Accurate & Easy-to-Deploy In-Home Energy Sensing

Jon Froehlich[1], Sidhant Gupta[1], Eric Larson[2], Gabe Cohn[2], Kate Everitt[1]
Professors James Fogarty[1], James Landay[1], Shwetak N. Patel[1,2]

[1]Computer Science and Engineering
[2]Electrical Engineering

dub design: use: build: university of washington
ubicomp lab university of washington
sustain sustainability research

mpg?

Ford

Quality is Job 1.

VEHICLE DESCRIPTION

RANGER

1998 RANGER
XL 112" WHEE
2.5L EFI I-4 EN
5-SPD MAN O

STANDARD EQUIPMENT **INCLUDED AT NO EXTRA CHARGE**

SAFETY/SECURITY
- DRIVER & PASS SRS AIR BAG
- REAR ANTI-LOCK BRAKES
- ADJ HEIGHT FRT SEAT BELTS
- SIDE DOOR GUARD BEAMS
- REAR HIGH MOUNT STOP LAMP
- 24 HR ROADSIDE ASSISTANCE

FUNCTIONAL
- POWER STEERING/BRAKES
- FRONT/REAR MUD FLAPS
- BATTERY SAVER
- GAS-FILLED SHOCKS
- 100K MILE TUNE-UP INTERVAL
- PREPPED FOR TOW HARNESS
- SLA SUSPENSION

EXTERIOR
- SOLAR TINT GLASS
- P205/75RX14 BSW A/S TIRES
- ARGENT STYLED STEEL WHEELS W/BRIGHT HUB COVERS
- INTERMITTENT FRONT WIPERS
- BLACK SAIL MOUNT MIRRORS
- MED PLAT GRILLE/FRT BUMPER
- MED PLAT REAR STEP BUMPER
- EASILY REMOVABLE TAILGATE

INTERIOR
- 60/40 VINYL SPLIT BENCH ST
- 12V PWRPOINT
- FLOOR CONSOLETTE
- GAUGE PACKAGE
- CIGARETTE LIGHTER
- INSIDE HOOD RELEASE
- FULL DOOR TRIM PANELS
- DAY-NIGHT REAR VIEW MIRROR
- SUN VISORS

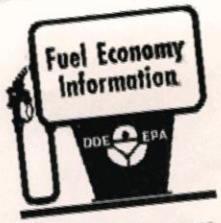
WARRANTY
- 3/36 BUMPER TO BUMPER

Compare this vehicle to others in the FREE FUEL ECONOMY GUIDE available at the dealer.

CITY MPG

22

Actual Mileage will vary with options, driving conditions, driving habits and vehicle's condition. Results reported to EPA indicate that the majority of vehicles with these estimates will achieve between
18 and **26** mpg in the city
and between
22 and **32** mpg on the highway.



1998 RANGER PICKUP 4X2,
2.5 LITER ENGINE
(FEEDBACK FUEL SYSTEM),
4 CYLINDER, FUEL INJECTION
CATALYST, 5-SPEED MANUAL.

Estimated Annual Fuel Cost: $ 781

HIGHWAY MPG

27

For Comparison Shopping all vehicles classified as **STANDARD PICKUP** have been issued mileage ratings ranging from **11** to **22** mpg city and **15** to **27** mpg highway.

SOLD TO

WESTLAND FORD
1330 WALL AVE
OGDEN UT 84401

SHIP TO (IF OTHER THAN SOLD TO)


E
F
20 30 40 50 60 70 80 90 100 110 120
9
3


RPM
x1000
MPH
P R N D M
AVERAGE ECONOMY
16.3 MPG
46°F
0MPH
N


RPM
Hybrid
P R N D M
AVERAGE ECONOMY
16.3 MPG
46°F
0MPH
N
MPH

how much energy does your dryer use?

why

the

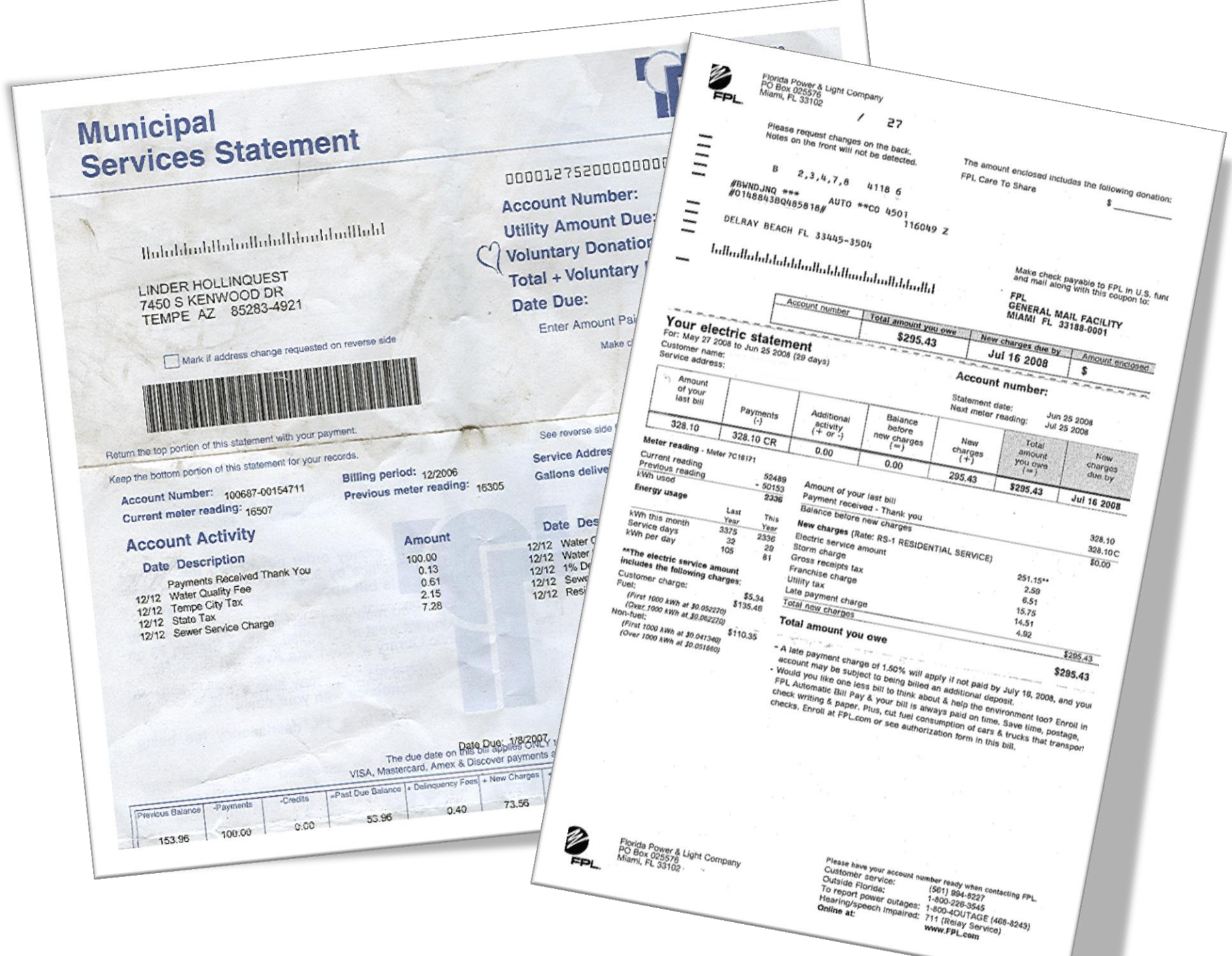
dis-

connect?


KILOWATTHOURS
240V 3W
DE435


smart meters
ELSTER
00001
kWh
SERIAL # 07 000 683
ELSTER
TYPE R1S
FCC ID: QZC-RX9
27229
BOROUGH OF LANSDALE
*1NG007000683
CL200, 240V, 3W, 60Hz
FM 2S Watthour Meter
R03.6-0711
Kh 1.0 TA 30
LAN ID: 071-0000942546
ZCC39000000

what about in-home "eco-feedback" displays?



Municipal Services Statement

LINDER HOLLINQUEST
7450 S KENWOOD DR
TEMPE AZ 85283-4921

Mark if address change requested on reverse side

Return the top portion of this statement with your payment.

Keep the bottom portion of this statement for your records.

Account Number: 100687-00154711
Current meter reading: 16507

Billing period: 12/2006
Previous meter reading: 16305

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

Account Number:
Utility Amount Due:
Voluntary Donation
Total + Voluntary
Date Due:

Enter Amount Pa

Make c

See reverse side

Service Addres
Gallons delive

Date Des
12/12 Water C
12/12 Water
12/12 1% D
12/12 Sewe
12/12 Resi

Date Due: 1/8/2007

The due date on this bill applies ONLY
VISA, Mastercard, Amex & Discover payments a

Previous Balance	-Payments	-Credits	=Past Due Balance	+ Delinquency Fees	+ New Charges
153.96	100.00	0.00	53.96	0.40	73.56

Florida Power & Light Company
PO Box 025576
Miami, FL 33102

/ 27

Please request changes on the back.
Notes on the front will not be detected.

B 2,3,4,7,8 4118 6
#BWNDJNQ ***
#0148843BQ485818# AUTO **CO 4501
116049 Z
DELRAY BEACH FL 33445-3504

The amount enclosed includes the following donation:
FPL Care To Share $ _____

Make check payable to FPL in U.S. fund
and mail along with this coupon to:
FPL
GENERAL MAIL FACILITY
MIAMI FL 33188-0001

Account number	Total amount you owe	New charges due by	Amount enclosed
	$295.43	Jul 16 2008	$

Your electric statement

For: May 27 2008 to Jun 25 2008 (29 days)
Customer name:
Service address:

Account number:

Statement date: Jun 25 2008
Next meter reading: Jul 25 2008

Amount of your last bill	Payments (-)	Additional activity (+ or -)	Balance before new charges (=)	New charges (+)	Total amount you owe (=)	New charges due by
328.10	328.10 CR	0.00	0.00	295.43	$295.43	Jul 16 2008

Meter reading - Meter 7C18171

Current reading	52489
Previous reading	- 50153
kWh used	2336

Energy usage

	Last Year	This Year
kWh this month	3375	2336
Service days	33	29
kWh per day	105	81

****The electric service amount includes the following charges:**

Customer charge:		$5.34
Fuel:		
(First 1000 kWh at $0.052270)		$135.46
(Over 1000 kWh at $0.062270)		
Non-fuel:		
(First 1000 kWh at $0.041340)		$110.35
(Over 1000 kWh at $0.051660)		

Amount of your last bill	328.10
Payment received - Thank you	328.10C
Balance before new charges	$0.00
New charges (Rate: RS-1 RESIDENTIAL SERVICE)	
Electric service amount	251.15**
Storm charge	2.59
Gross receipts tax	6.51
Franchise charge	15.75
Utility tax	14.51
Late payment charge	4.92
Total new charges	$295.43
Total amount you owe	**$295.43**

- A late payment charge of 1.50% will apply if not paid by July 16, 2008, and your account may be subject to being billed an additional deposit.
- Would you like one less bill to think about & help the environment too? Enroll in FPL Automatic Bill Pay & your bill is always paid on time. Save time, postage, check writing & paper. Plus, cut fuel consumption of cars & trucks that transport checks. Enroll at FPL.com or see authorization form in this bill.

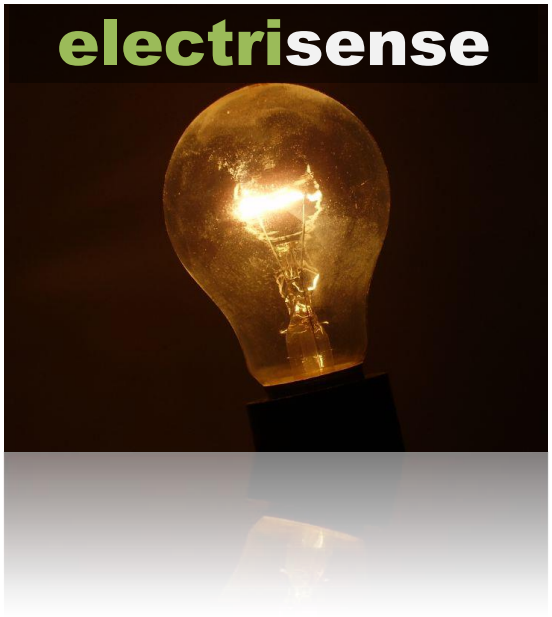
Florida Power & Light Company
PO Box 025576
Miami, FL 33102

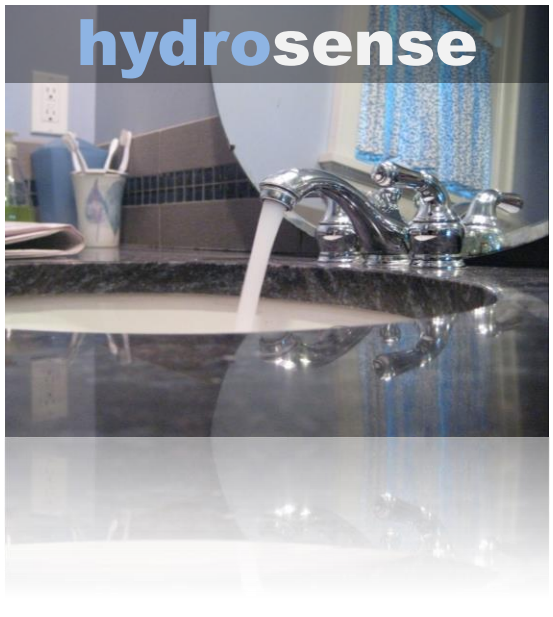
Please have your account number ready when contacting FPL.

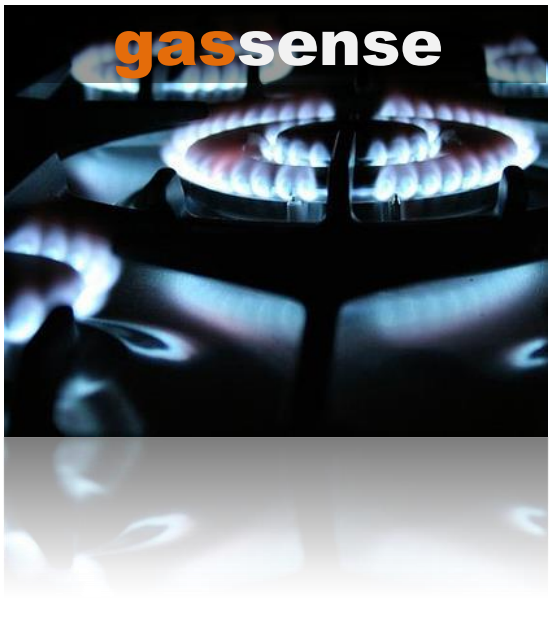
Customer service:	(561) 994-8227
Outside Florida:	1-800-226-3545
To report power outages:	1-800-4OUTAGE (468-8243)
Hearing/speech impaired:	711 (Relay Service)
Online at:	www.FPL.com

Kempton and Layne, 1994

high resolution resource consumption sensing for electricity, water and gas







three design goals

low-cost

easy-to-install

device-level information

device-level information

sometimes called *disaggregated* or *disambiguated* data

information down to the *source of consumption*

or

or

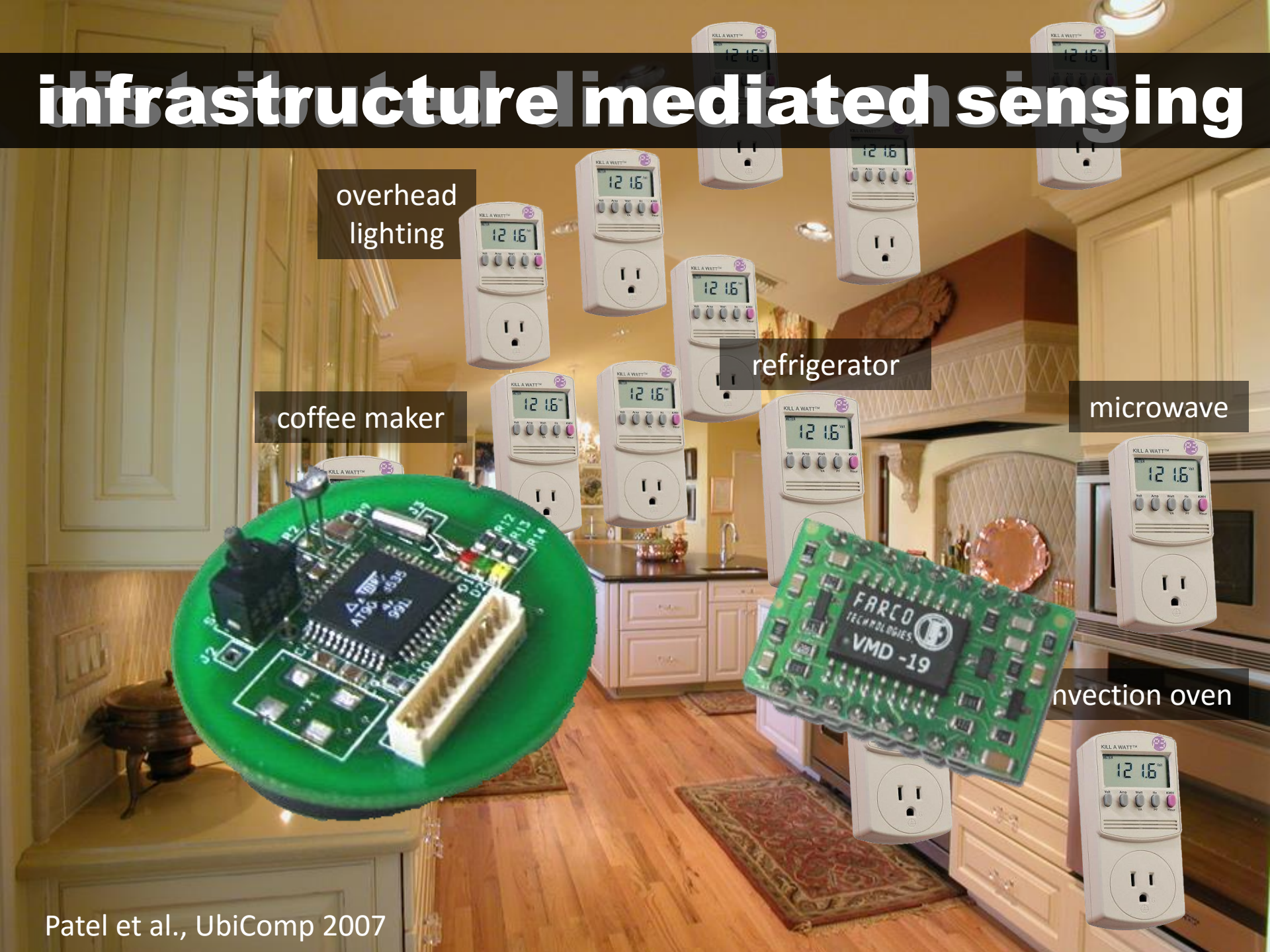
or

how much energy does your dryer use?

appliance + sensor = appliance-level data!

distributed direct sensing

infrastructure mediated sensing



Patel et al., UbiComp 2007

electrisense: appliance level sensing with two sensors

powerline event detection sensor

automatically detects and classifies electrical events on the home powerline

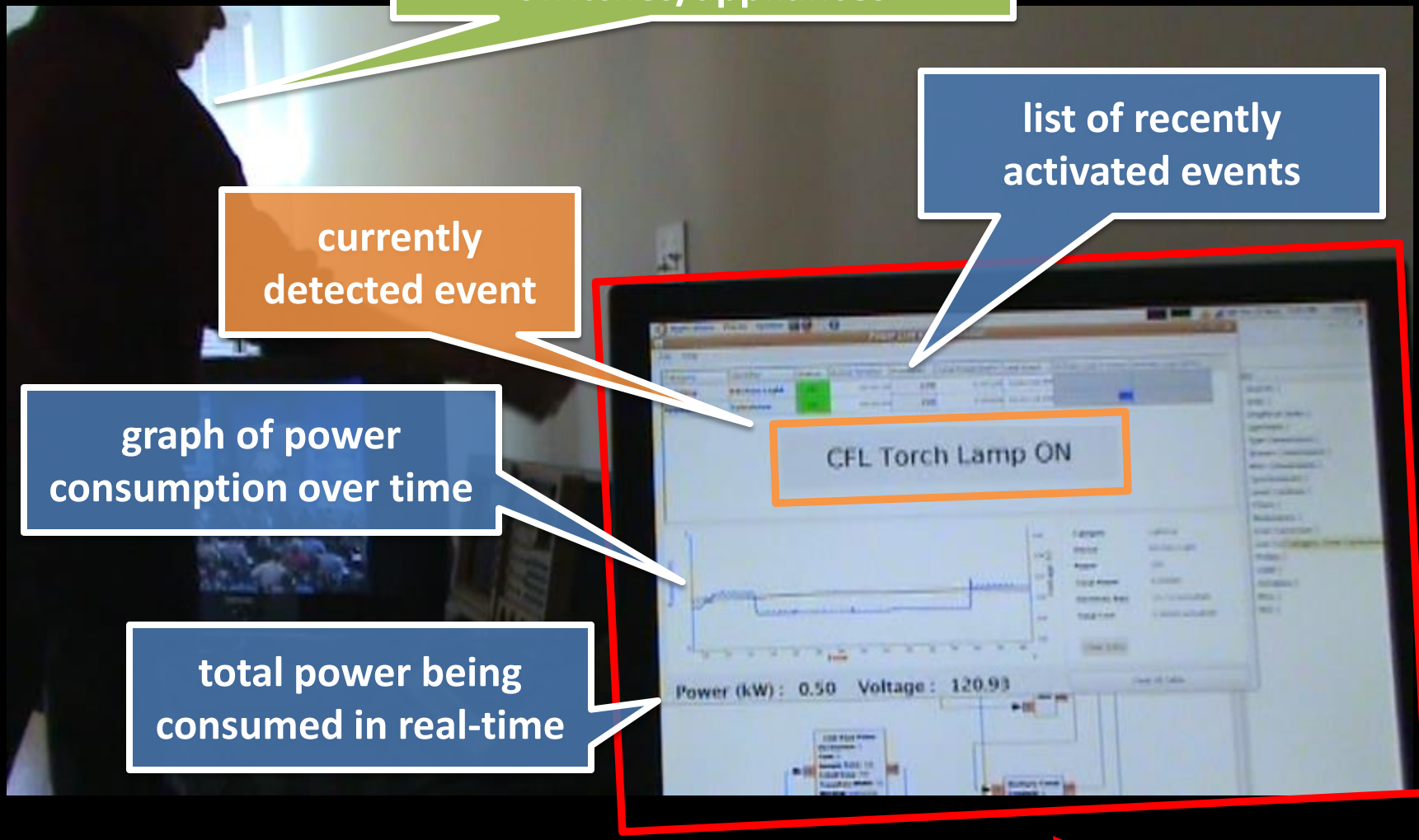
Patel et al., UbiComp 2007

contactless power consumption sensor

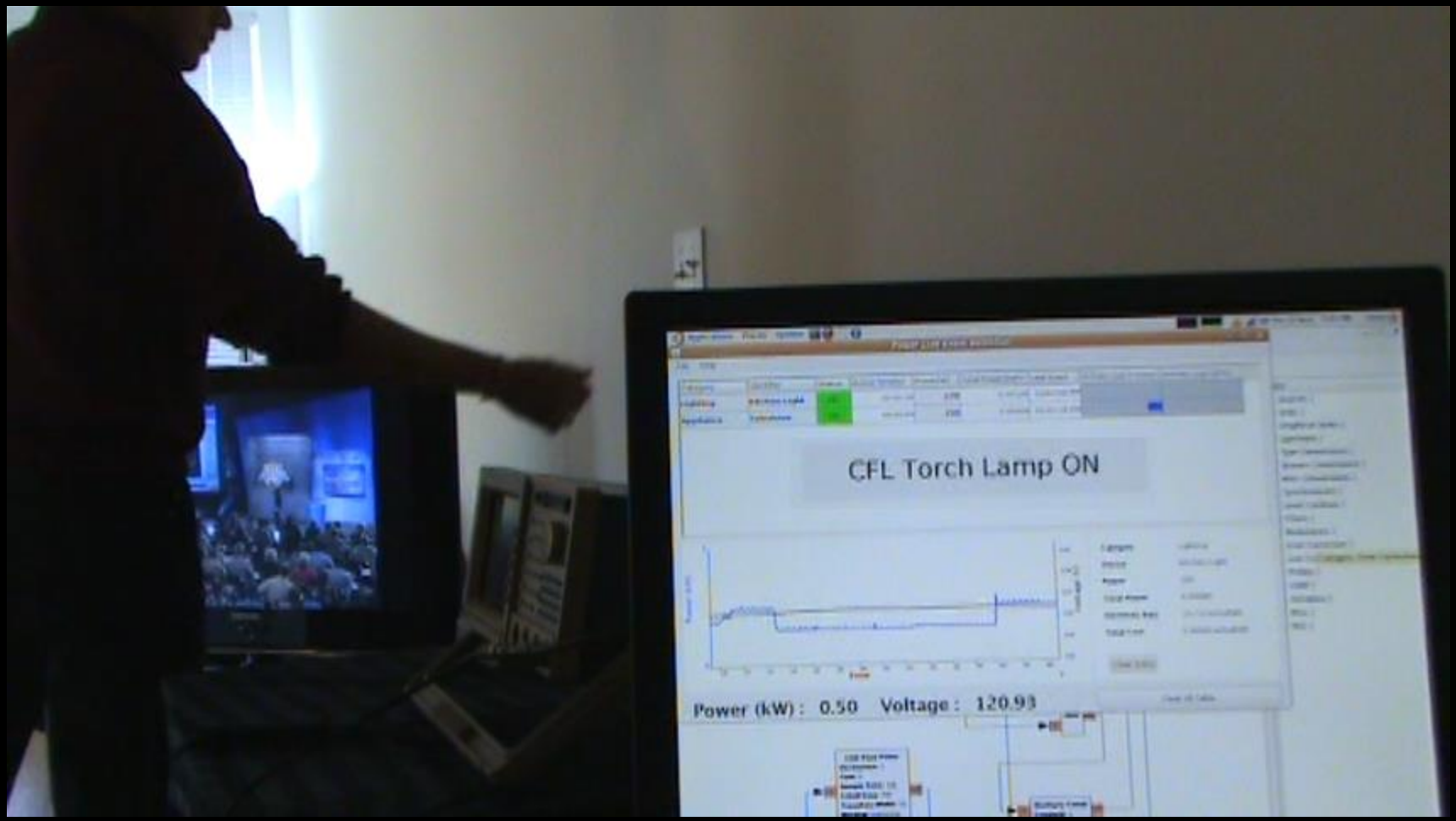
whole-home power consumption sensing from outside breaker panel

Patel et al., *To Appear*

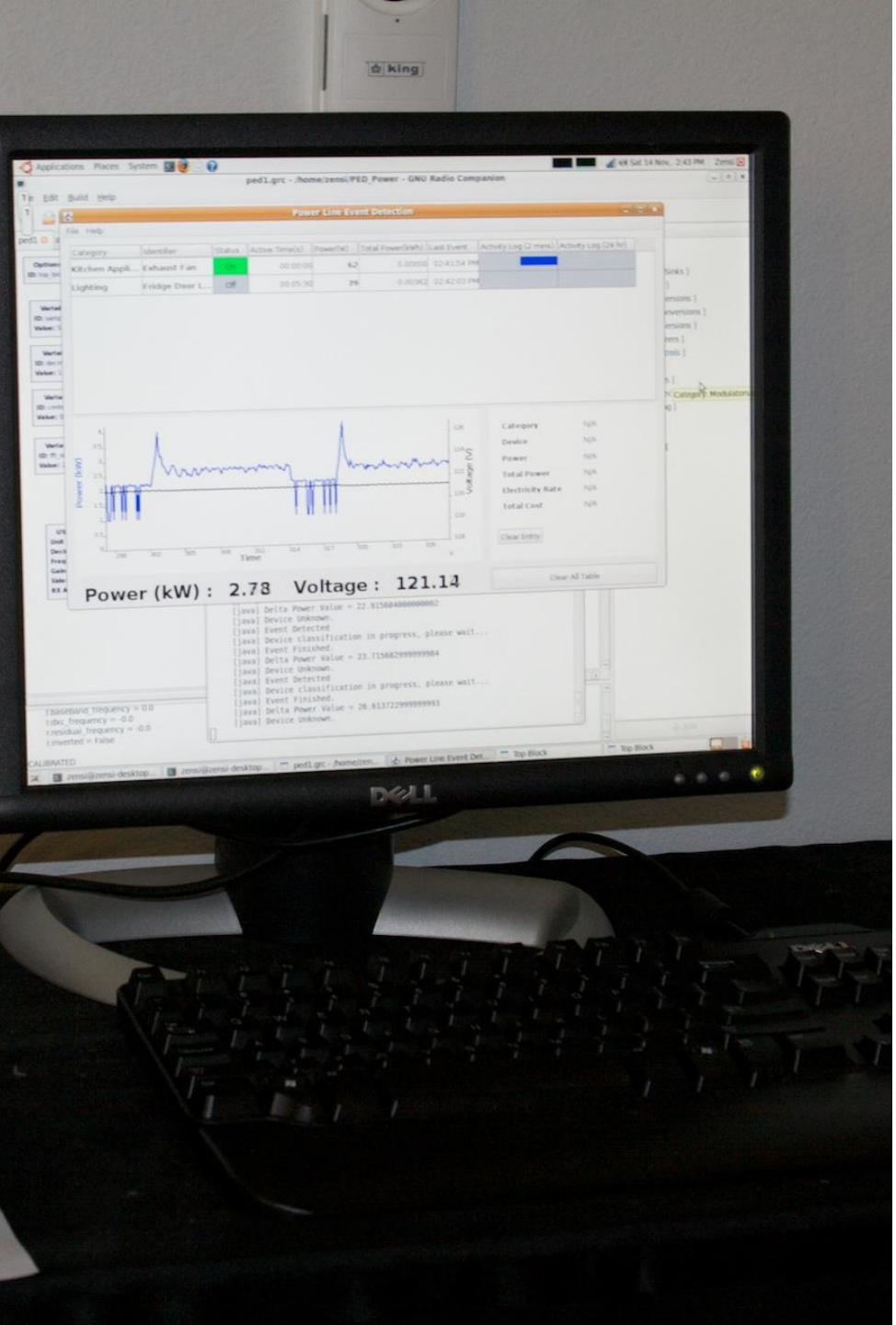
demo


my colleague, sidhant, will walk around using various electrical switches/appliances
list of recently activated events
currently detected event
graph of power consumption over time
total power being consumed in real-time
CFL Torch Lamp ON
Power (kW) : 0.50 Voltage : 120.93
not for end users

demo



movie removed for
public posting of slide deck



how does this work?

electrisense: appliance level sensing with two sensors

powerline event detection sensor

automatically detects and classifies electrical events on the home powerline

Patel et al., UbiComp 2007

contactless power consumption sensor

whole-home power consumption sensing from outside breaker panel

Patel et al., *To Appear*

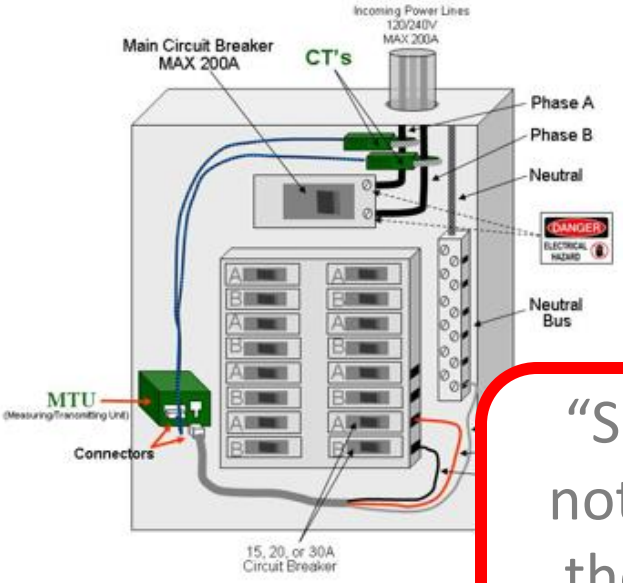
requirement:

we need

real-time

power consumption data

installing the energy detective (ted)

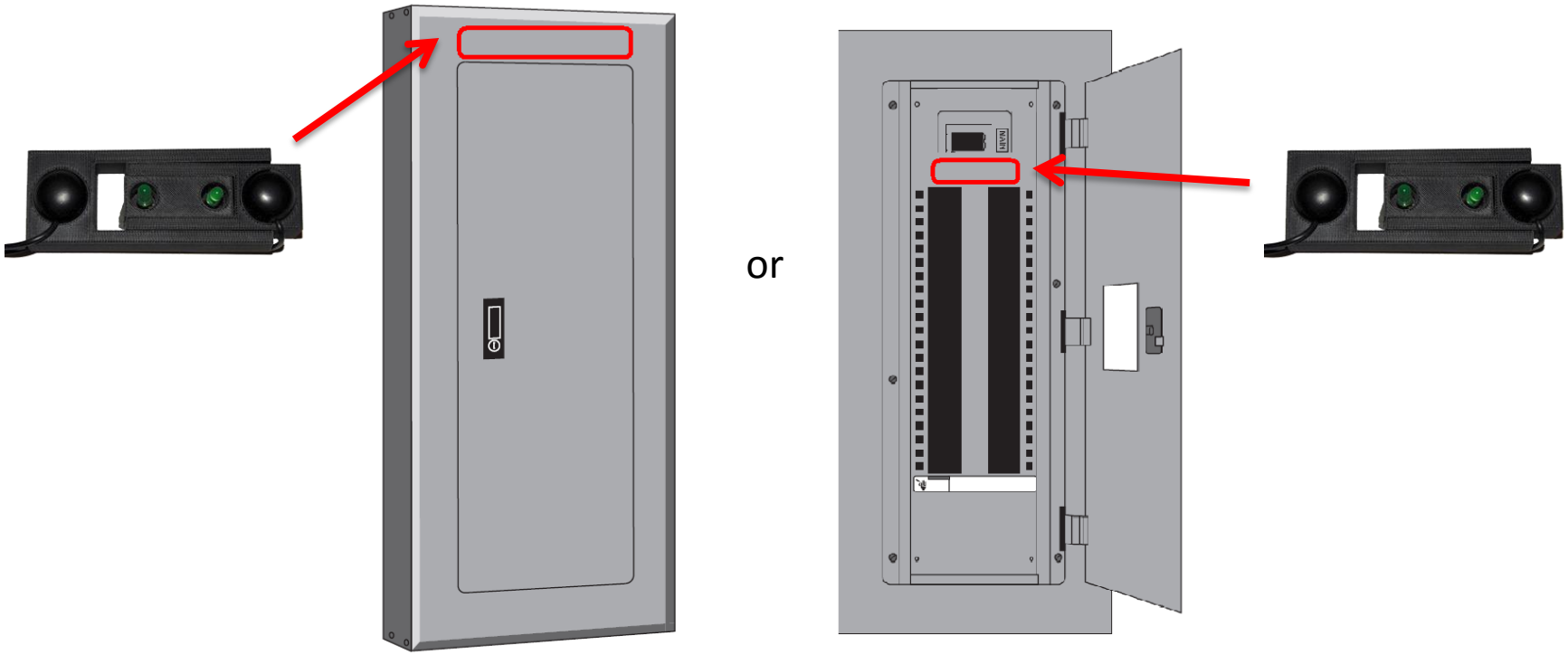


Installing MTU and clip-on CT
Typical Combination Circuit Breake

Circuit Breaker Box

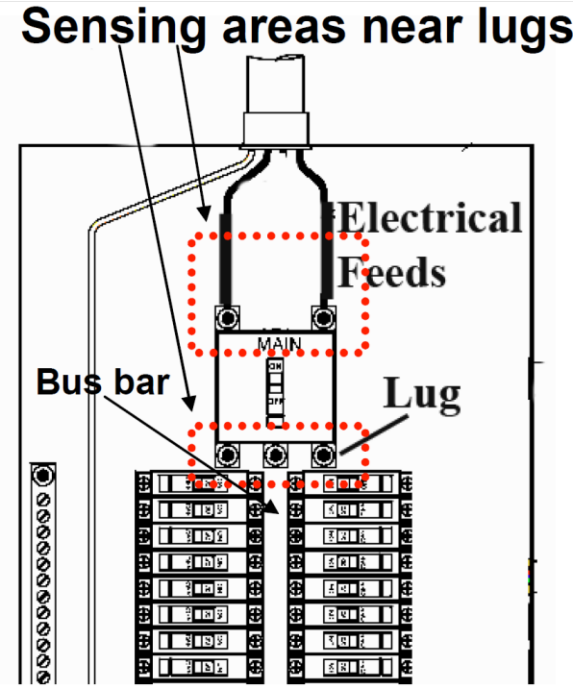
"Serious injury/death could occur if you're not familiar with electrical components and the operation of the circuit breaker panel"
– TED website

installing contactless power consumption sensor



installs *on the outside* of the circuit breaker box

how contactless power consumption sensing works



calculate current flow based on the magnetic field generated by the two electrical feeds in the breaker box

use a magnetoresistive sensor to measure magnetic field, which radiates a few centimeters outward, even through sheet metal

electrisense: appliance level sensing with two sensors

powerline event detection sensor

automatically detects and classifies electrical events on the home powerline

Patel et al., UbiComp 2007

contactless power consumption sensor

whole-home power consumption sensing from outside breaker panel

Patel et al., *To Appear*

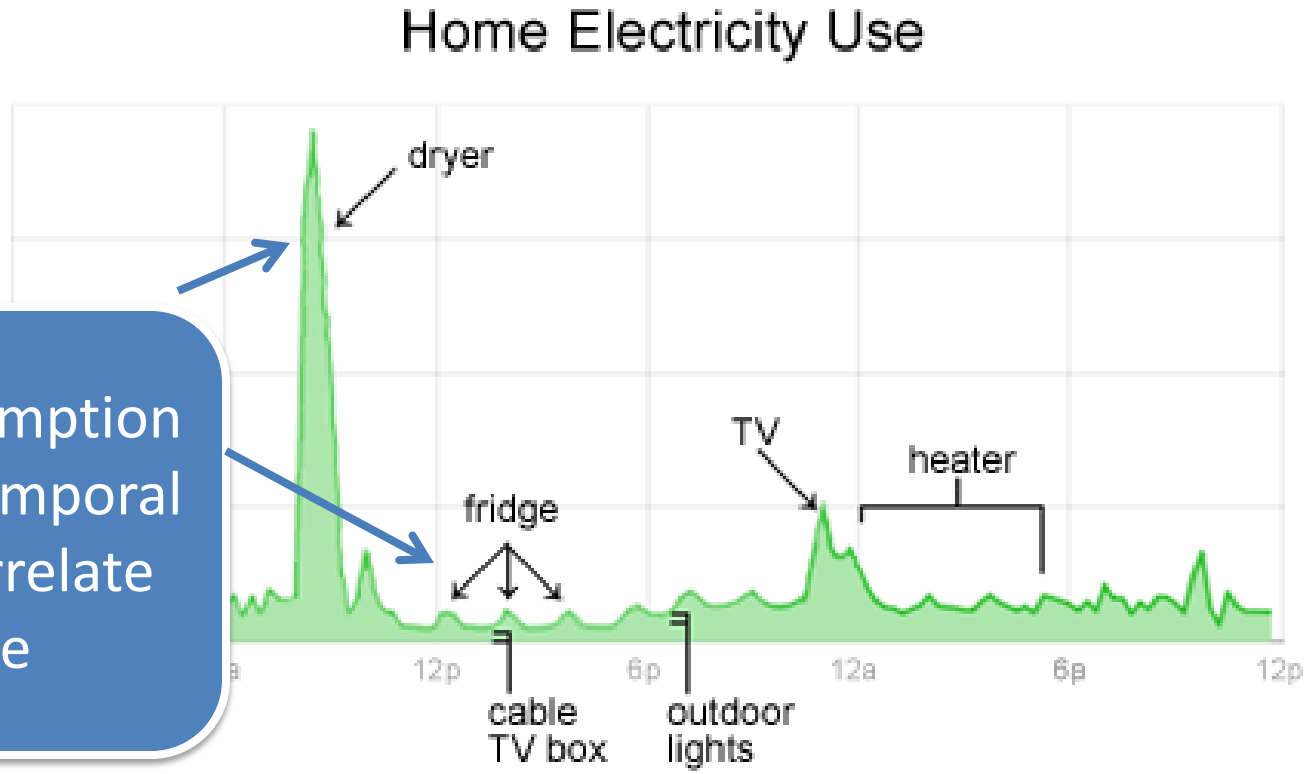
installing power line event detection (ped)

listens for noise on powerline and monitors line voltage

programmable hardware for fourier analysis and feature extraction


Power Line Event Detection
Power (kW) : 2.78 Voltage : 121.14
DELL

Google™ PowerMeter



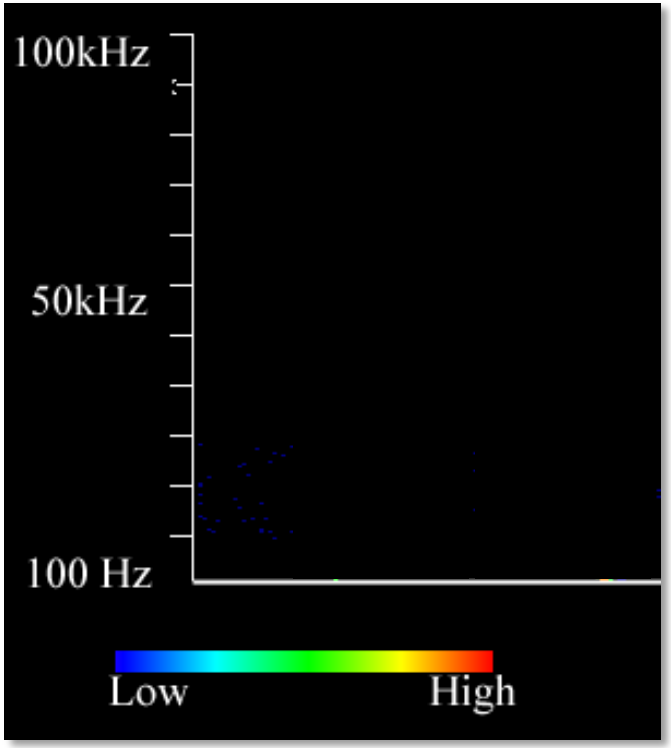
power consumption spikes and temporal patterns correlate to usage

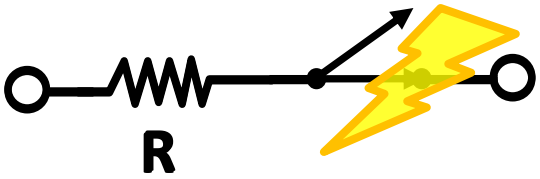
this is only ***one*** input feature into our machine learning algorithm!

your noise is our signal

how ped works

mechanical switches

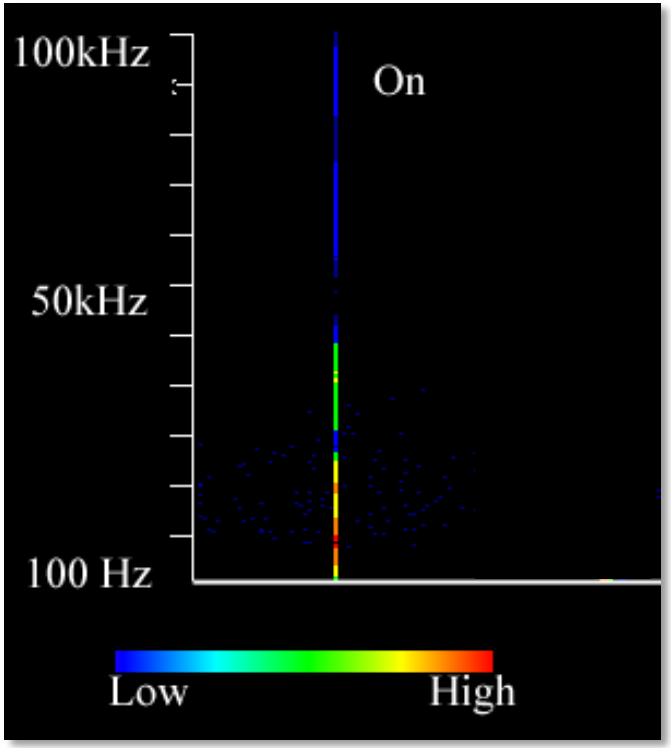


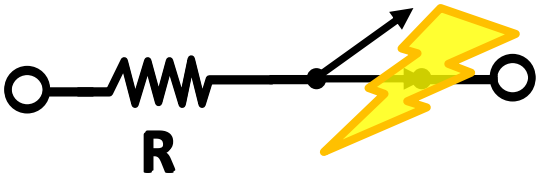


electrical noise transient

how ped works

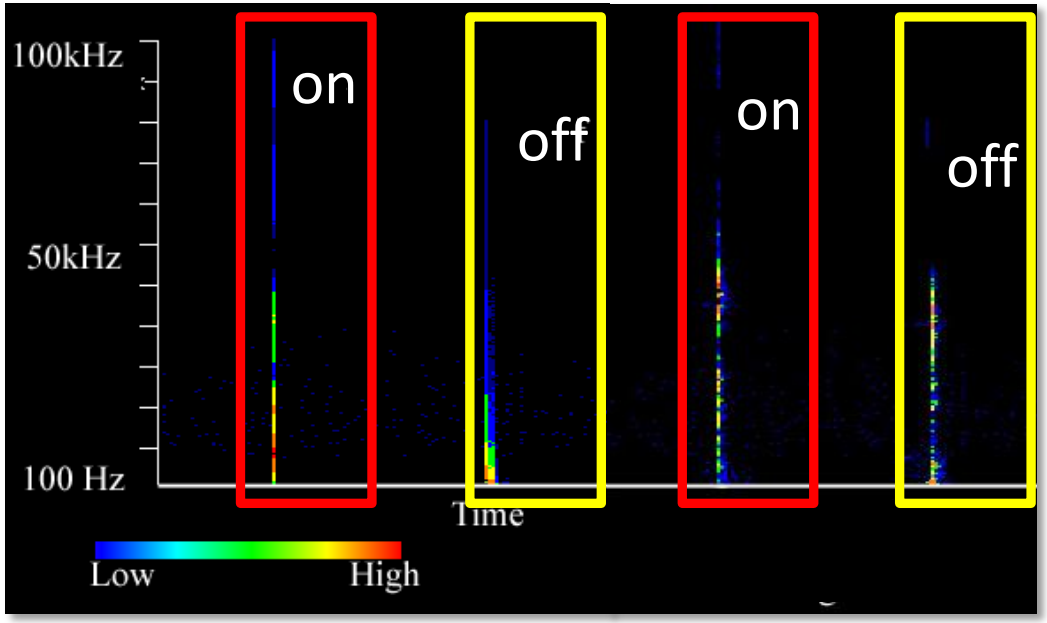
mechanical switches





electrical noise transient

each switch has a unique transient signature



based on:

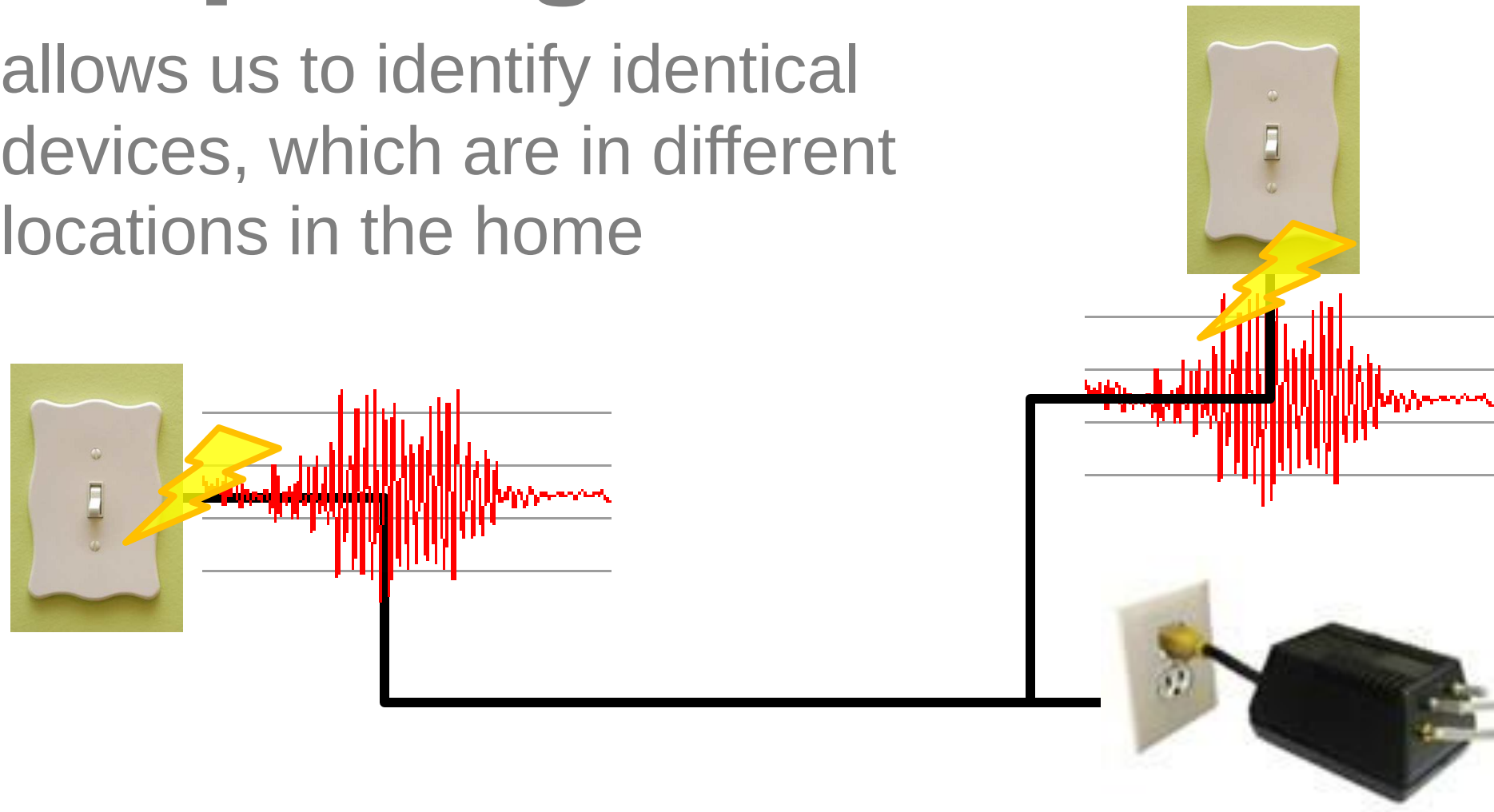
1. switching mechanisms
2. load characteristics
3. position on transmission line

switch 1

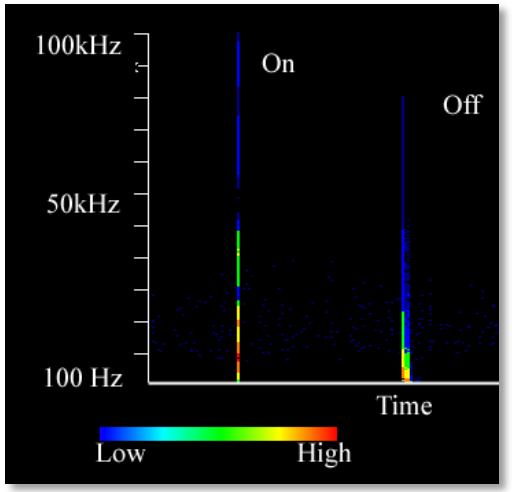
switch 2

transmission line shapes signal

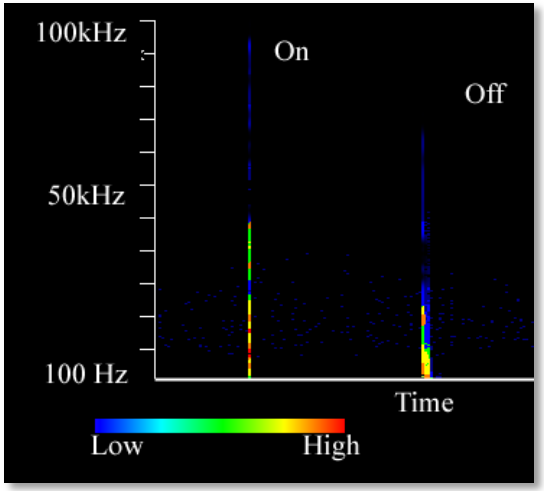
allows us to identify identical devices, which are in different locations in the home



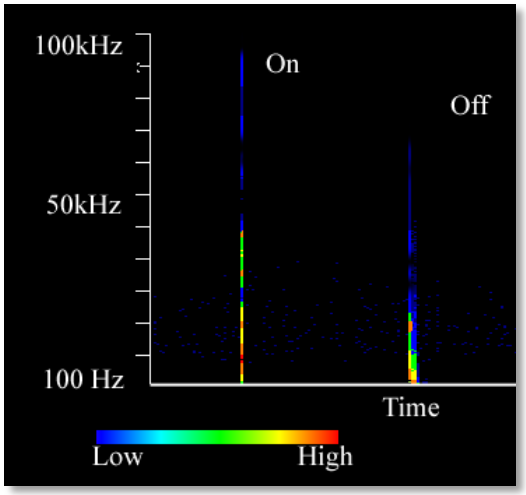
signal is stable over time



day 1



day 2



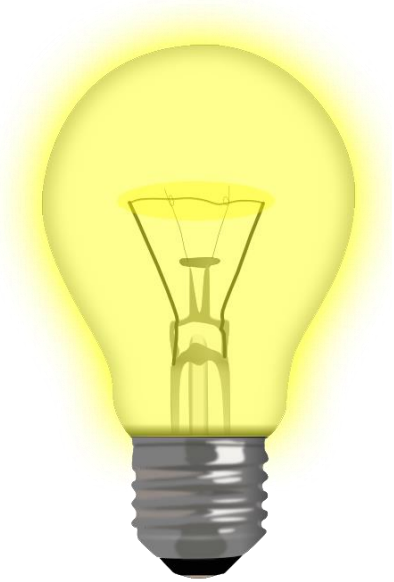
day 7

switch 1

movie removed for
public posting of slide deck

how ped works

three classes of noise



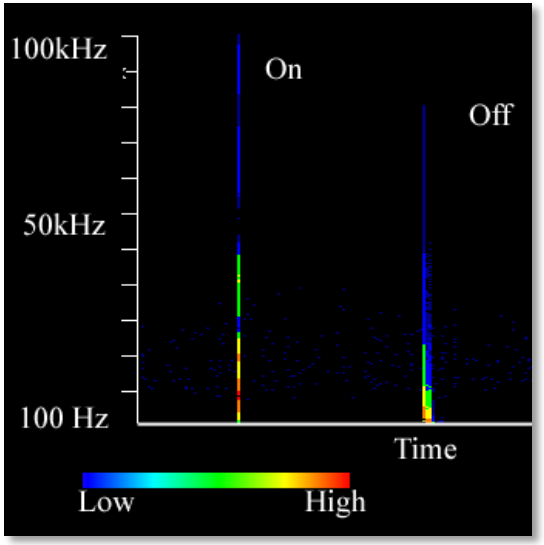
resistive

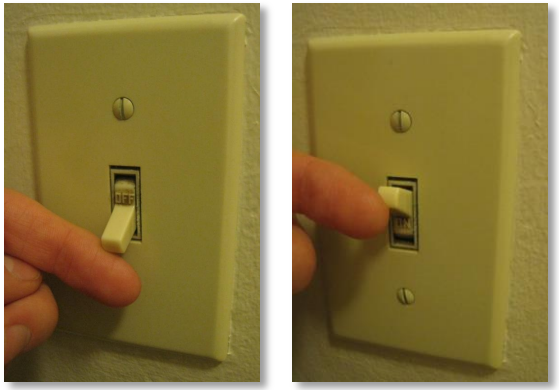
generates continuous noise

inductive loads
(e.g., from motors)

loads with solid state switching
(e.g., tvs, cfls, computers)

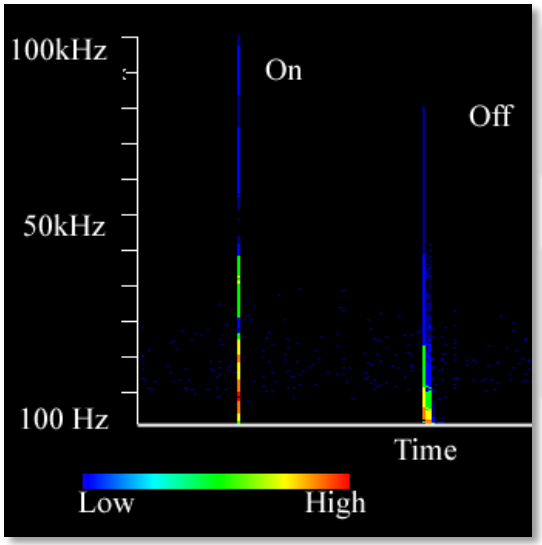
transients





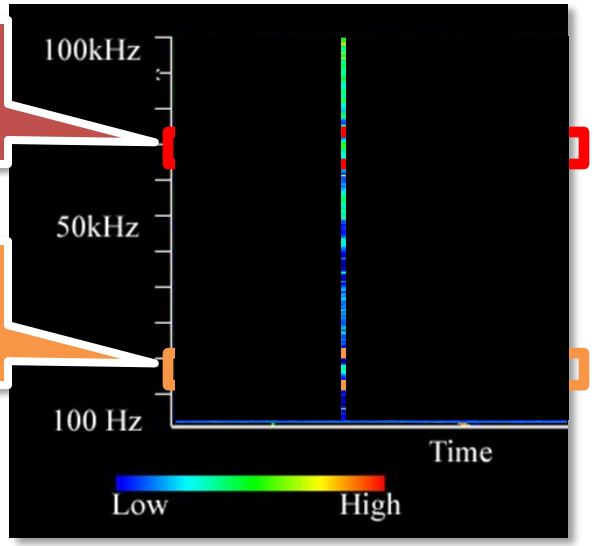
transients

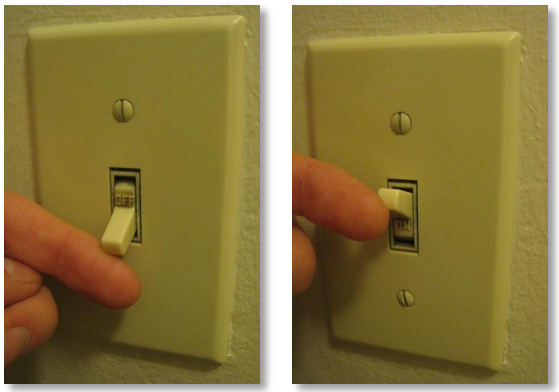
continuous noise

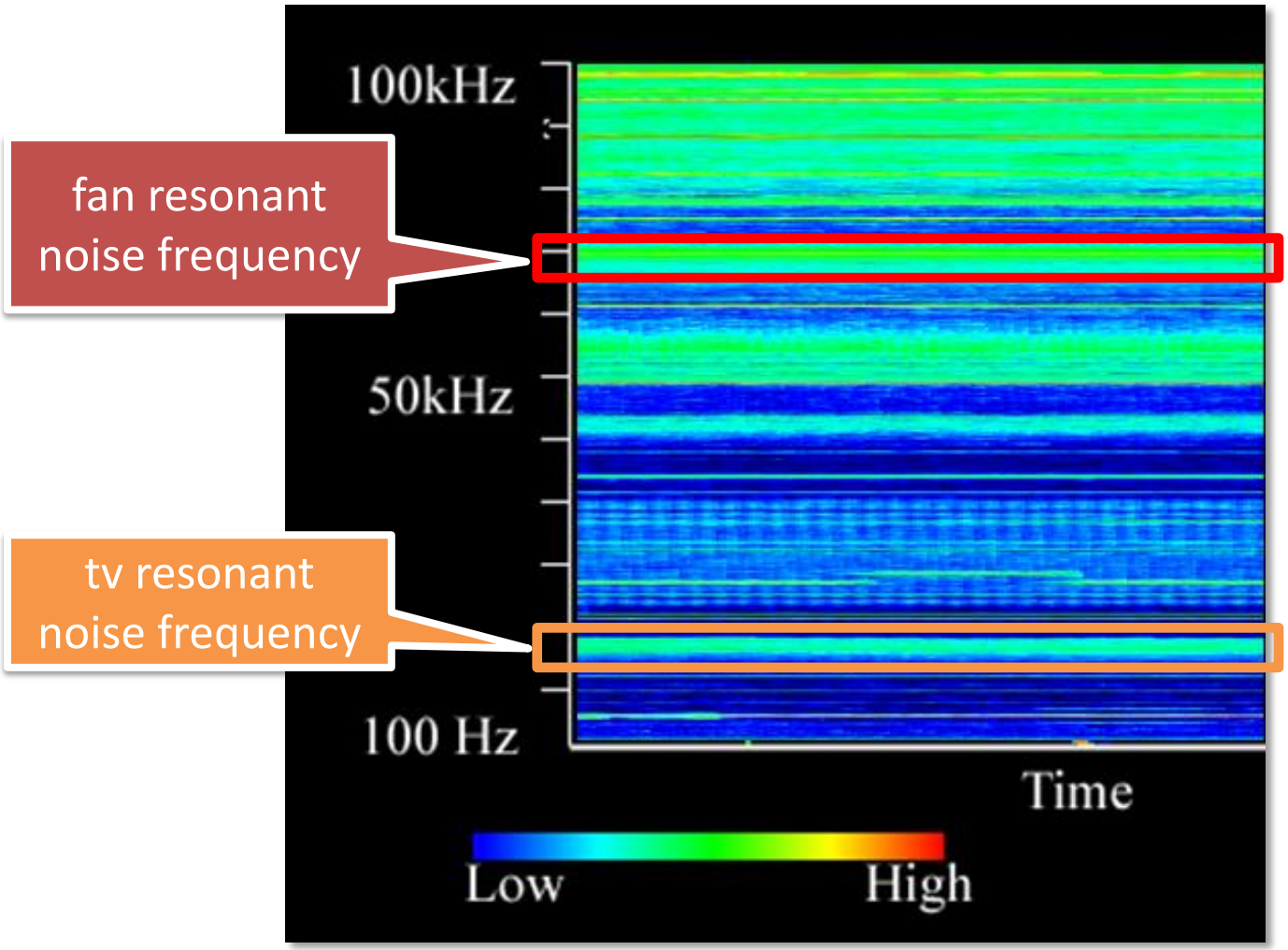


fan resonant noise frequency

tv resonant noise frequency






fan resonant noise frequency
tv resonant noise frequency
100kHz
50kHz
100 Hz
Time
Low
High

movie removed for
public posting of slide deck

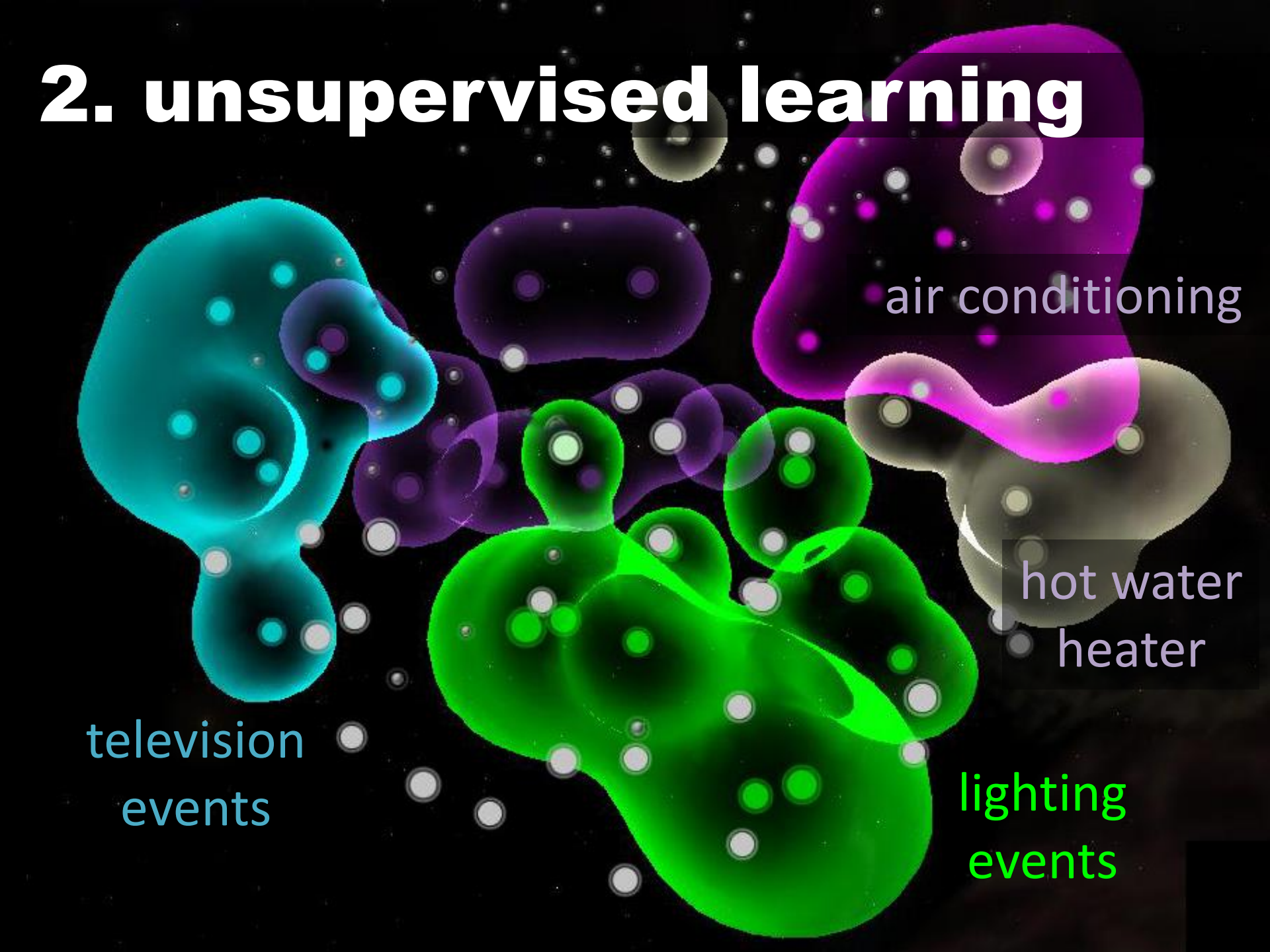
calibration:

3 approaches

1. the early adopters

2. unsupervised learning

2. unsupervised learning



3. the cloud

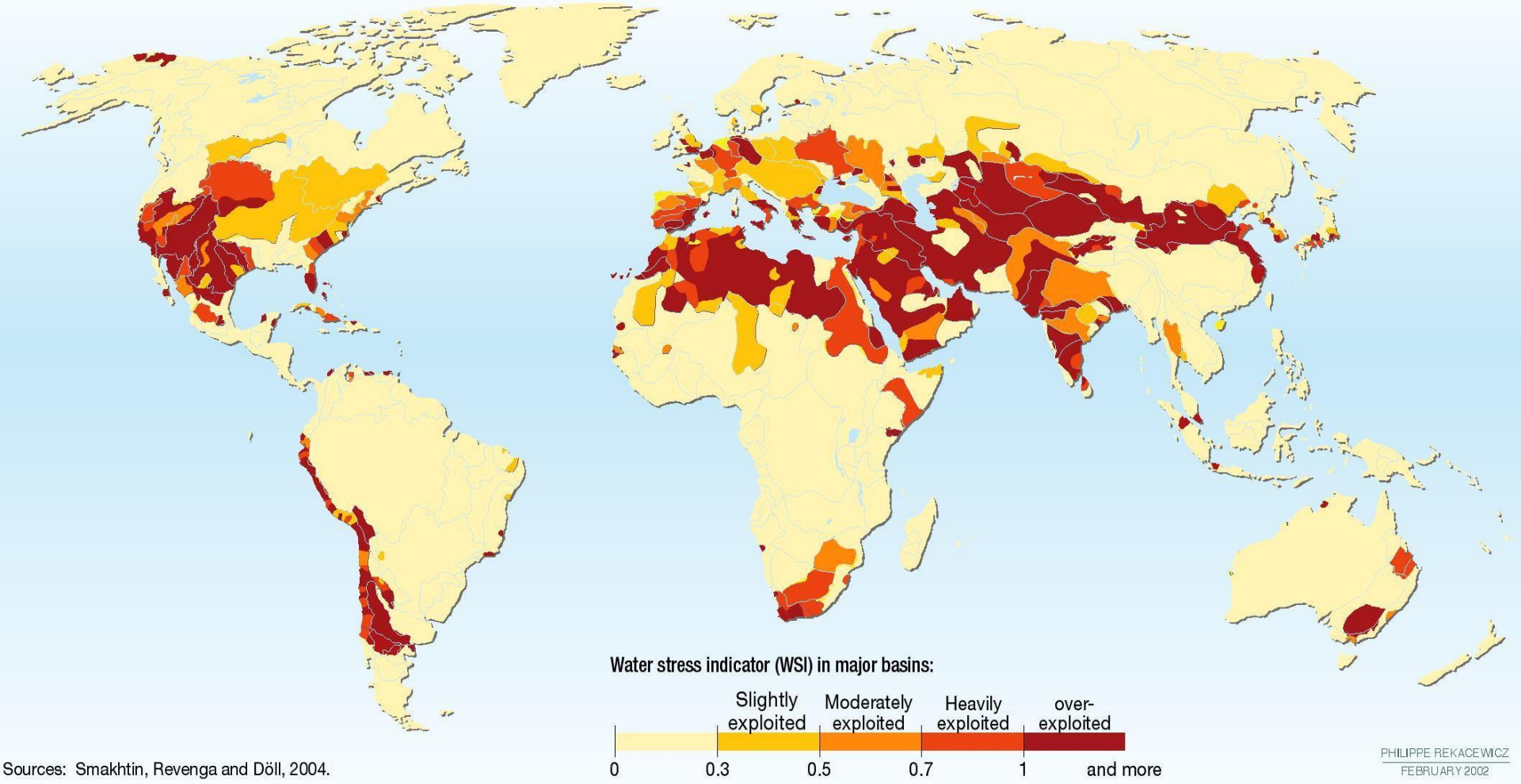
HYDROSENSE

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

water scarcity



Sources: Smakhtin, Revenga and Döll, 2004.

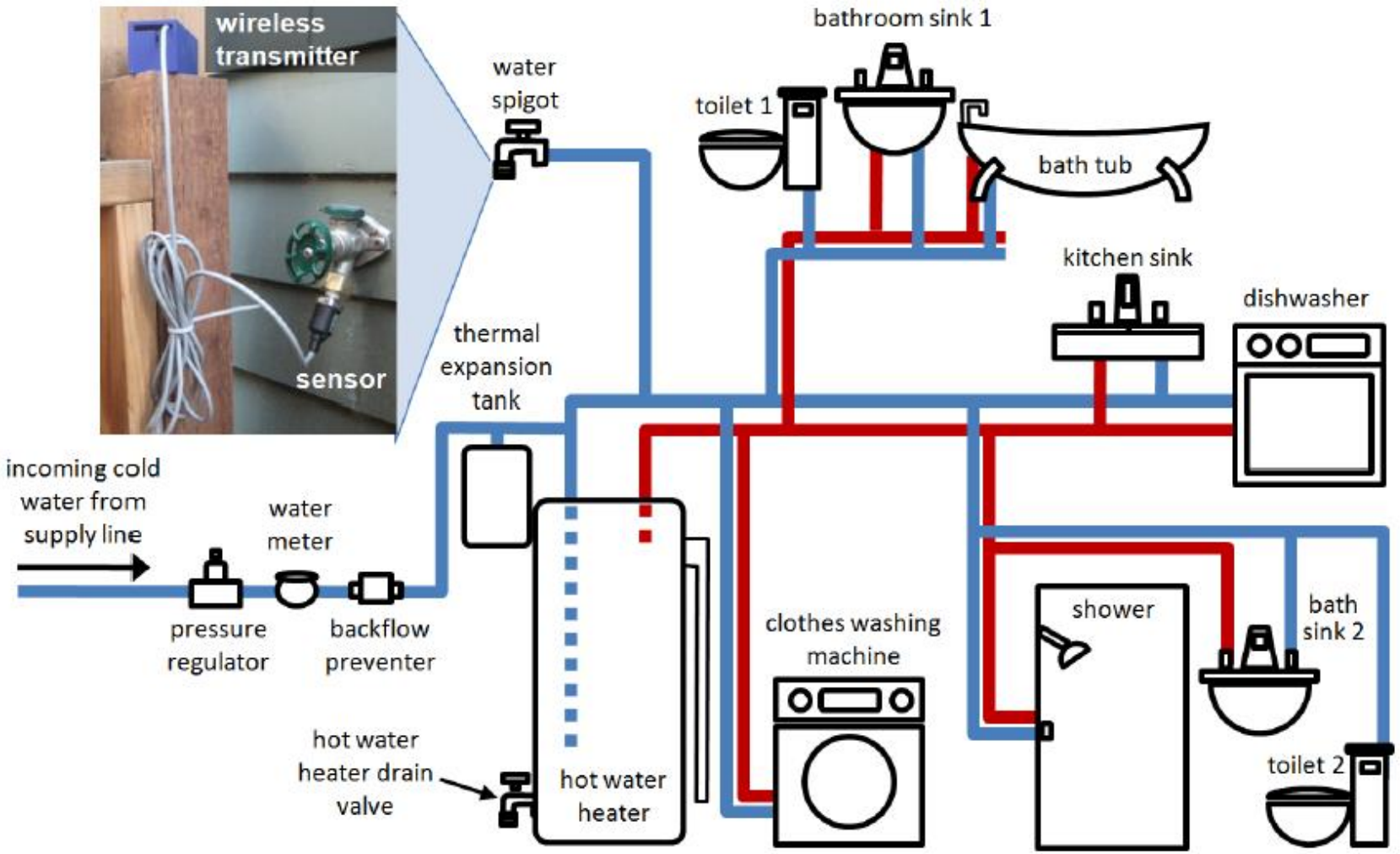
PHILIPPE REKACEWICZ
FEBRUARY 2002

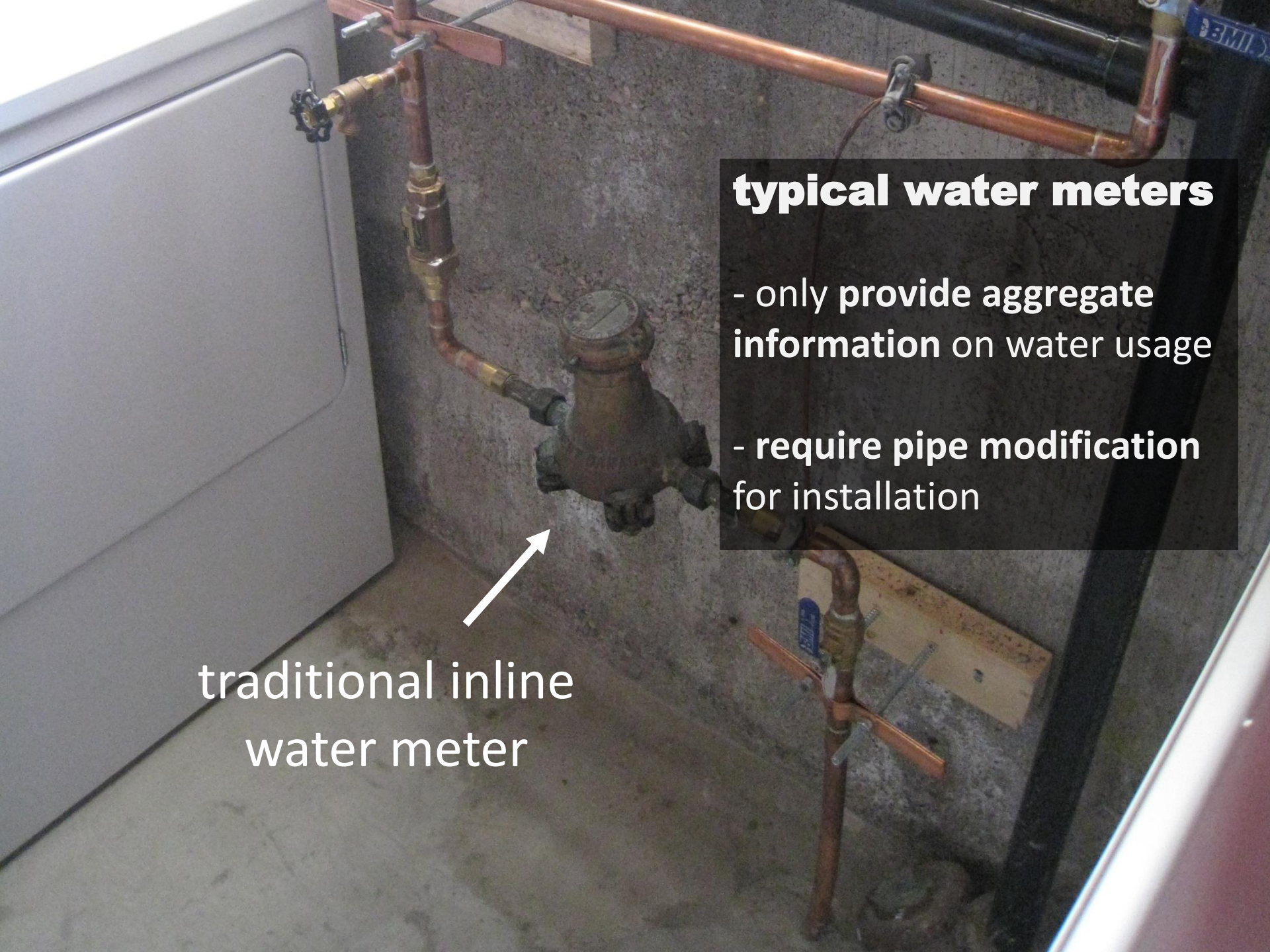
hydrosense

- **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**

hydrosense: pressure-based sensor

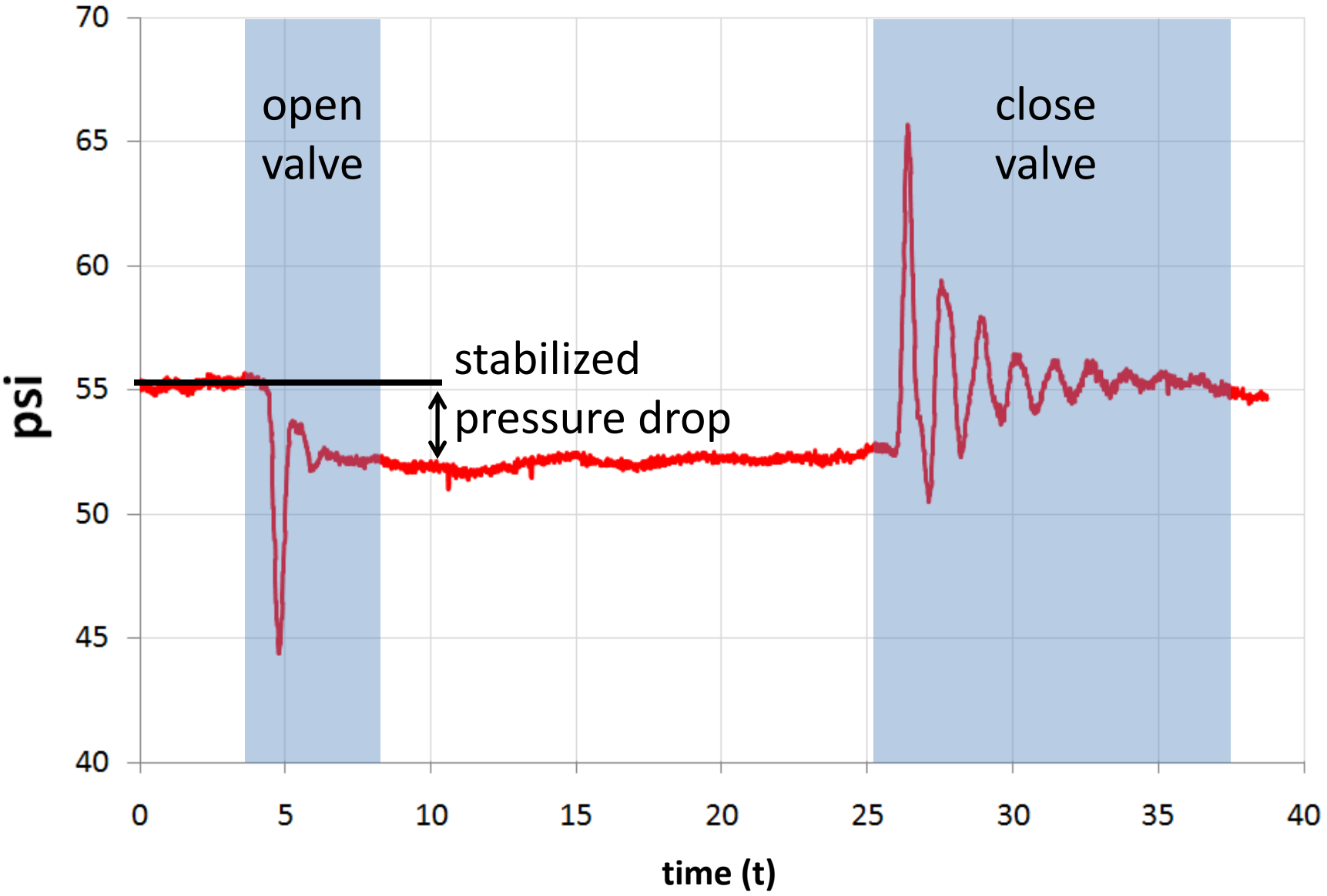
closed pressure system



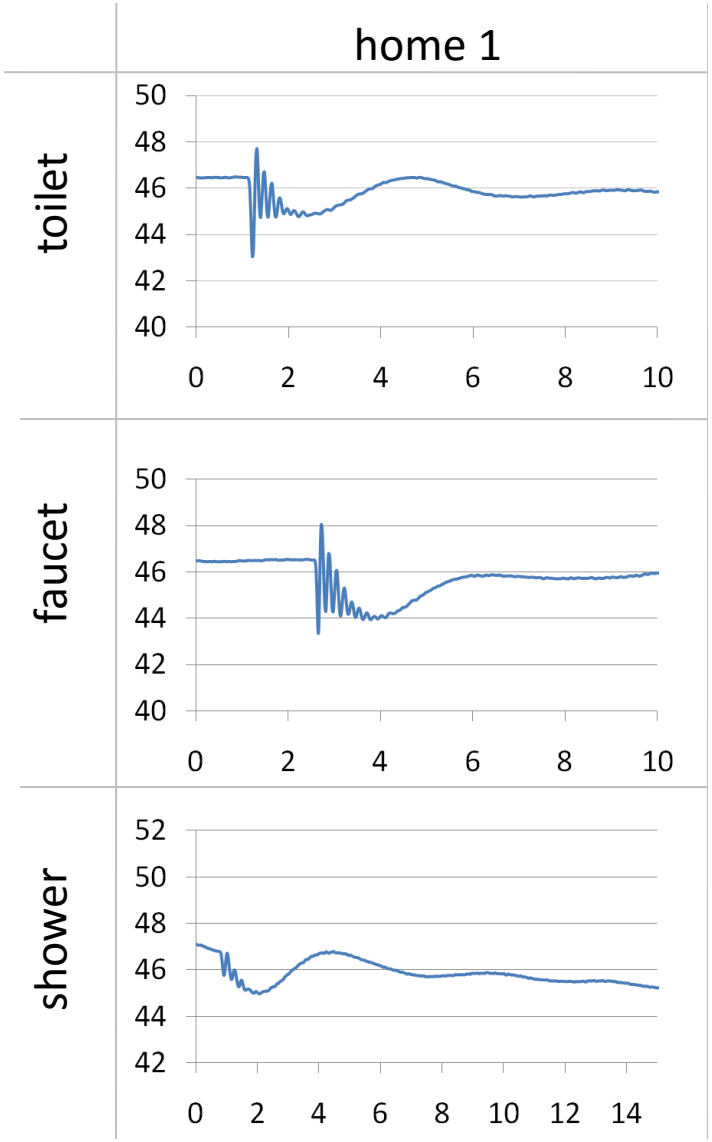

typical water meters
- only provide aggregate information on water usage
- require pipe modification for installation
traditional inline water meter

movie removed for
public posting of slide deck

raw bathroom sink signal



example open events



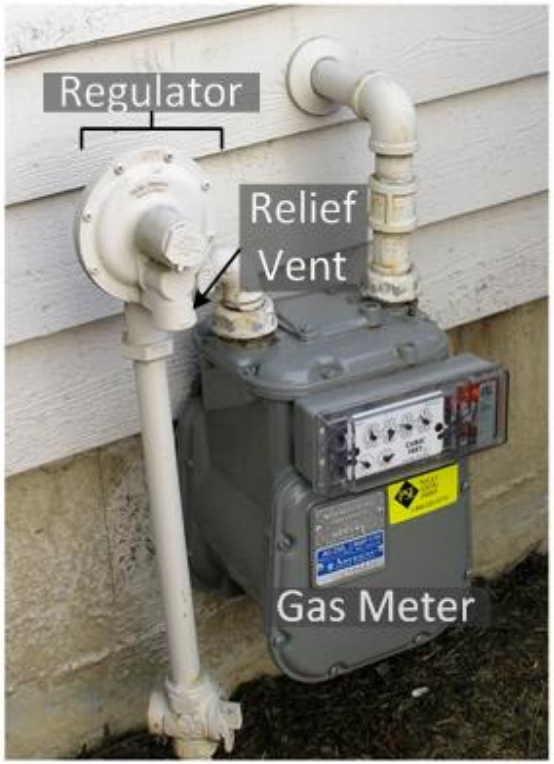
signature dependent on:

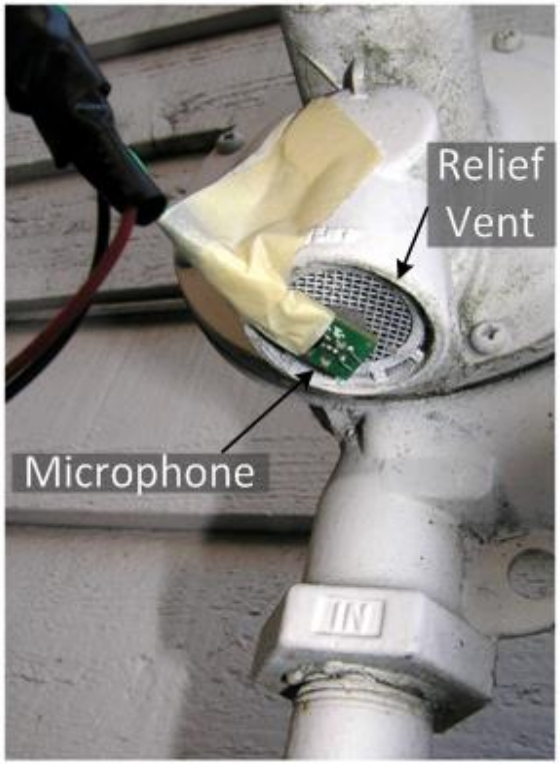
- **fixture type**
- **fixture location in home**

GasSense: Appliance-Level, Single-Point Sensing of Gas Activity in the Home

Gabe Cohn[1], Sidhant Gupta[2], Jon Froehlich[2], Eric Larson[1], Shwetak Patel[1,2]
[1]Electrical Engineering, [2]Computer Science and Engineering

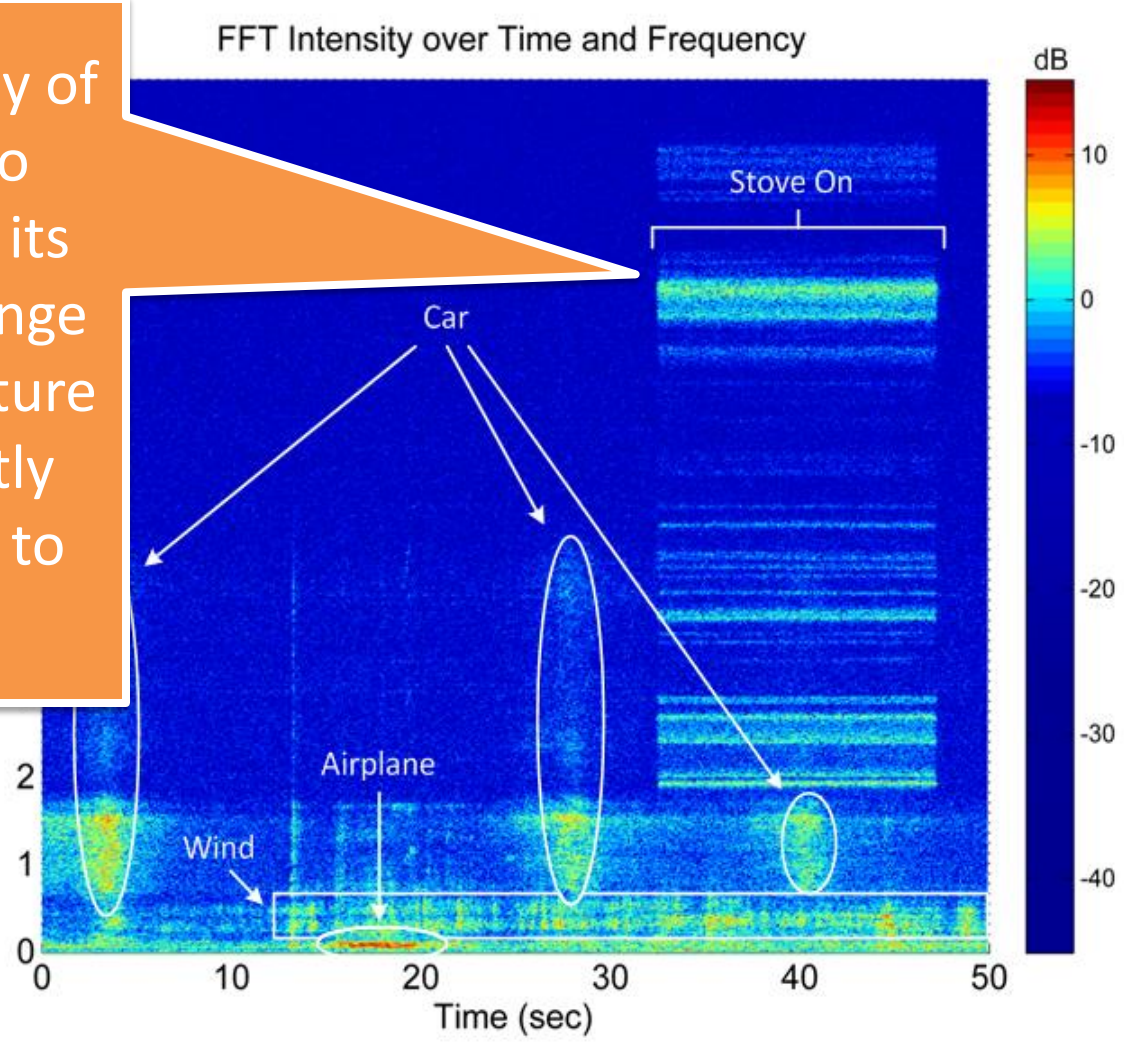
gassense installs on outside of gas regulator





the gassense signal

the intensity of this audio signal and its rate of change indicate fixture and directly correlates to flow



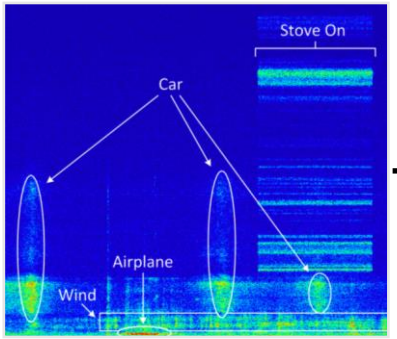
how gassense works

a gas event

instrumented regulator

Filter Ambient Noise and Extract Hissing

data cleansing

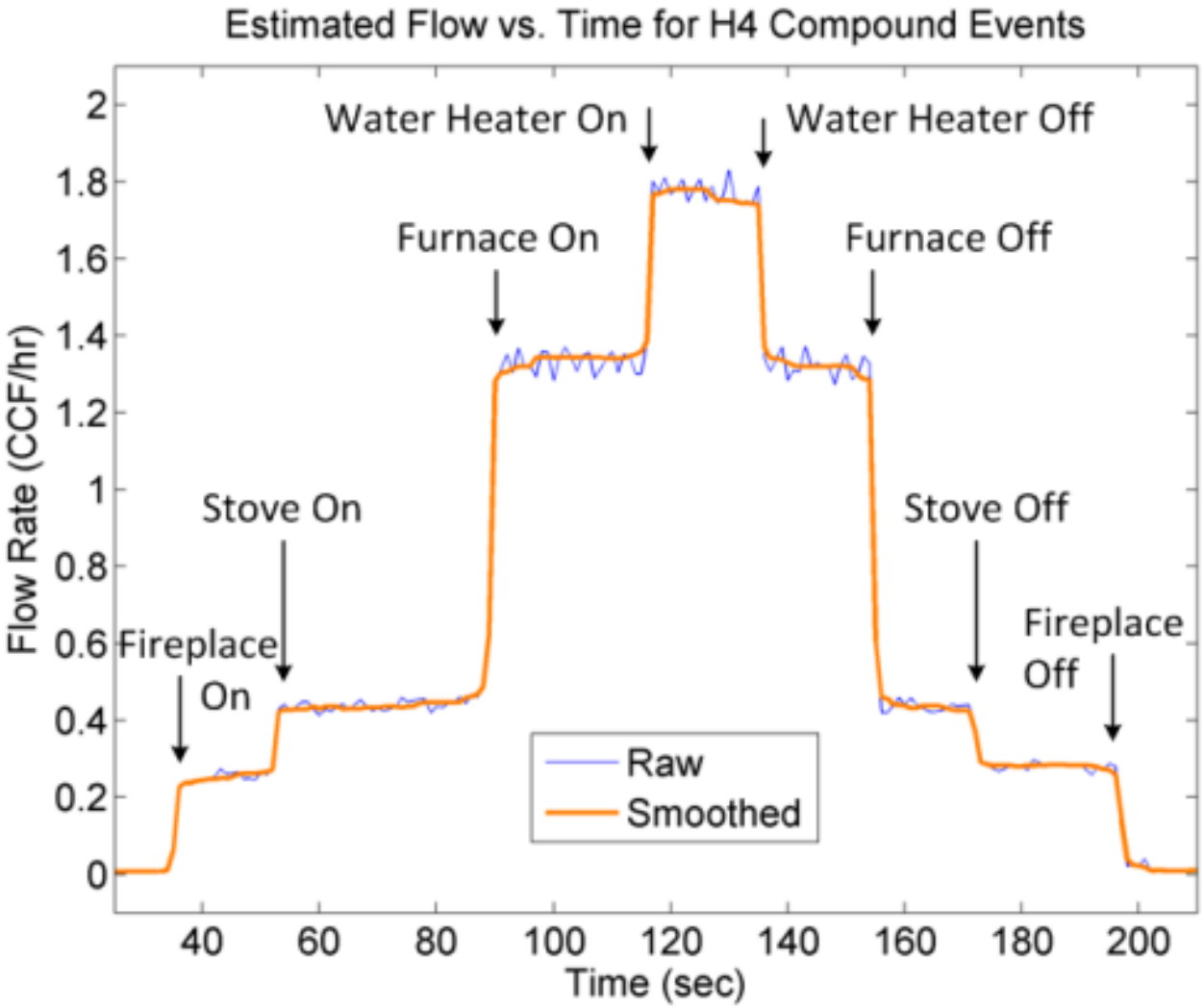


extract signal

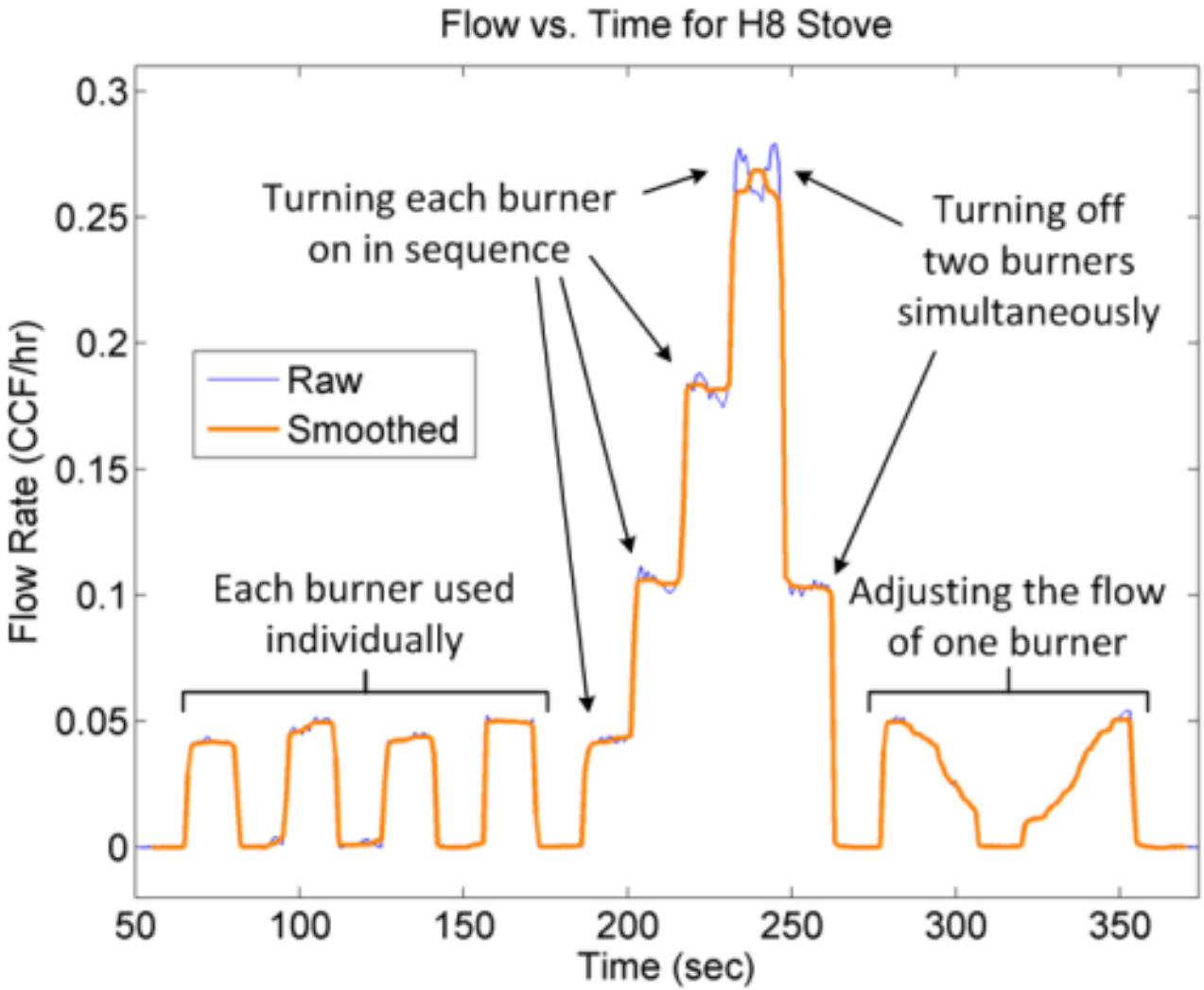
ML Algorithms

classify event

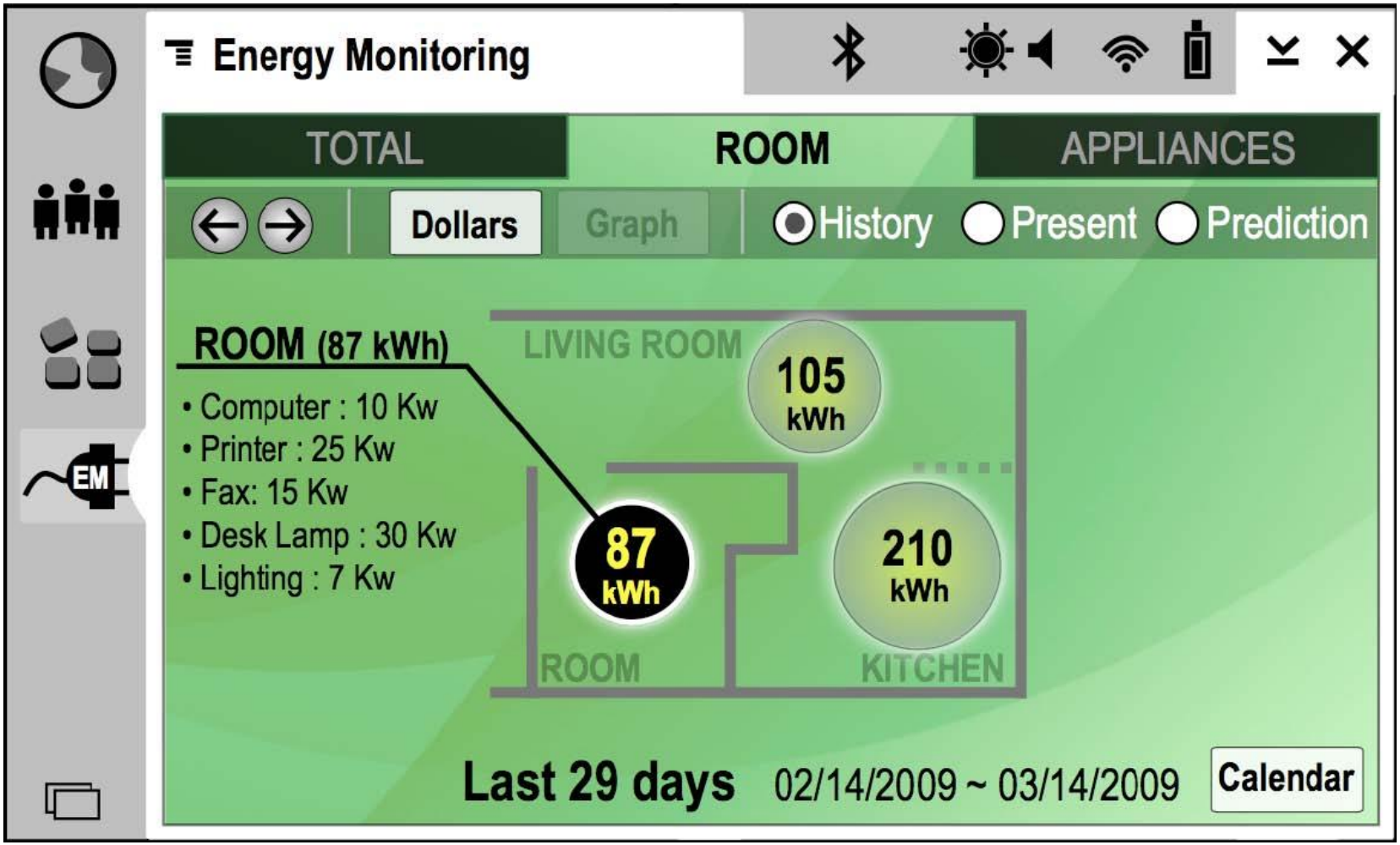
example data



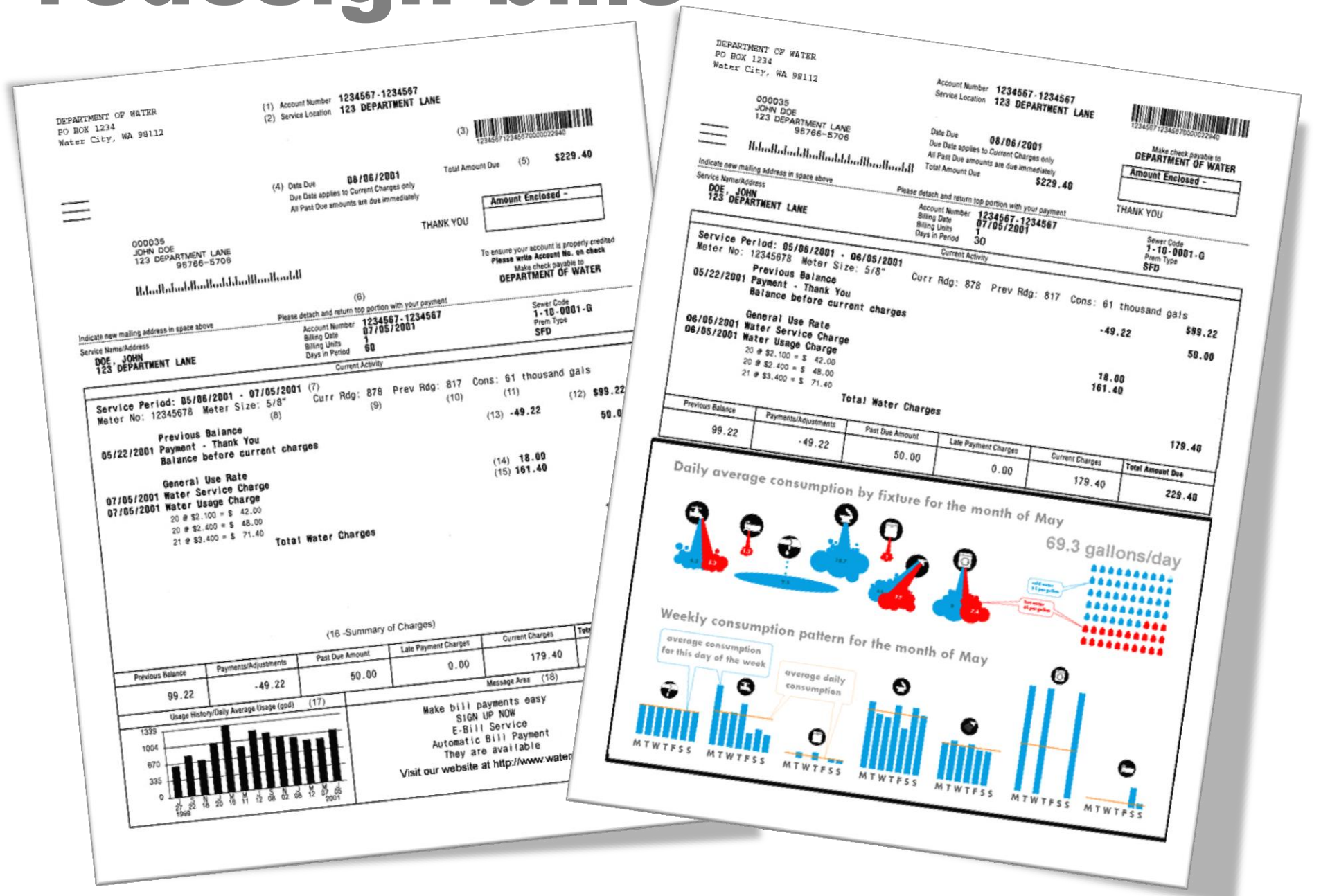
using the stove



enable new kinds of consumption feedback



redesign bills



DEPARTMENT OF WATER
PO BOX 1234
Water City, WA 98112

(1) Account Number 1234567-1234567
(2) Service Location 123 DEPARTMENT LANE

(3) Total Amount Due (5) $229.40

(4) Date Due 08/06/2001
Due Date applies to Current Charges only
All Past Due amounts are due immediately

Amount Enclosed -

THANK YOU

000035
JOHN DOE
123 DEPARTMENT LANE
98766-5706

To ensure your account is properly credited
Please write Account No. on check
Make check payable to
DEPARTMENT OF WATER

(6) Please detach and return top portion with your payment

Indicate new mailing address in space above

Service Name/Address
DOE, JOHN
123 DEPARTMENT LANE

Account Number 1234567-1234567
Billing Date 07/05/2001
Billing Units 1
Days in Period 60

Sewer Code 1-10-0001-G
Prem Type SFD

Current Activity

Service Period: 05/06/2001 - 07/05/2001 (7)
Meter No: 12345678 Meter Size: 5/8" (8) Curr Rdg: 878 Prev Rdg: 817 (9) Cons: 61 thousand gals

	Previous Balance	(10)	(11) (12) $99.22
05/22/2001	Payment - Thank You		(13) -49.22 50.0
	Balance before current charges		
	General Use Rate		
07/05/2001	Water Service Charge		(14) 18.00
07/05/2001	Water Usage Charge		(15) 161.40
	20 @ $2.100 = $ 42.00		
	20 @ $2.400 = $ 48.00		
	21 @ $3.400 = $ 71.40		
	Total Water Charges		

(16 -Summary of Charges)

Previous Balance	Payments/Adjustments	Past Due Amount	Late Payment Charges	Current Charges	Tot
99.22	-49.22	50.00	0.00	179.40	

Usage History/Daily Average Usage (gpd) (17)

Message Area (18)

Make bill payments easy
SIGN UP NOW
E-Bill Service
Automatic Bill Payment
They are available
Visit our website at http://www.water

DEPARTMENT OF WATER
PO BOX 1234
Water City, WA 98112

Account Number 1234567-1234567
Service Location 123 DEPARTMENT LANE

000035
JOHN DOE
123 DEPARTMENT LANE
98766-5706

Date Due 08/06/2001
Due Date applies to Current Charges only
All Past Due amounts are due immediately
Total Amount Due $229.40

Make check payable to
DEPARTMENT OF WATER

Amount Enclosed -

THANK YOU

Indicate new mailing address in space above

Please detach and return top portion with your payment

Service Name/Address
DOE, JOHN
123 DEPARTMENT LANE

Account Number 1234567-1234567
Billing Date 07/05/2001
Billing Units 1
Days in Period 30

Sewer Code 1-10-0001-G
Prem Type SFD

Current Activity

Service Period: 05/06/2001 - 06/05/2001
Meter No: 12345678 Meter Size: 5/8" Curr Rdg: 878 Prev Rdg: 817 Cons: 61 thousand gals

	Previous Balance		$99.22
05/22/2001	Payment - Thank You	-49.22	
	Balance before current charges		50.00
	General Use Rate		
06/05/2001	Water Service Charge		18.00
06/05/2001	Water Usage Charge		161.40
	20 @ $2.100 = $ 42.00		
	20 @ $2.400 = $ 48.00		
	21 @ $3.400 = $ 71.40		
	Total Water Charges		179.40

Previous Balance	Payments/Adjustments	Past Due Amount	Late Payment Charges	Current Charges	Total Amount Due
99.22	-49.22	50.00	0.00	179.40	229.40

Daily average consumption by fixture for the month of May

69.3 gallons/day

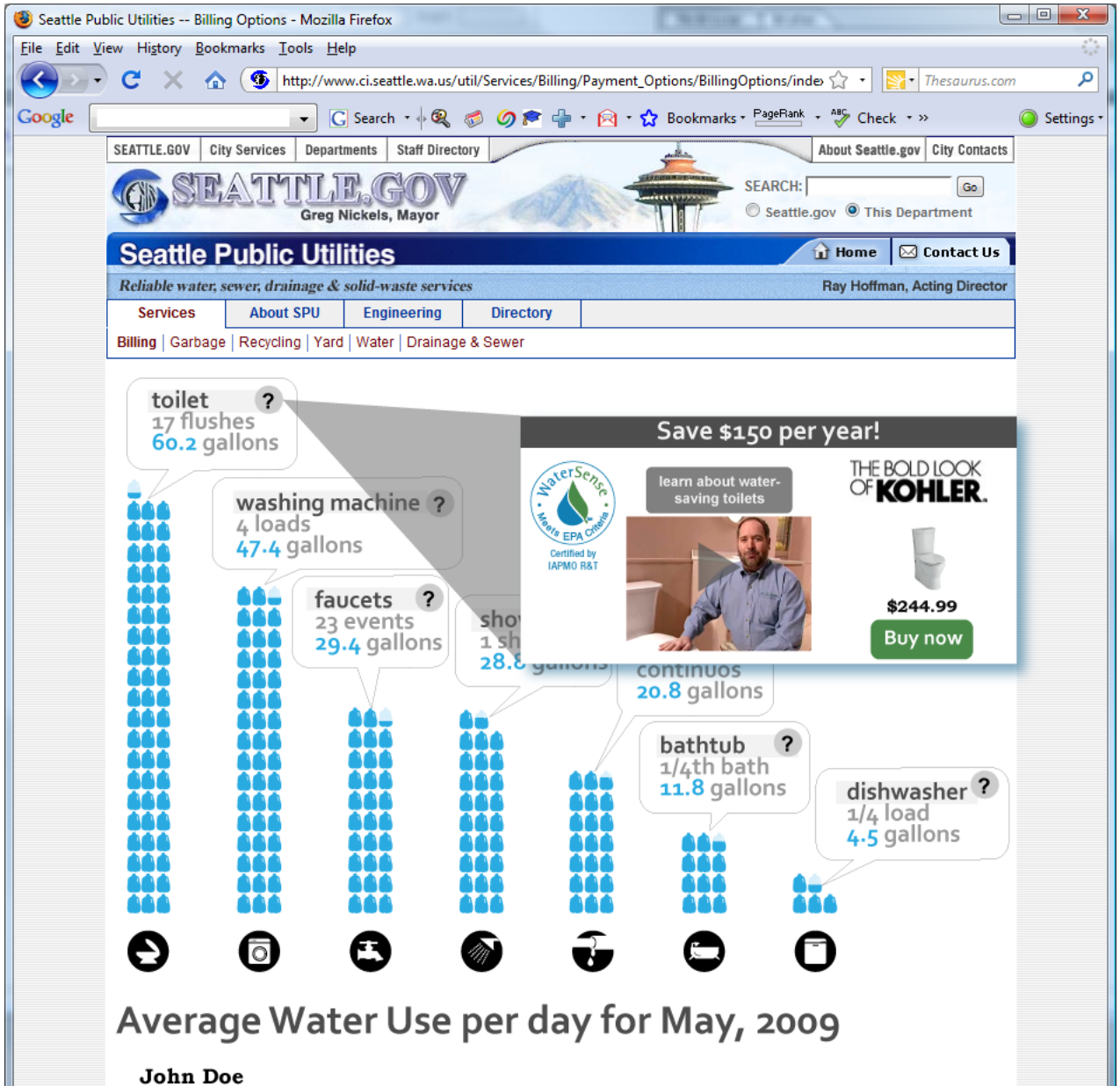
Weekly consumption pattern for the month of May

average consumption for this day of the week

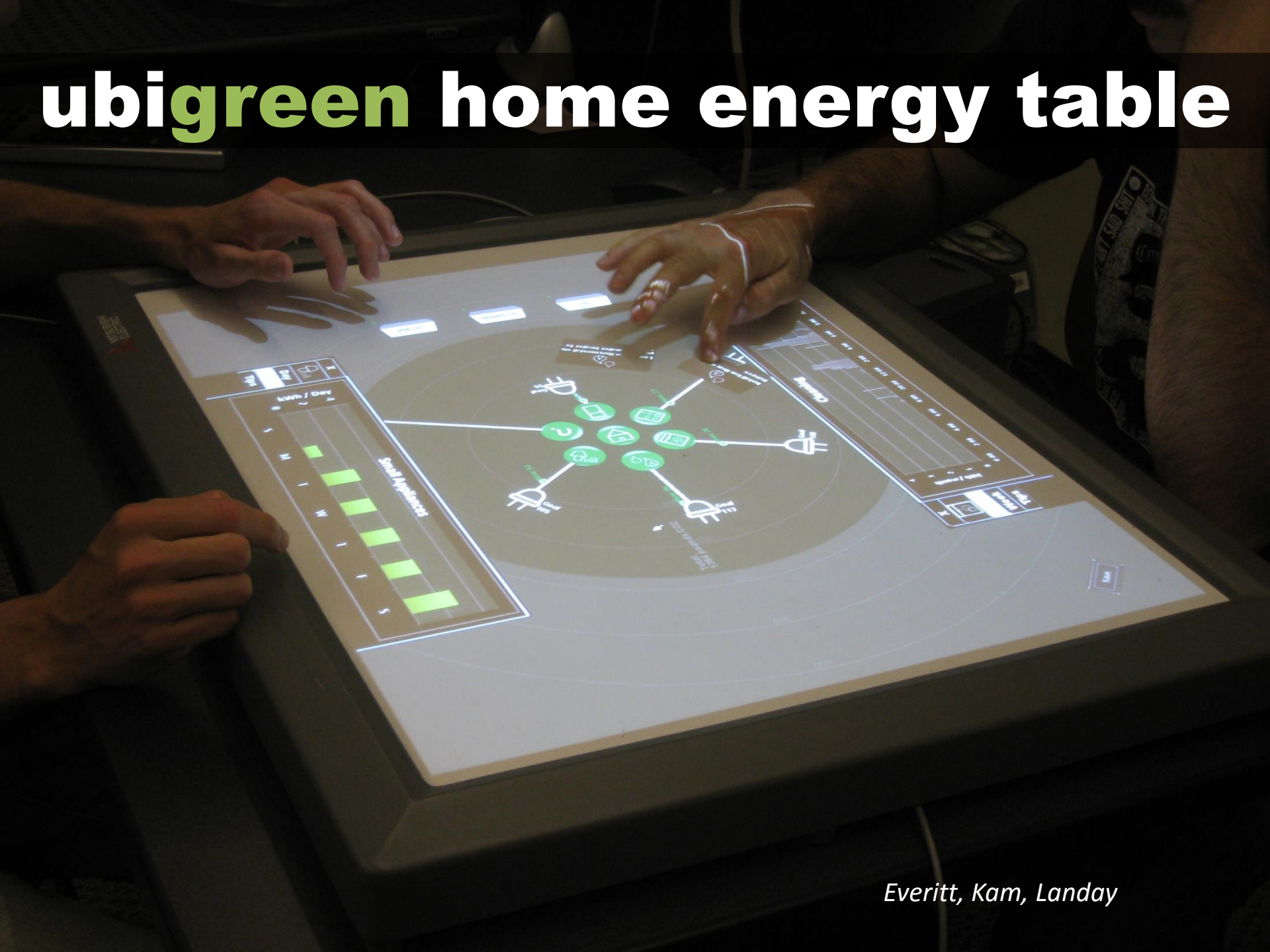
average daily consumption

M T W T F S S

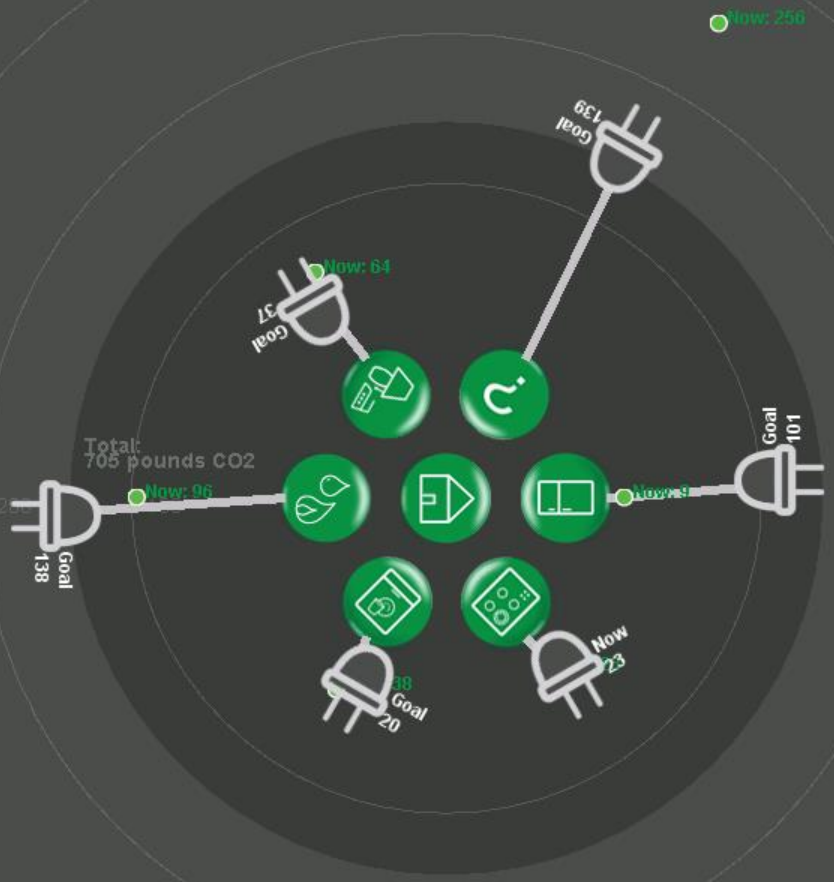
redesigned websites



ubigreen home energy table



Everitt, Kam, Landay



0 Will Do

1 Already Do

0 No

X

Day

Week

Example

Tips

Air dry your dishes.	Purchase a new dishwasher.	Only wash full loads in the dishwasher.	Buy a new ENERGY STAR clothes washer and/or dryer
Air dry your clothes.	Wash and dry only full loads in the laundry.	Wash your clothes in cold water	

disaggregated feedback study

advanced home resource consumption sensing

low-cost

easy-to-install

device-level information

Thank You!

jonfroehlich@gmail.com
twitter @jonfroehlich

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

students


Jon Froehlich


Gabe Cohn


Sidhant Gupta


Eric Larson


Tim Campbell


Kate Everitt


Marilyn Ostergren

faculty


Shwetak Patel


James Fogarty


James Landay

dub design: use: build:
university of washington

ubicomp lab
university of washington

sustain
sustainability research

Thank You!

jonfroehlich@gmail.com
twitter @jonfroehlich

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

students


Jon Froehlich


Gabe Cohn


Sidhant Gupta


Eric Larson


Tim Campbell


Kate Everitt


Marilyn Ostergren

faculty


Shwetak Patel


James Fogarty


James Landay

ZENSI

sense more waste less

dub design: use: build:
university of washington

ubicomp lab
university of washington

sustain
sustainability research

Thank You!

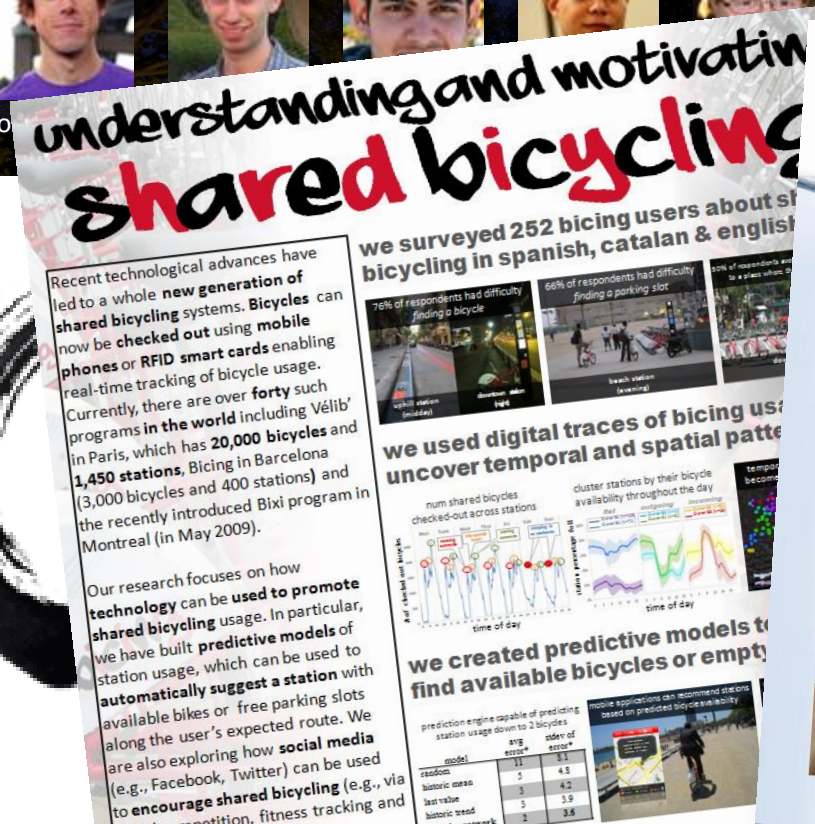
jonfroehlich@gmail.com
twitter @jonfroehlich

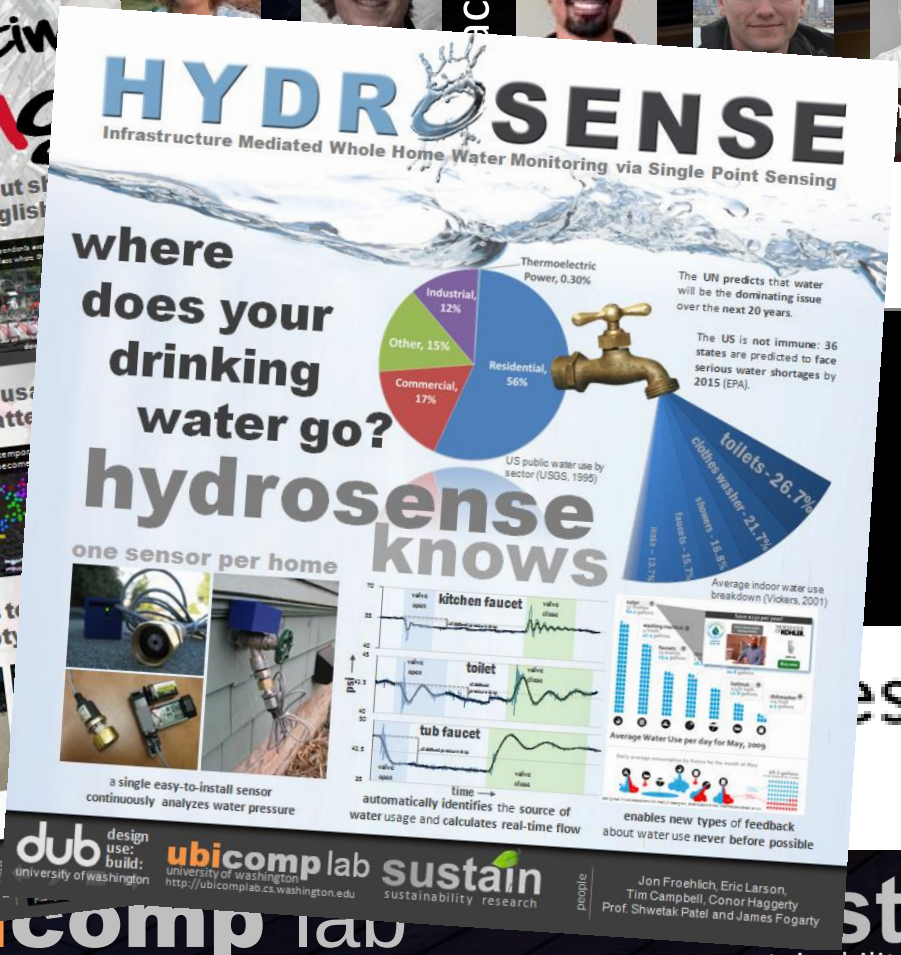
http://ubicomplab.cs.washington.edu
http://dub.washington.edu/

students

faculty

James Landay





dub university of washington

ubicomp lab university of washington

sustain sustainability research