

Energy-Harvesting Thermoelectric Sensing for Unobtrusive Water and Appliance Metering

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The Call for “Low Power Sensors”

“BTO [Building Technologies Office] is particularly interested in innovative approaches that **reduce the cost and power** consumption for data collection of common building operation variables (**temperature, pressure, relative humidity, etc.**)...”

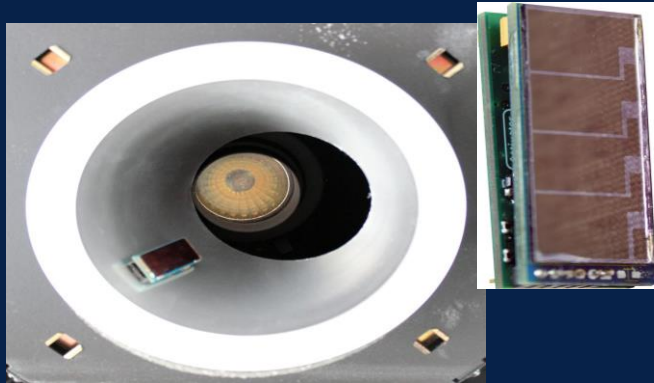
Source(s):

1. “Building Energy Efficiency Frontiers and Incubator Technologies (BENEFIT),” DE-FOA-0001027, 2014

An Energy Harvesting Architecture

The Monjolo Family

- Energy-neutral system
- Wireless communications



Light-level



Plug-load



Panel-mount

The Monjolo Principle

Monjolo: Portuguese water hammer

In an energy harvesting system:

The rate at which energy is harvested
is proportional to the intensity of the
measured phenomenon

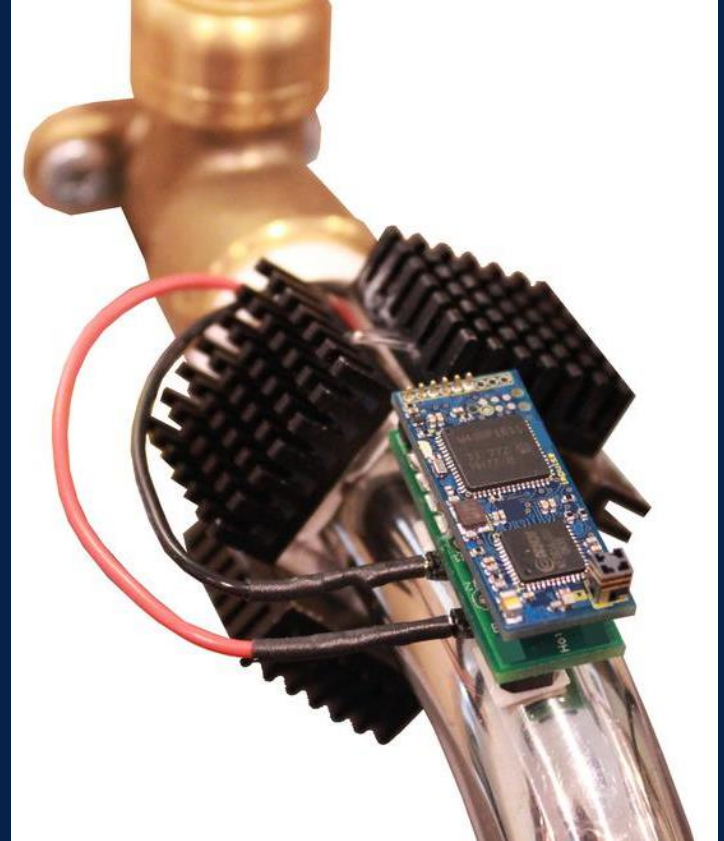
The energy harvester *is* the sensor



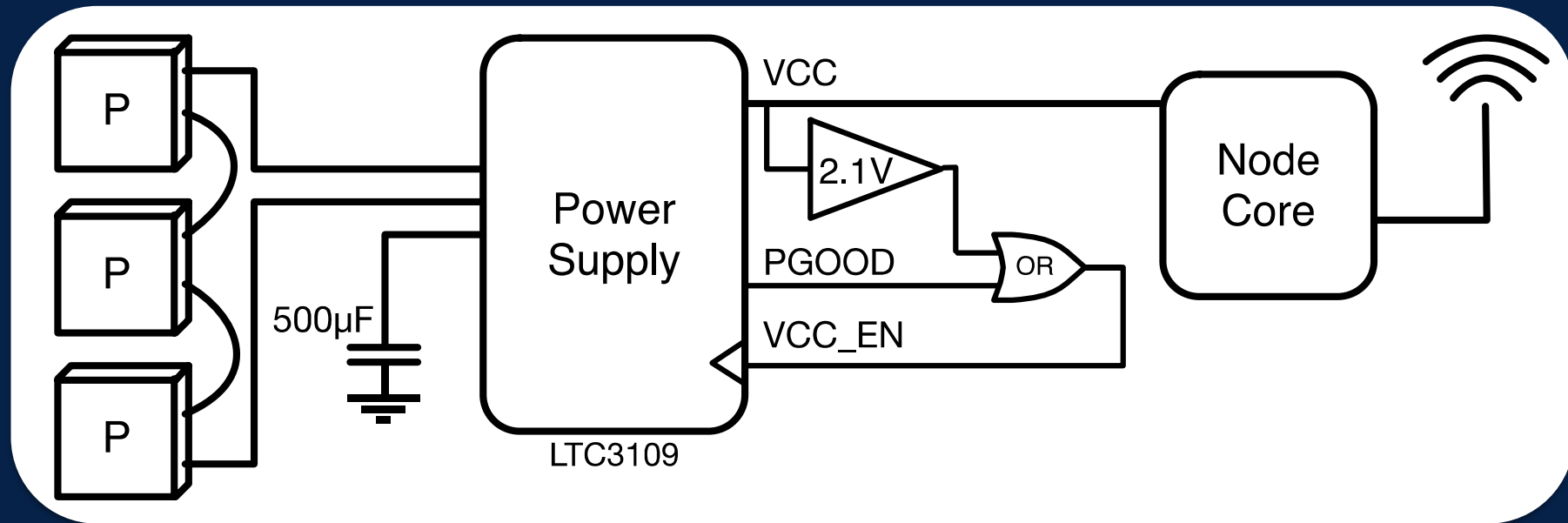
Our System Design

Thermes

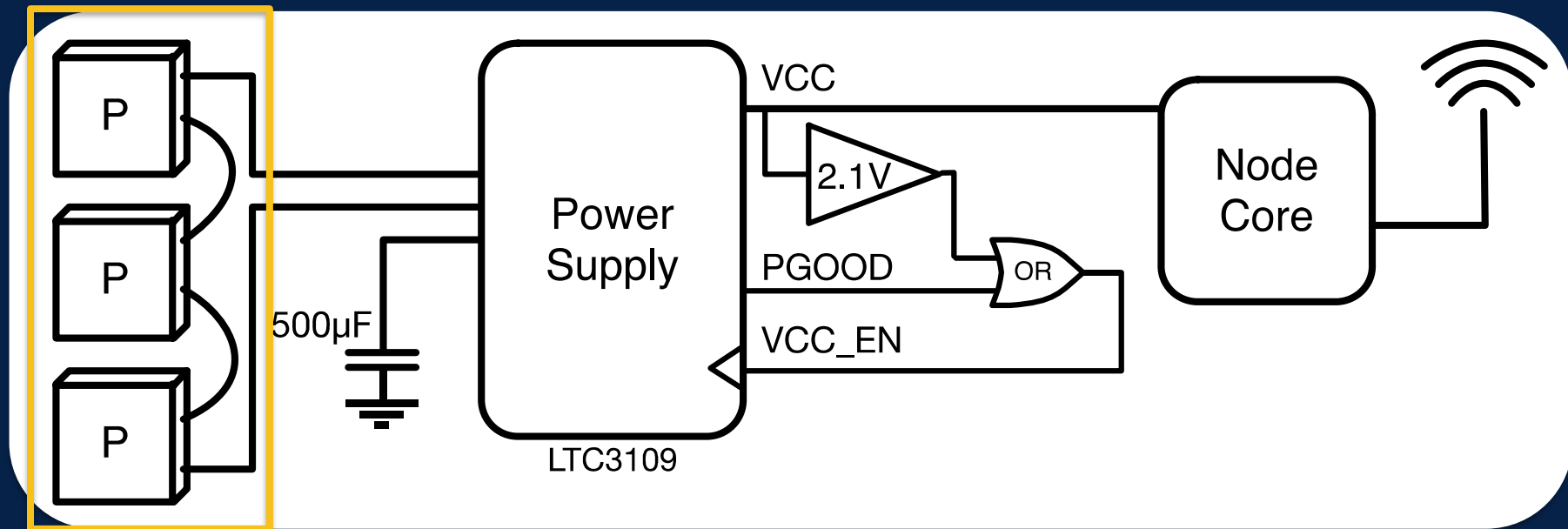
- Small form factor
- Thermal energy-harvesting
- Energy-neutral system
- Wireless communication



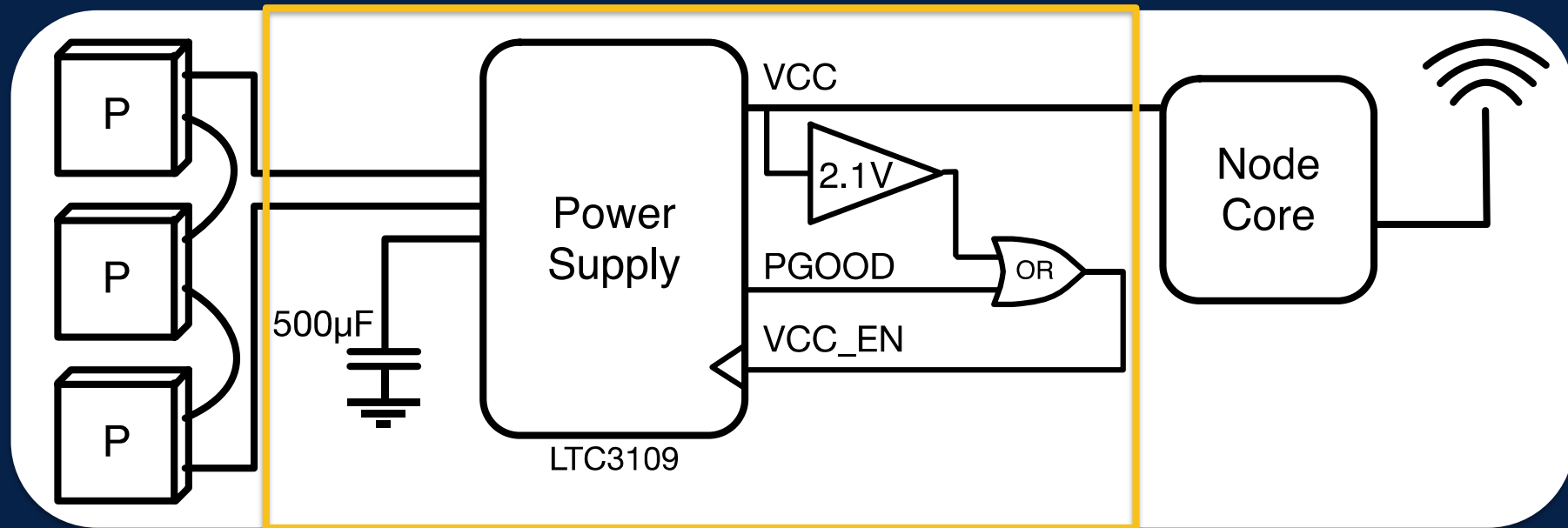
Thermes System Architecture



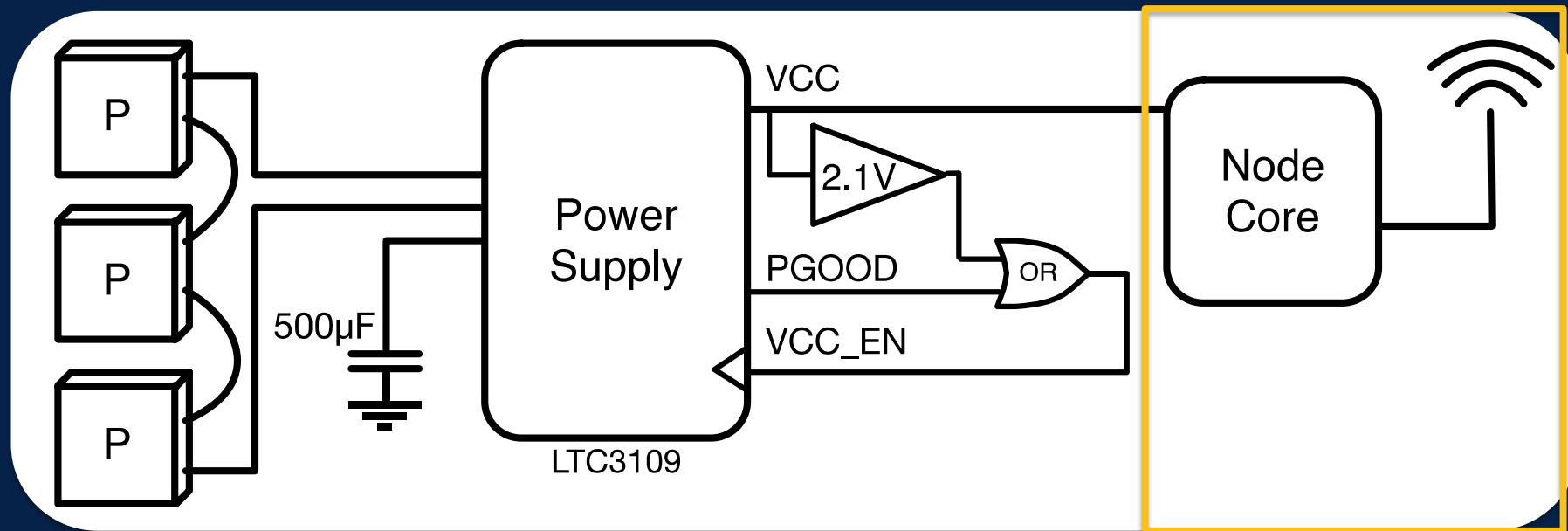
Thermes System Architecture



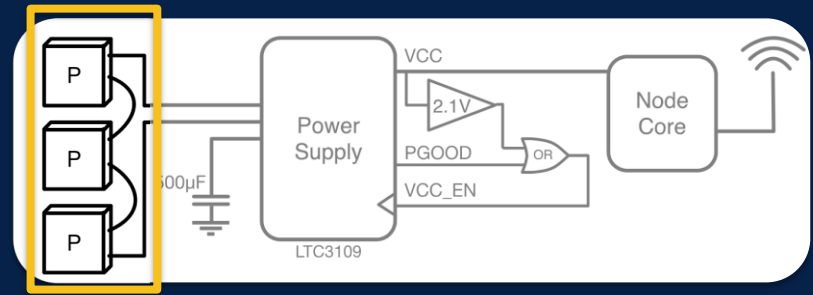
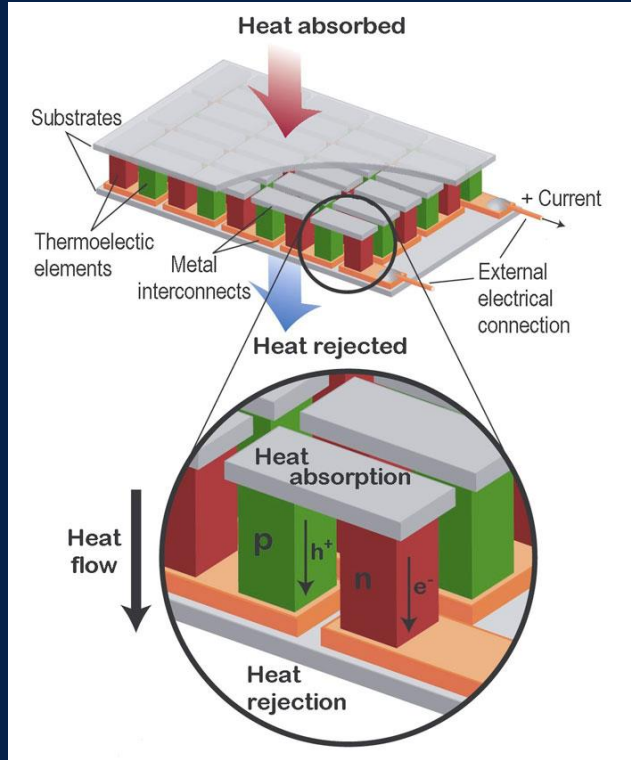
Thermes System Architecture



Thermes System Architecture



Harvesting Front End



Peltier junctions

- Temperature differential into current
- Low efficiency

Heat rejection is critical

Multiple junctions in series for more voltage

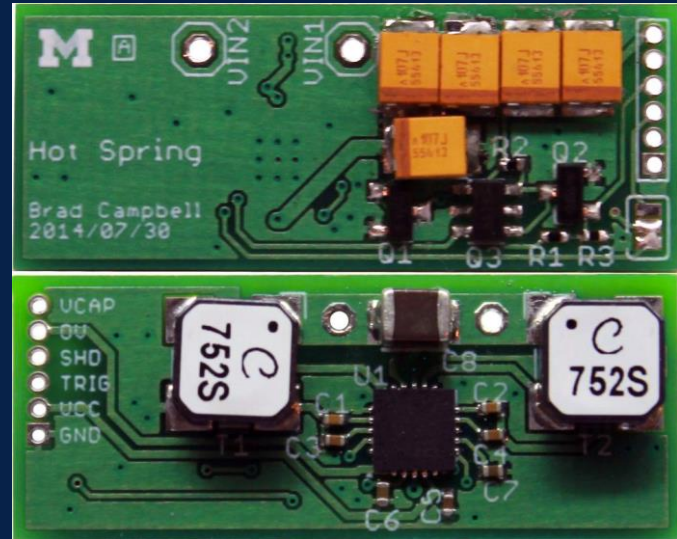
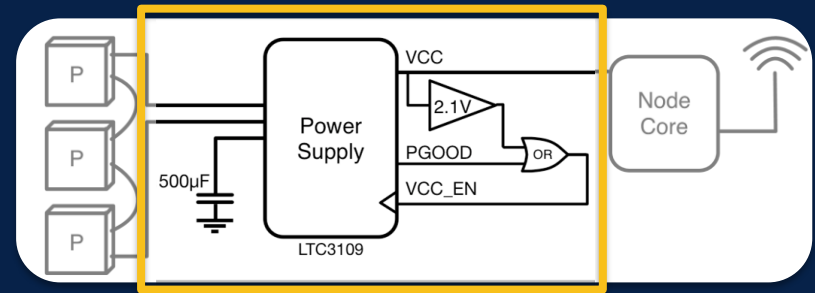
Zoom into Power System

Power supply

- Auto-polarity
- Harvesting begins at 30 mV

500 μ F capacitor bank

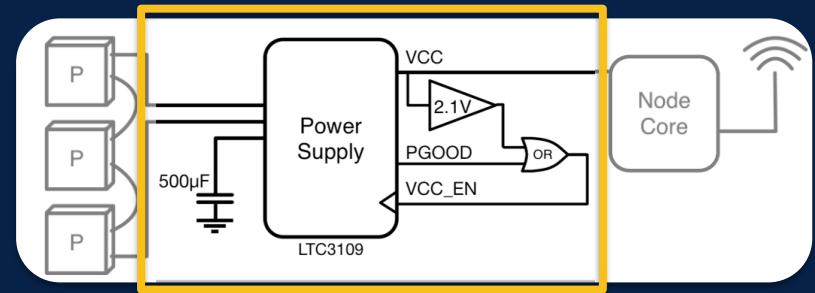
- No battery



Top

Bottom

Zoom into Latch Circuit

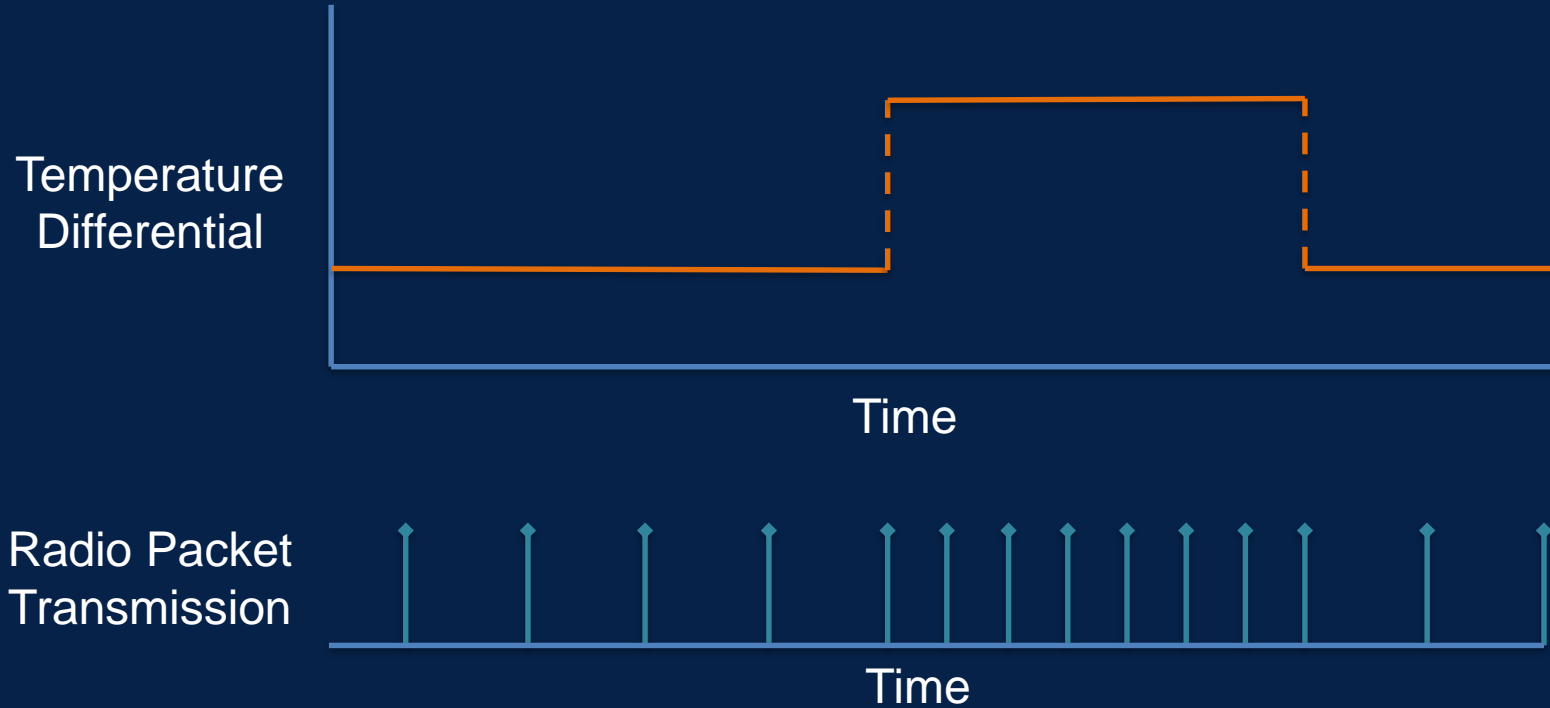


Latch sets size of “bucket” and turns the node core on and off

Turns on at 3.1 V, powers down at 2.1 V
Translates to 1.3 mJ per activation

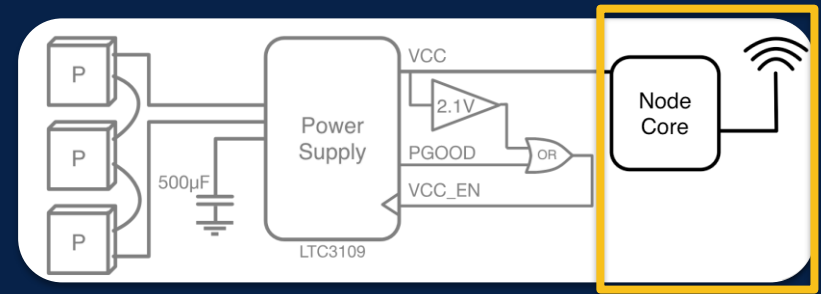


Transmission Rate Changes with Temperature



Zoom into Node Core

The classic node setup

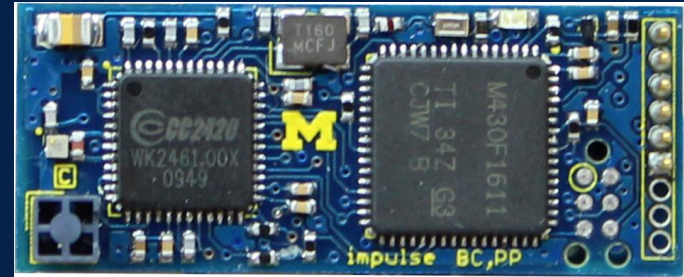


MSP430

- TinyOS

CC2420

- 802.15.4 communications



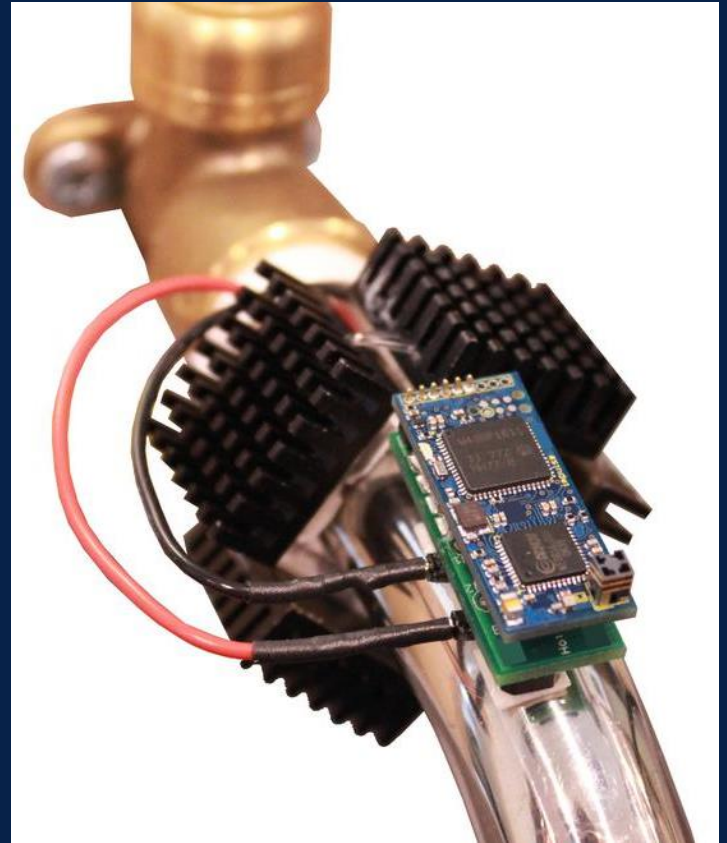
Top

Our System Design

Thermes

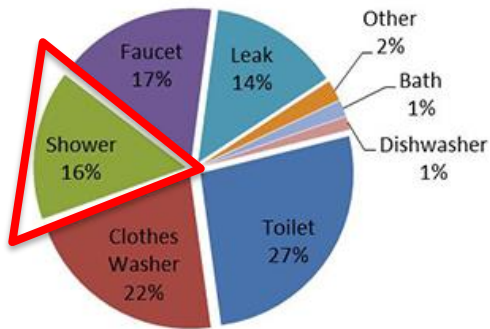
Energy-Neutral Thermal Sensing

But what can you do with such a sensor?



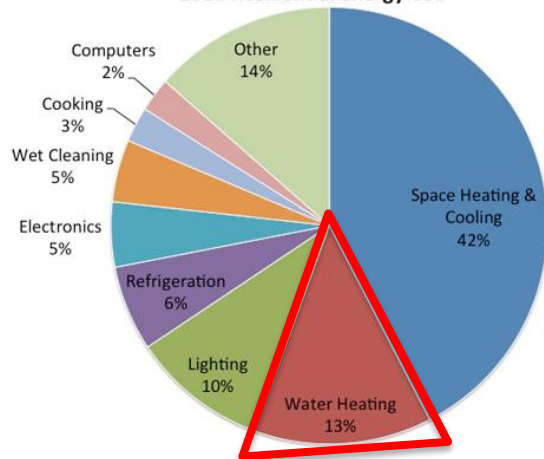
Shower Use Is a Contributing Factor

Indoor Water Use per capita in U.S.



American Water Works Association Research Foundation, "Residential End Uses of Water." 1999

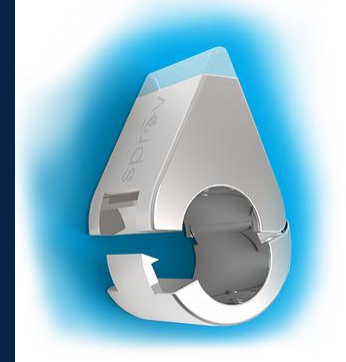
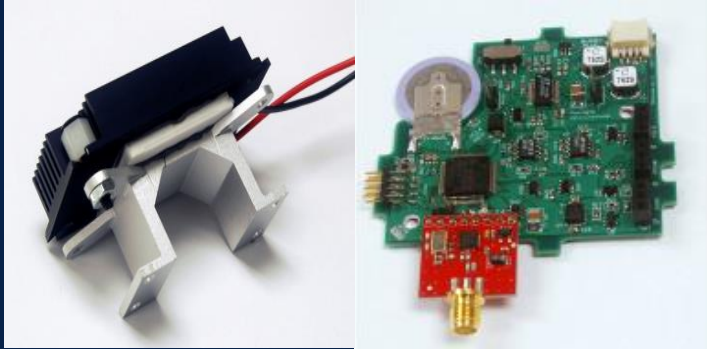
2010 Residential Energy Use



Department of Energy, "Building Energy Data Book." 2010

Consumers don't have insight into how this energy is being spent

Existing Water Meters



Acoustic Water Meters

High powered sensing

- Lifetime limitation



Upstream



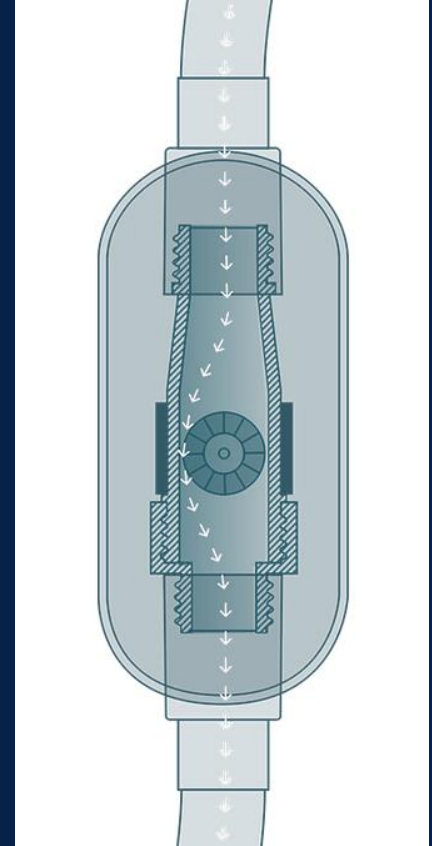
Sprav

Impeller-Based Water Meters

Impeller-based design

- Good for energy harvesting
- Difficult installation

Amphiro



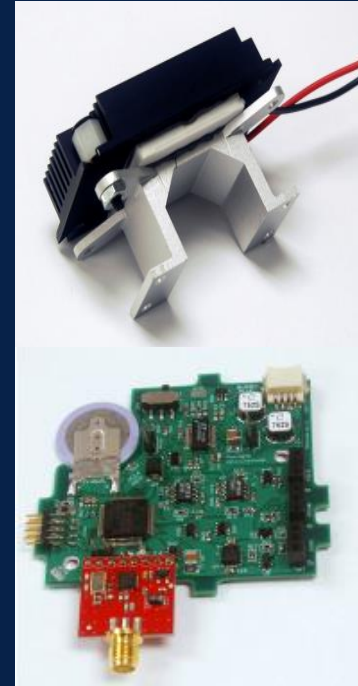
Thermal Harvesting Water Meters

Thermoelectric energy-harvesting

- Energy-neutral in some cases

Accelerometer-based sensing

- Increases energy needs



DoubleDip

Applying Our Solution

This is an area for which we designed Thermes

Trade accuracy and fine-grained detail
for continuous batteryless operation

Shower sensing is actually very challenging for this system

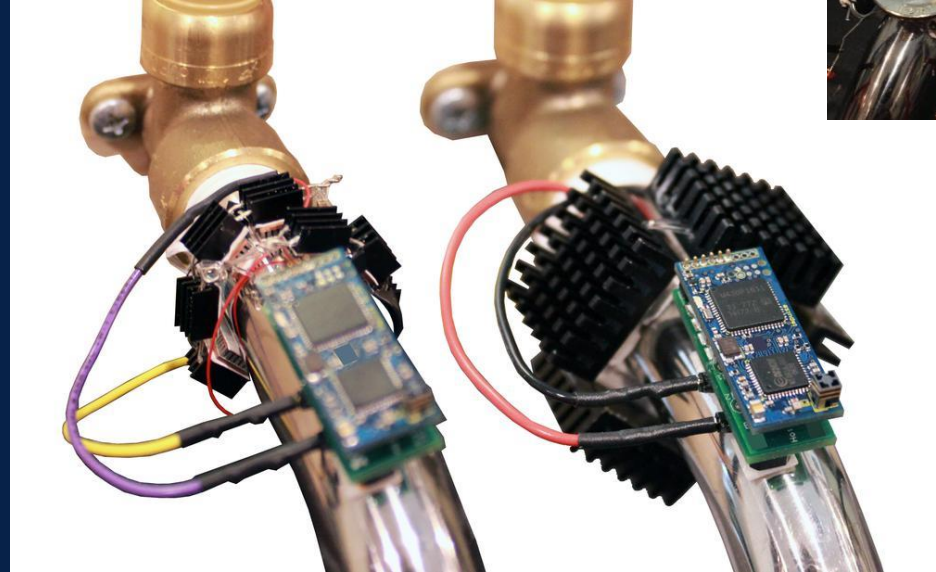
Thermes Implementations

Small Bracelet

- 6 Peltier Junctions
(7 mm x 6 mm)
- 9 Heatsinks

Large Bracelet

- 4 Peltier Junctions
(15 mm x 15 mm)
- 4 Heatsinks



Evaluation Criteria

- 1) How does it work at various water temperatures?
- 2) How well can it estimate start and stop times?
- 3) How well does it work on a real shower?
- 4) What other applications can it be used for?

Evaluation Setup

Mini-shower

Allows for configurable
constant water temperature

Ambient temperature remained
23° C for all tests



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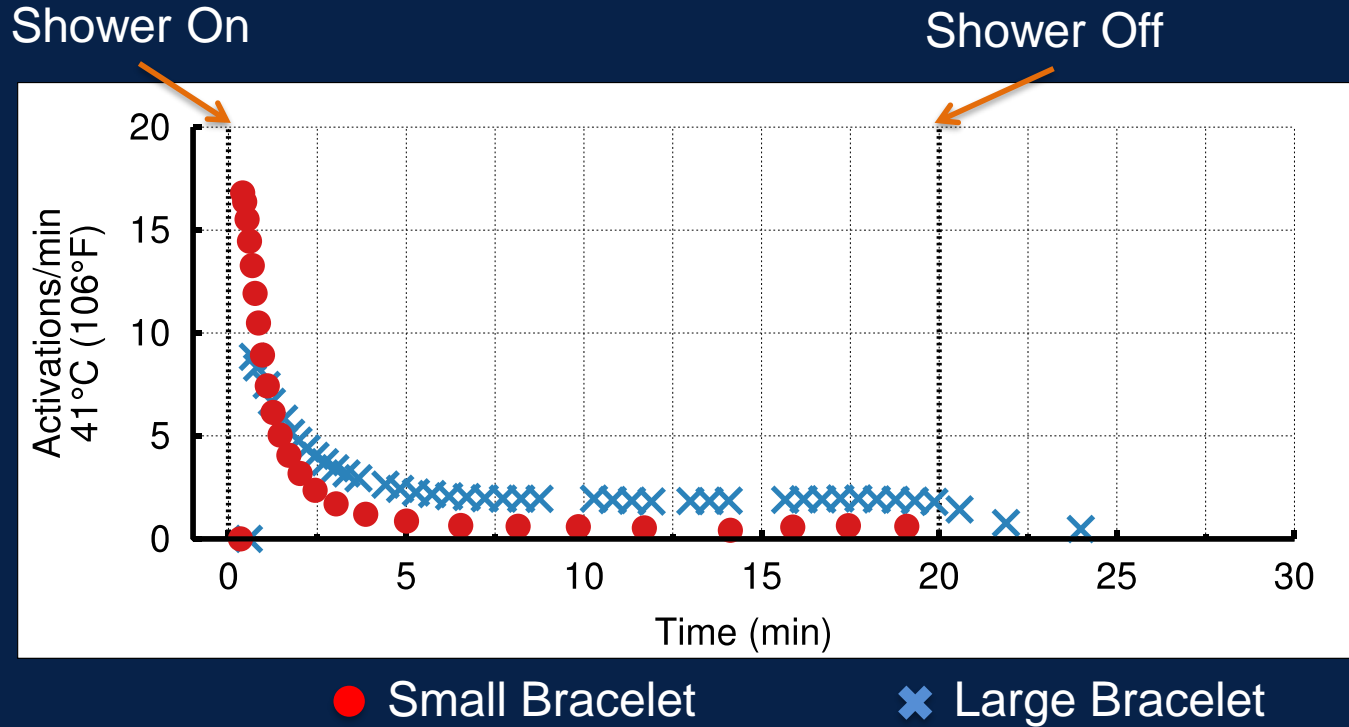
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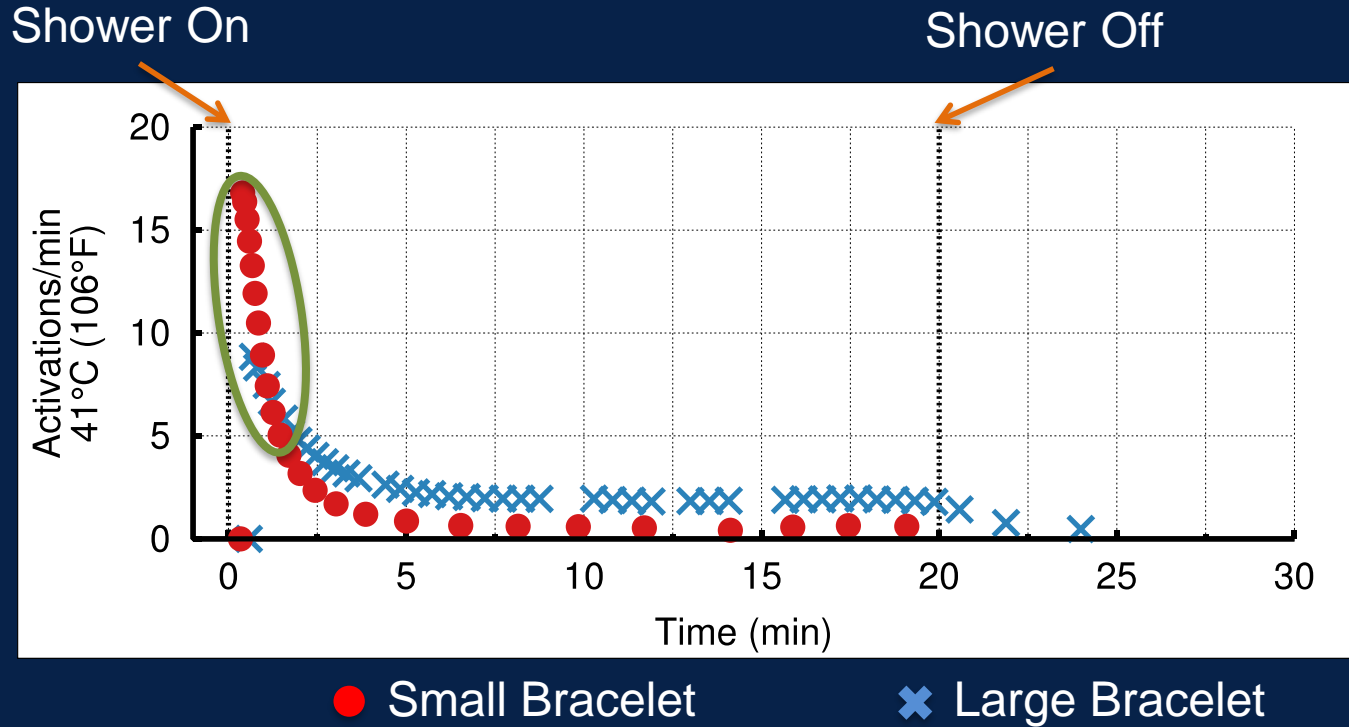
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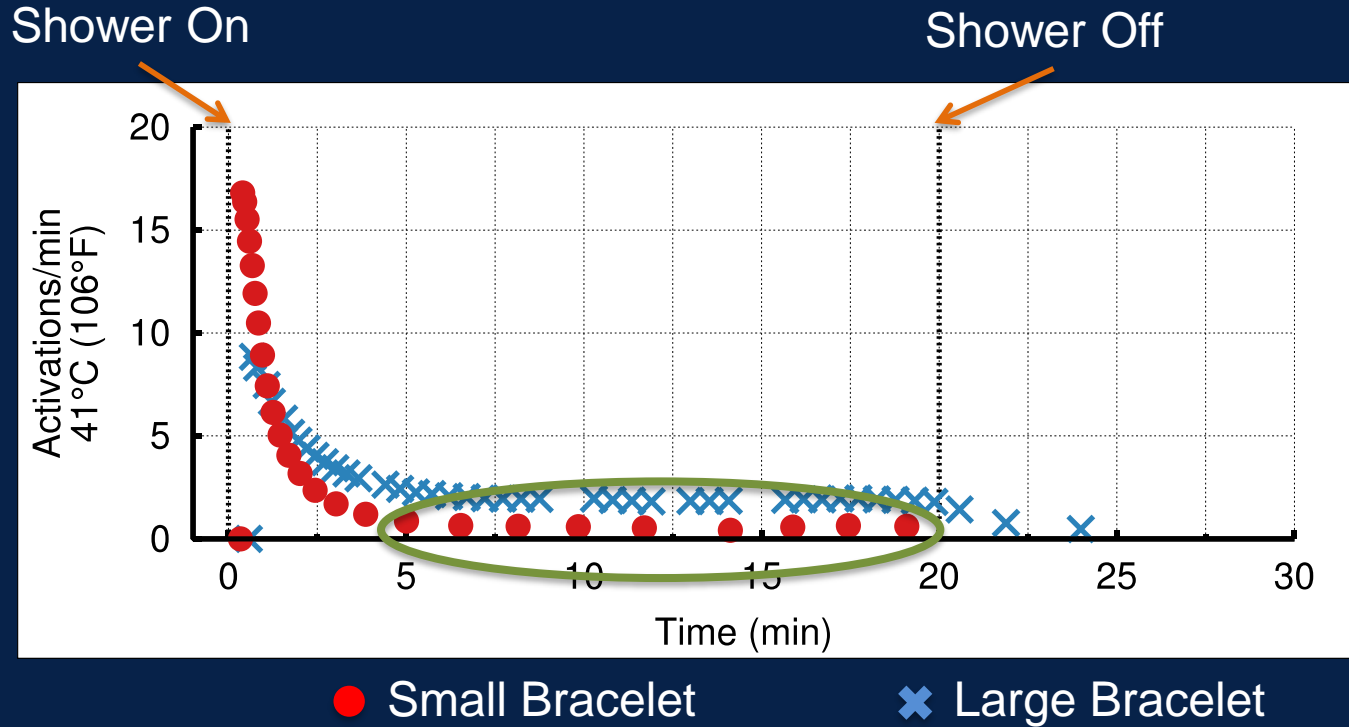
Operation at Average Shower Temperature



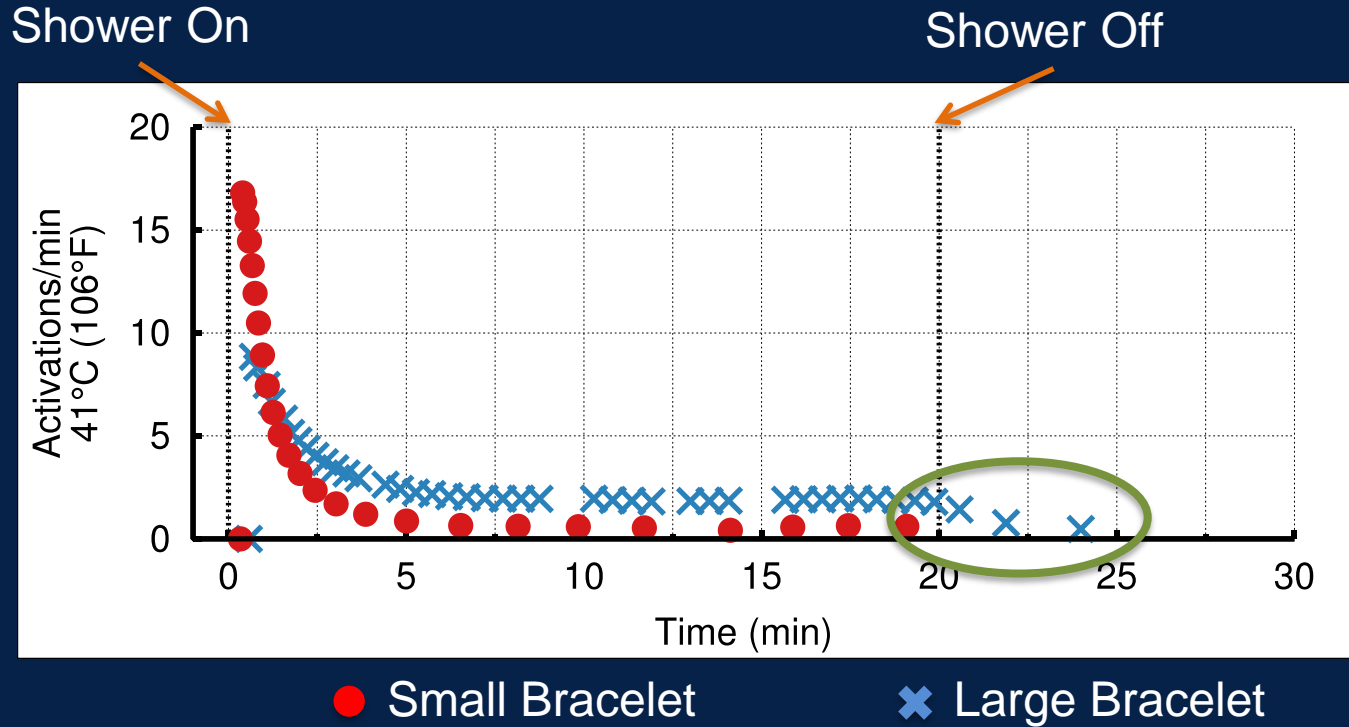
Operation at Average Shower Temperature



Operation at Average Shower Temperature



Operation at Average Shower Temperature



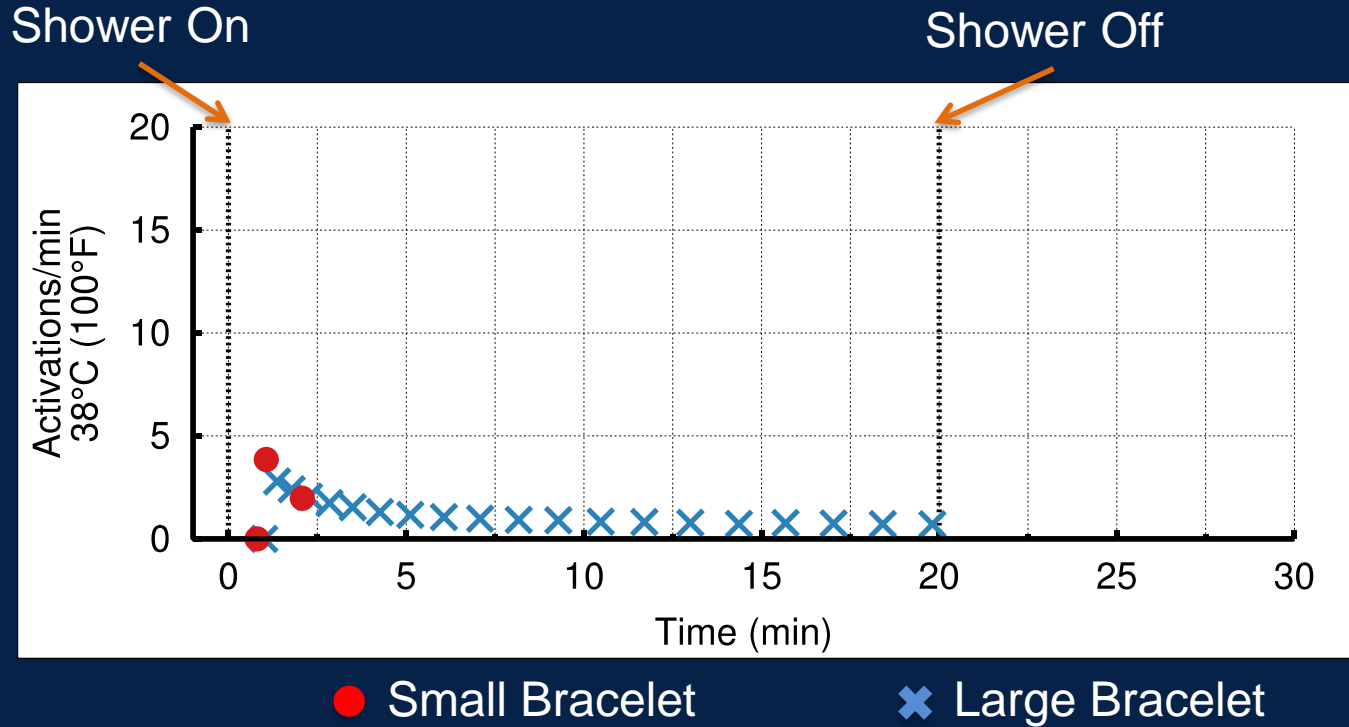
Equilibrium of the System



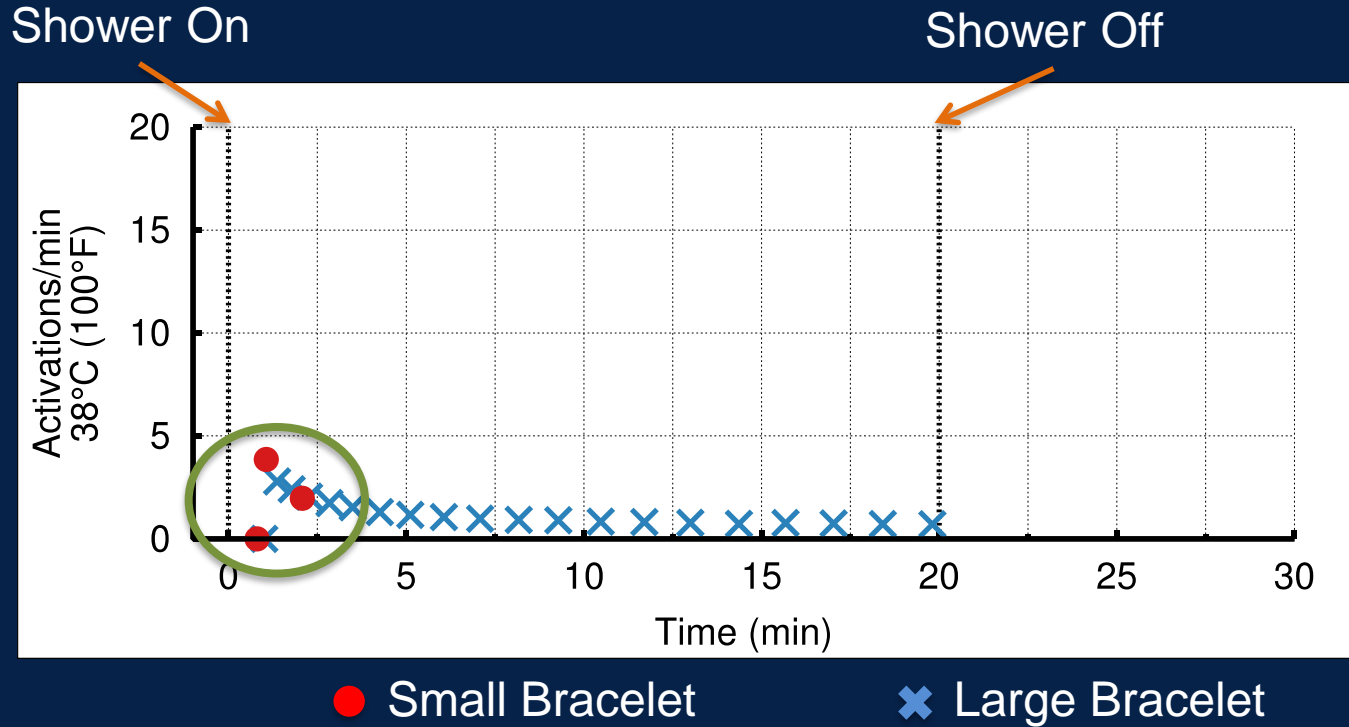
Equilibrium of the System



Lower Temperature Operation Is Troublesome



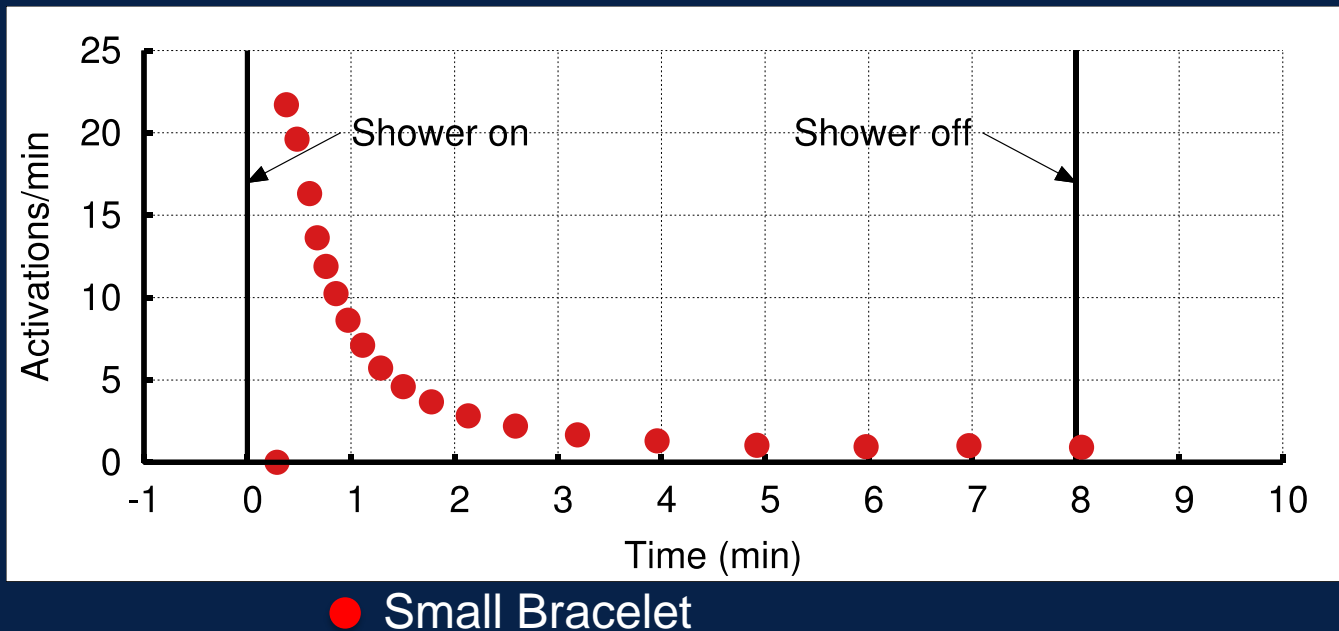
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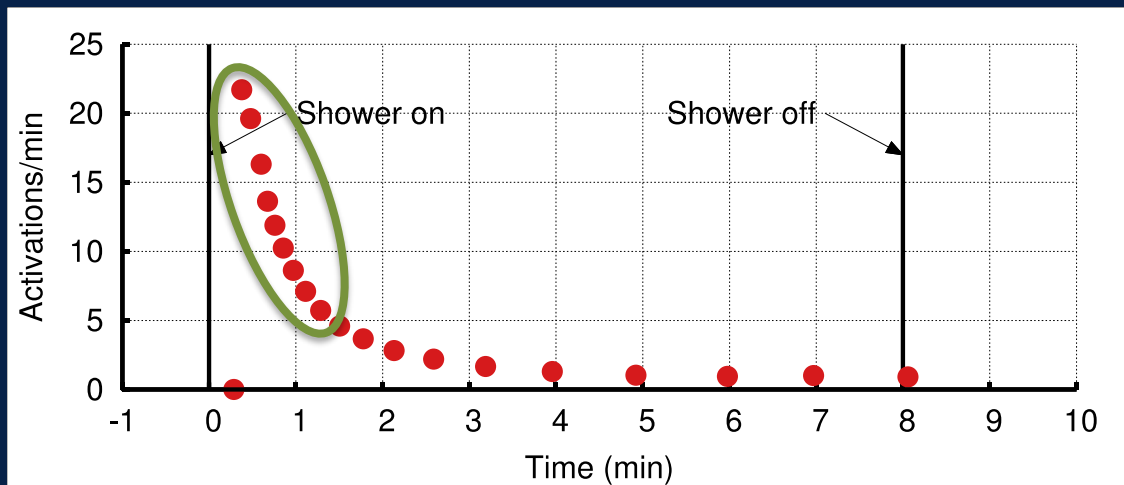
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Estimating Start and Stop Times



Estimating Start and Stop Times

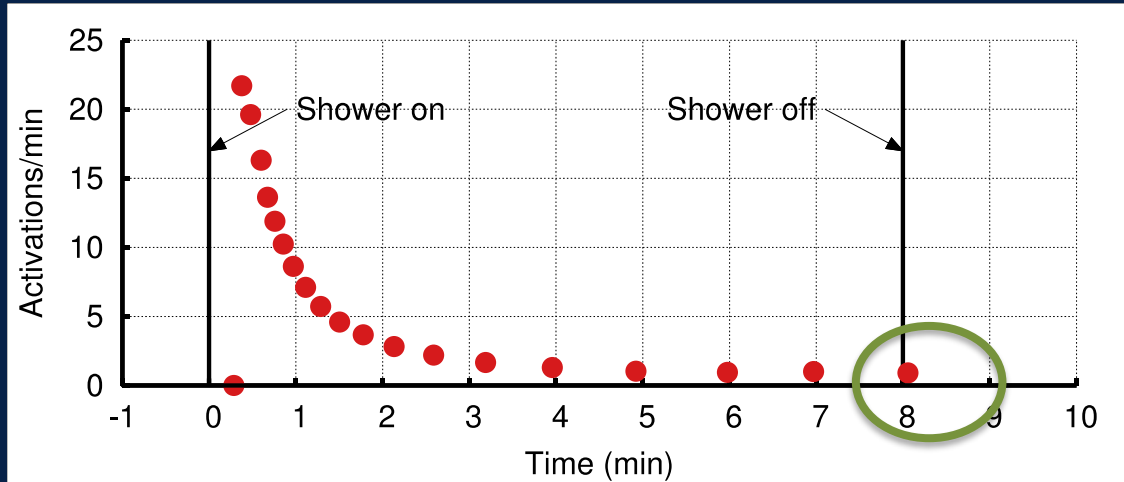
Determine likely delay before first packet based on initial packet rate



● Small Bracelet

Estimating Start and Stop Times

Look for change in steady state operation

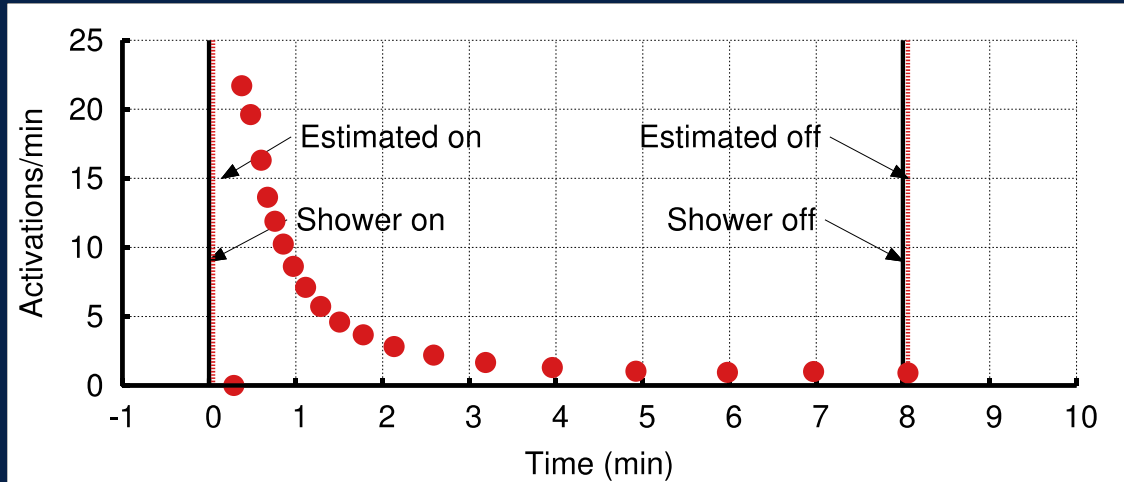


● Small Bracelet

Estimation Example

Test Results

- 3 second error on Start Time
- 9 second error on Stop Time



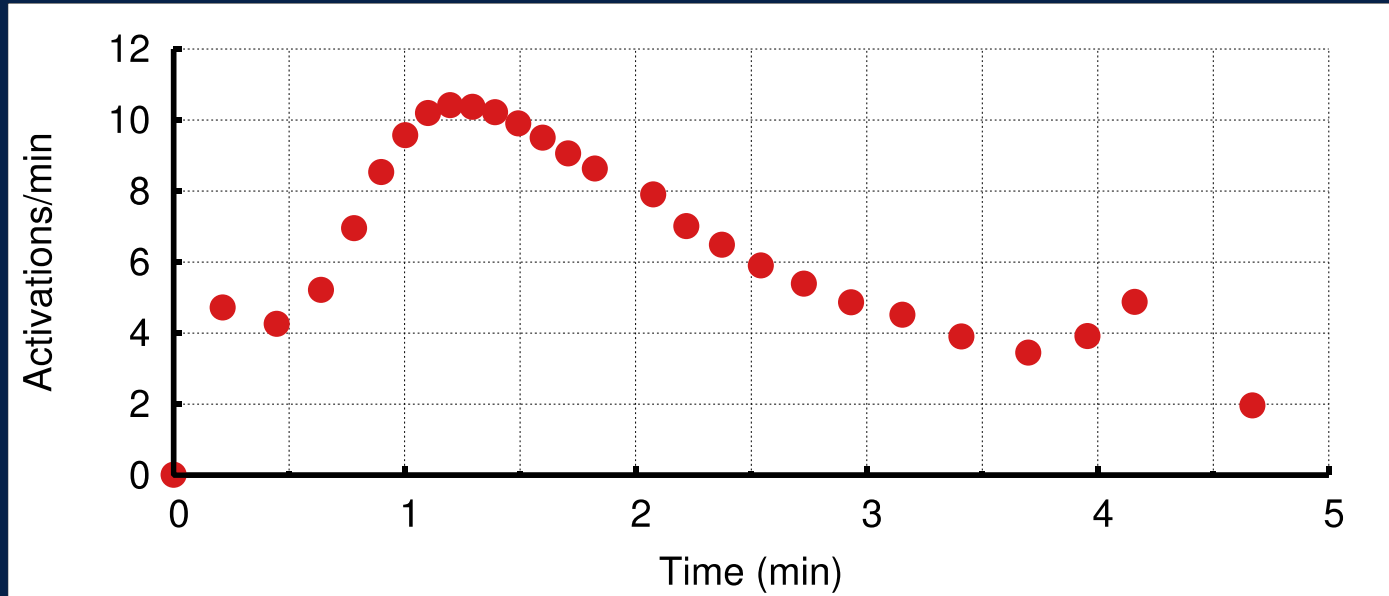
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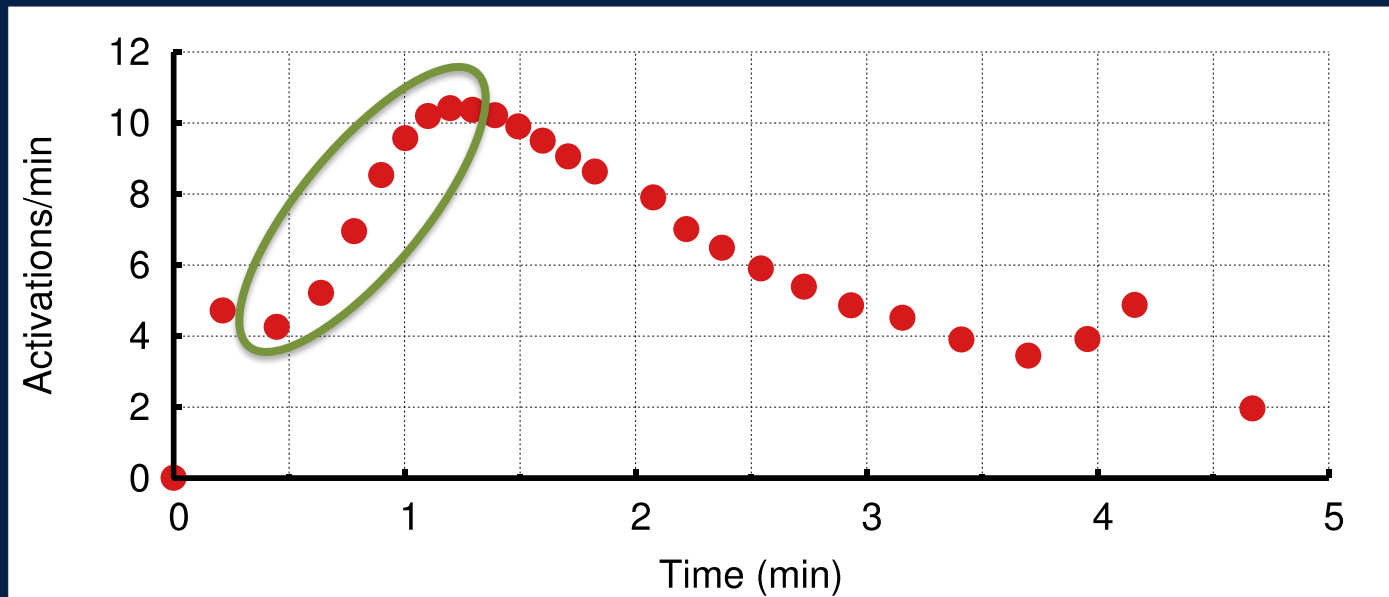
Real Showers

Shower started at time zero and continued for over ten minutes



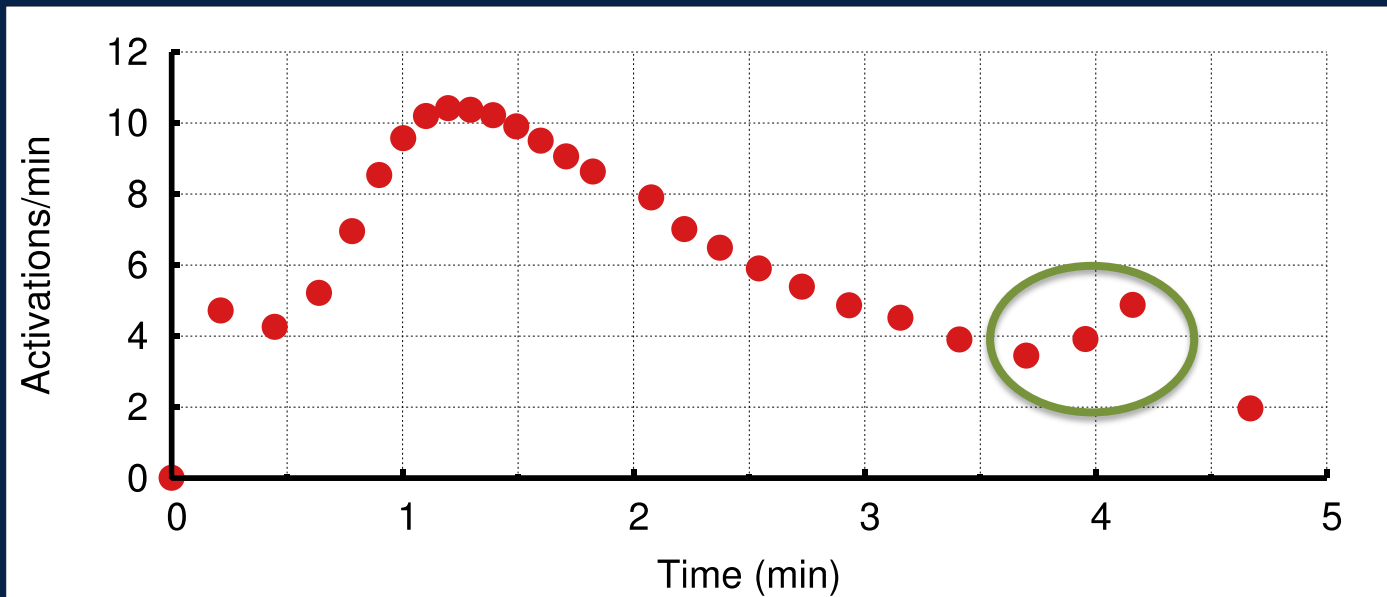
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Real Showers



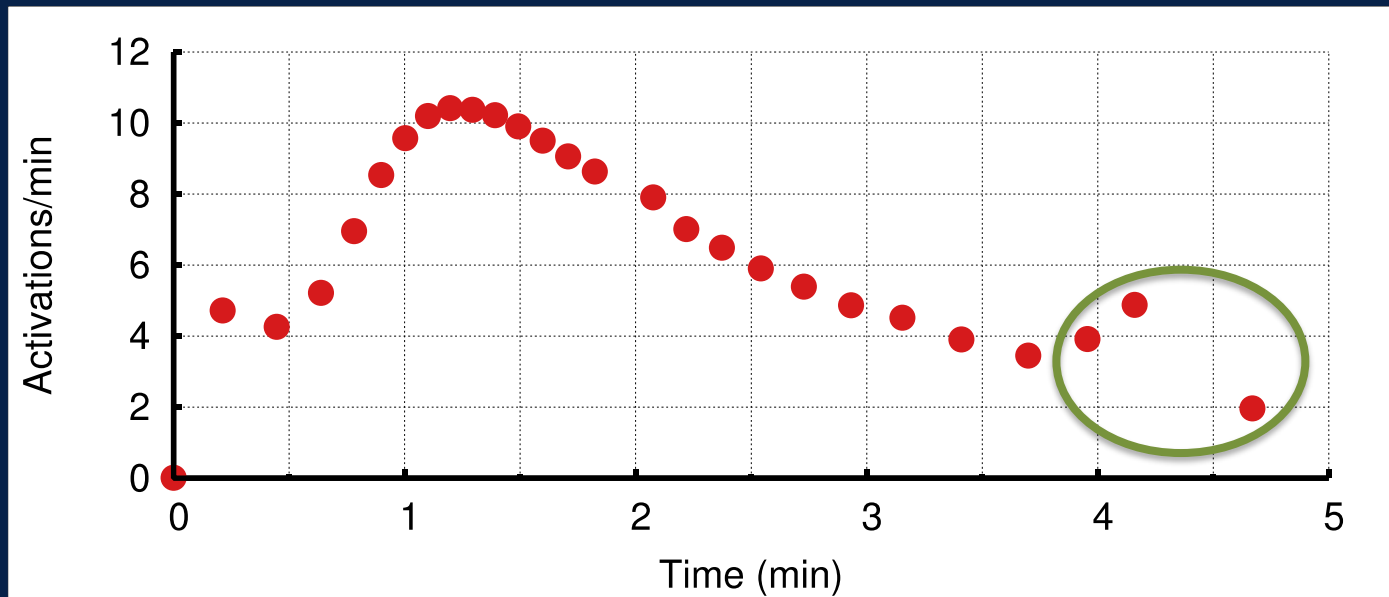
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Real Showers



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Real Showers



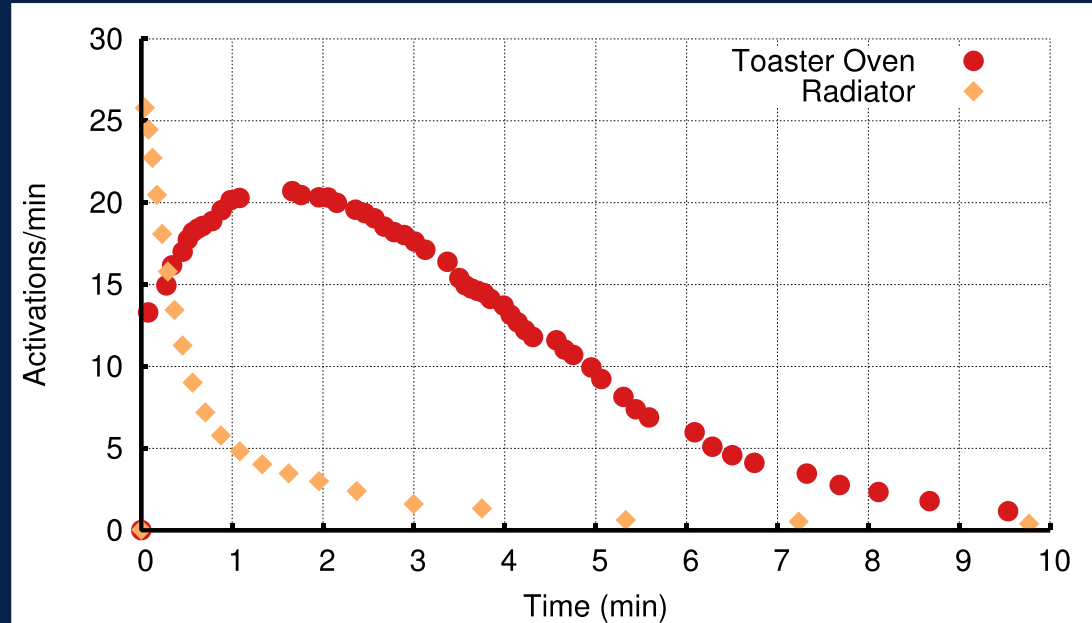
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Extending the Idea

Thermes can be used anywhere a temperature differential exists



Future Work

Better heat rejection

- Improved mechanical design is necessary

Cost of device

- Small form factor Peltier Junctions are expensive

Long-term deployment

- What kind of data can we gain from continuous data collection?

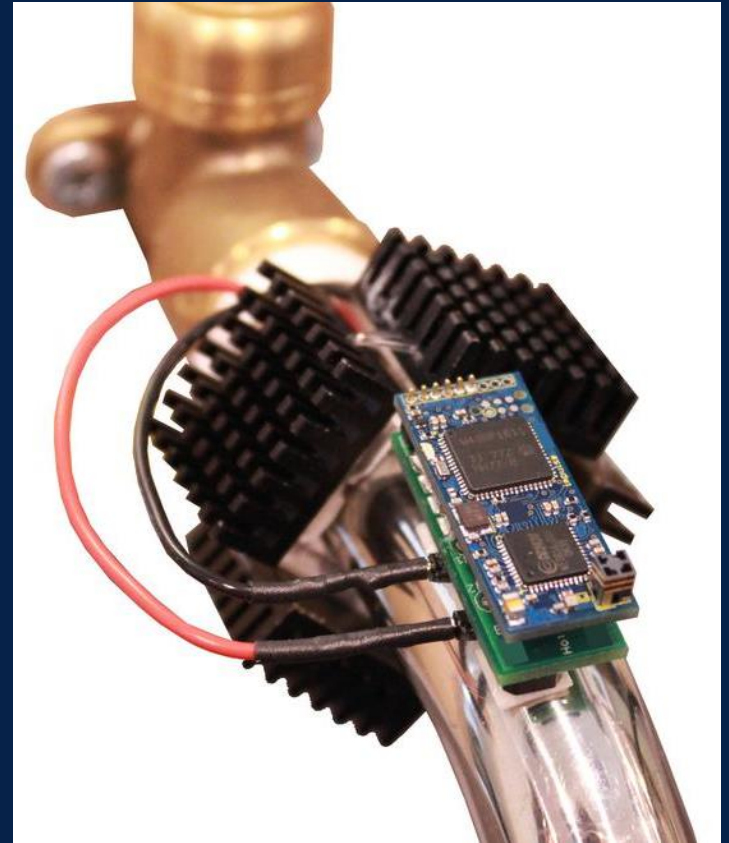
Conclusion

Thermes

Energy-neutral thermal sensing

Reductionist Sensing

A new tool for ubiquitous and
continuous sensing



Questions?

Energy-Harvesting Thermoelectric Sensing for Unobtrusive Water and Appliance Metering

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Prabal Dutta

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<http://github.com/lab11/monjolo>

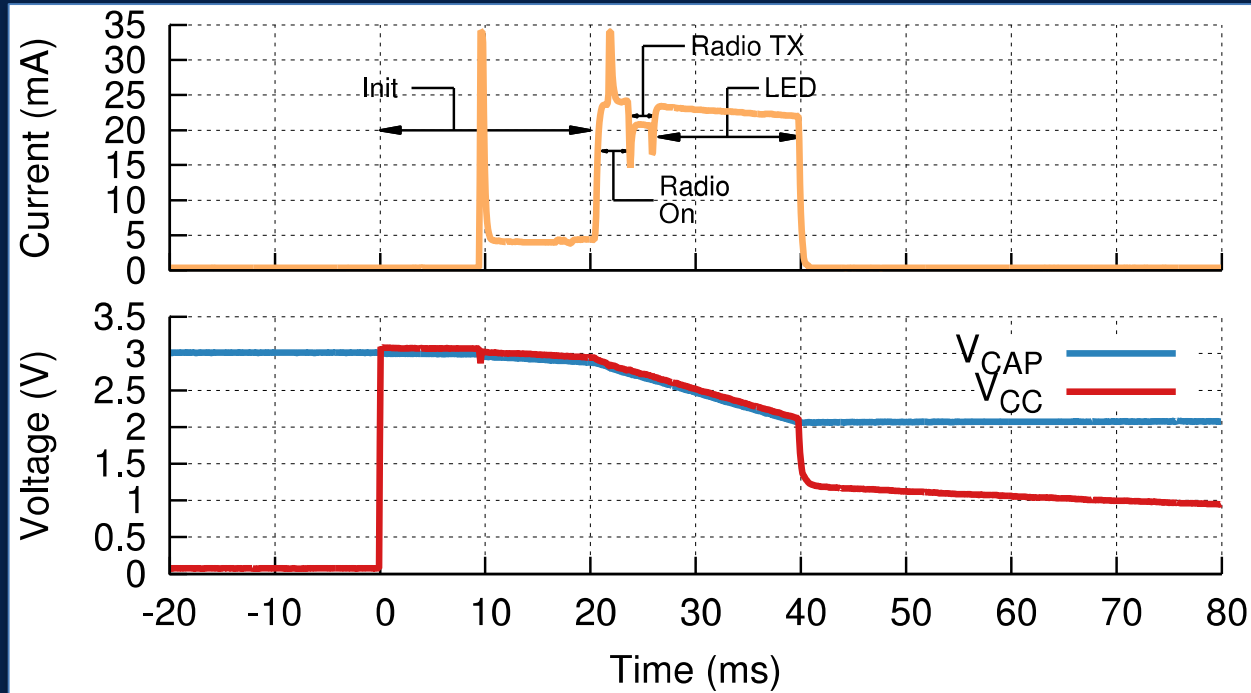


Bonus Slides

Wired Water Meters



View of a Single Activation



Energy Harvester Performance

Activations/min are proportional to temperature

