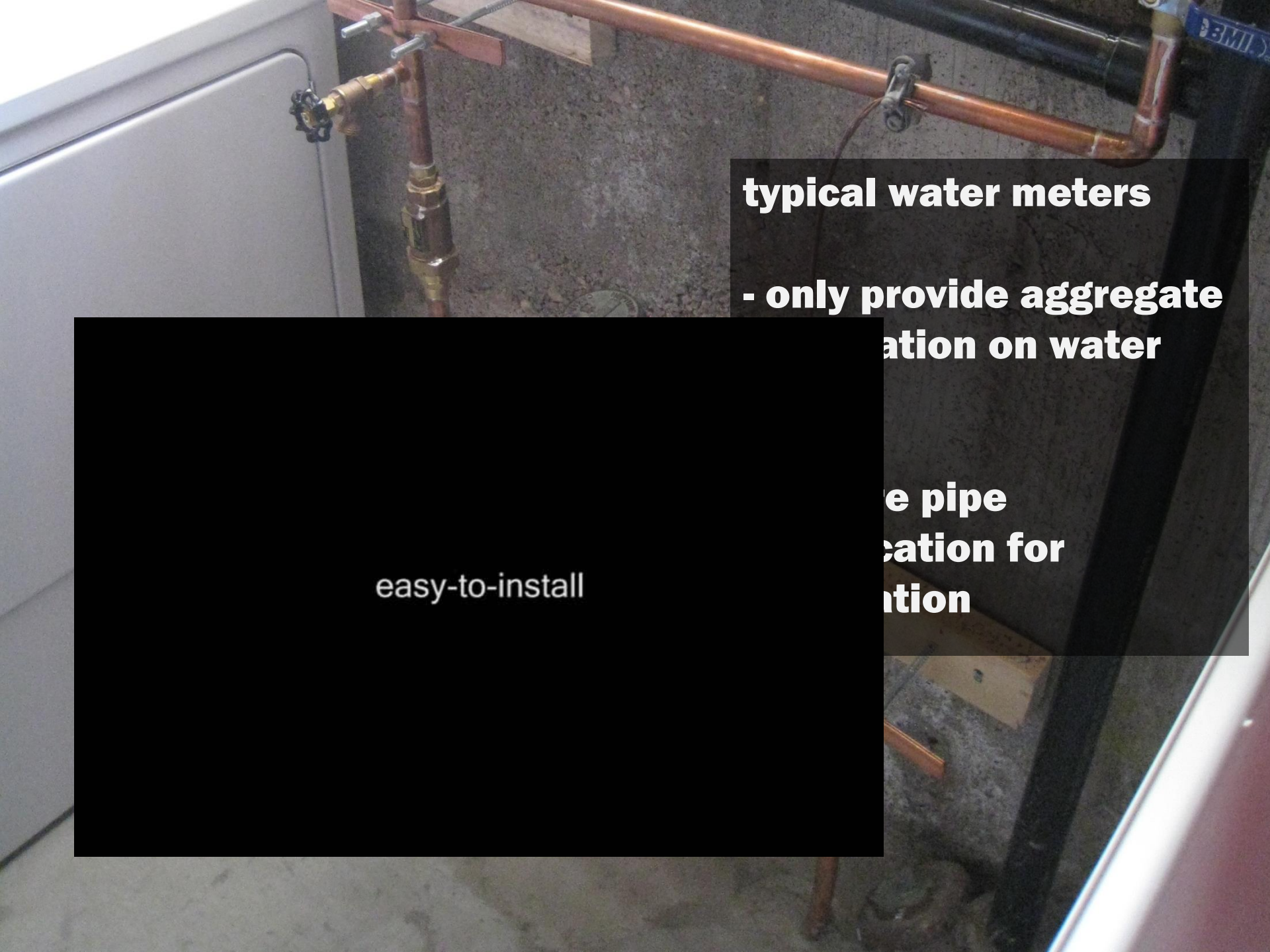
computer science and engineering


EXIT
Interview Room
167


DFW/HPI
TROUP, TEXAS
WATER METER

flow estimation




typical water meters
- only provide aggregate
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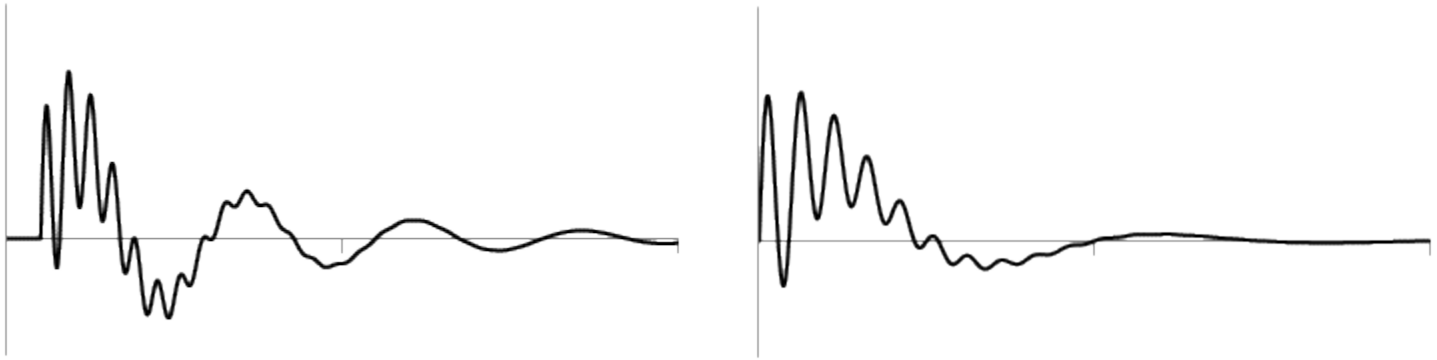
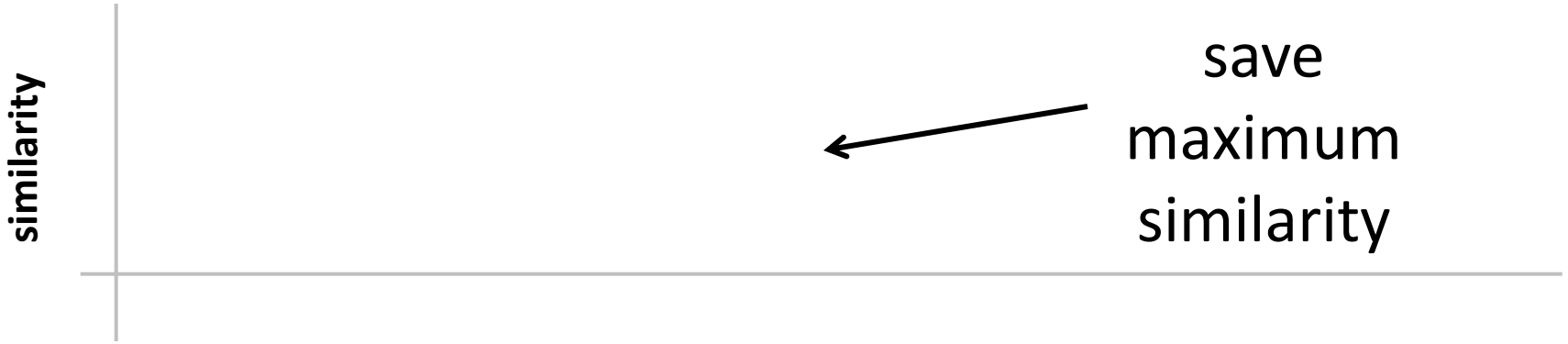
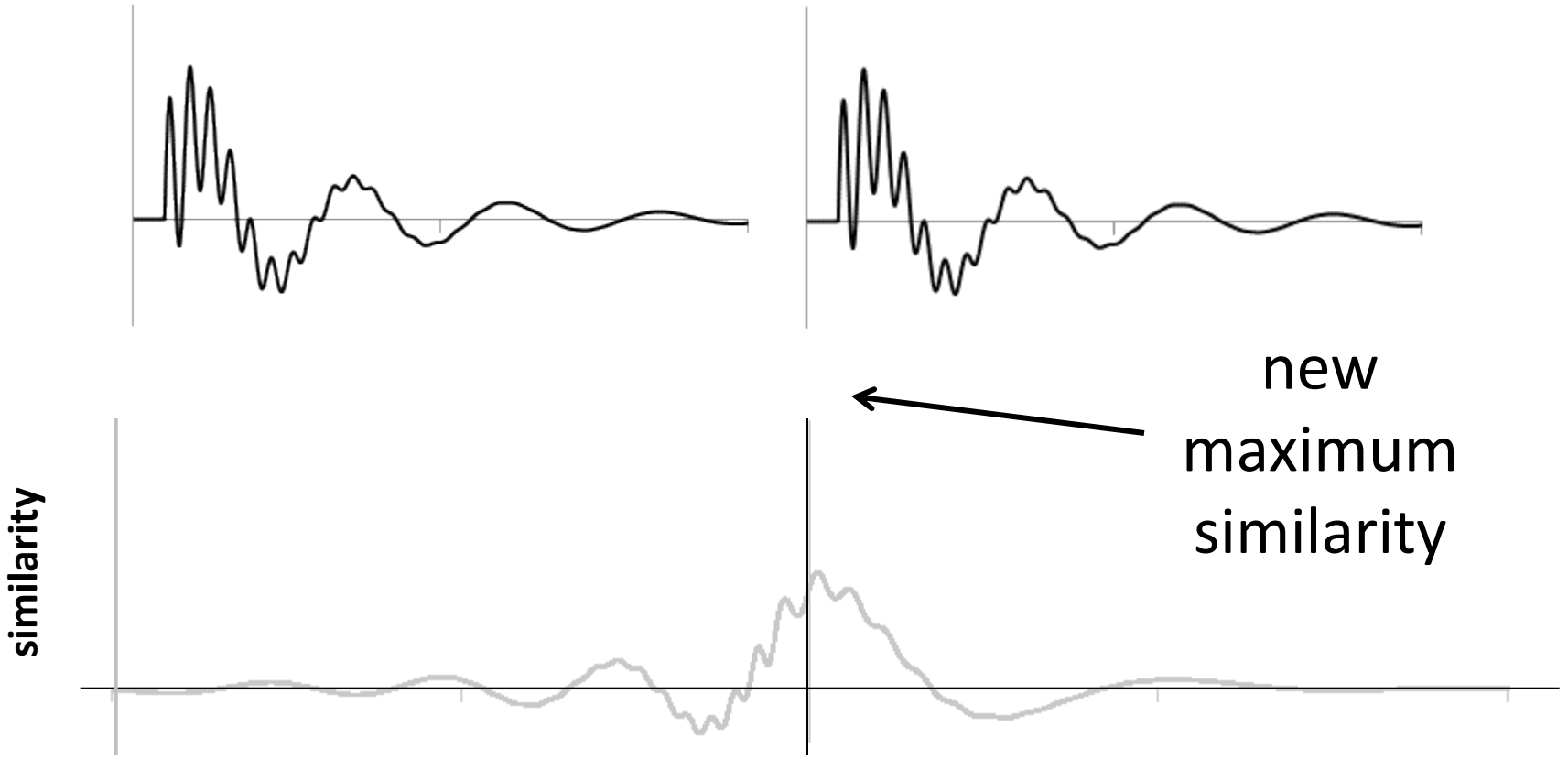
easy-to-install

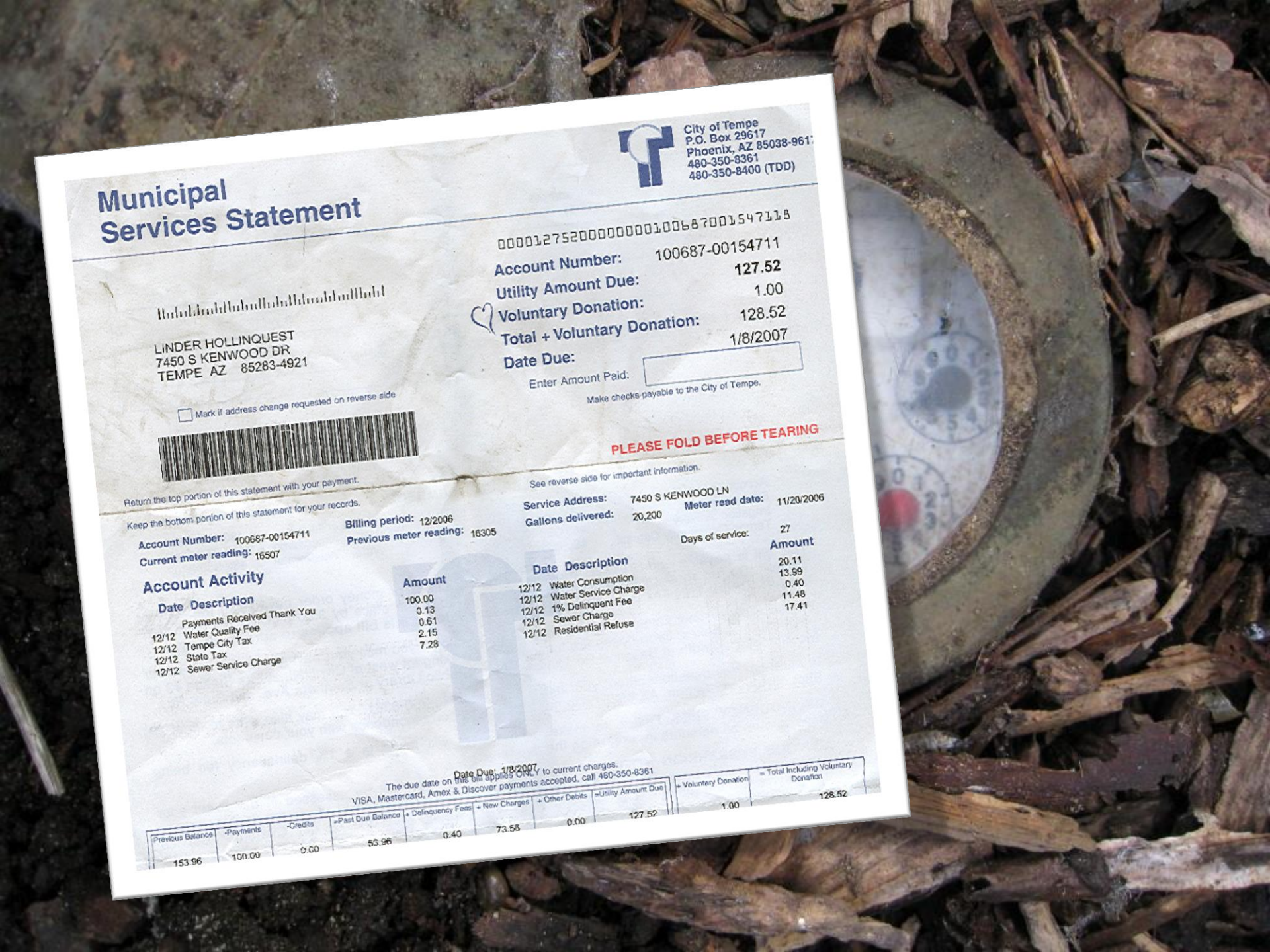
matched filtering





matched filtering





Municipal Services Statement

City of Tempe
P.O. Box 29617
Phoenix, AZ 85038-961
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
Gallons delivered: 20,200
Meter read date: 11/20/2006
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

Date Due: 1/8/2007
The due date on this bill applies ONLY to current charges.
VISA, Mastercard, Amex & Discover payments accepted, call 480-350-8361

Previous Balance	-Payments	-Credits	=Past Due Balance	+ Delinquency Fees	+ New Charges	+ Other Debits	=Utility Amount Due	+ Voluntary Donation	= Total Including Voluntary Donation
153.96	100.00	0.00	53.96	0.40	73.56	0.00	127.52	1.00	128.52