Energy-Harvesting Thermoelectric Sensing for Unobtrusive Water and Appliance Metering

Brad Campbell, **Branden Ghena**, and Prabal Dutta

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.**)…"
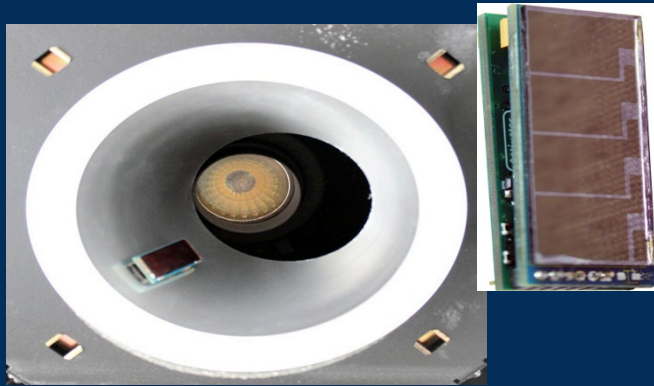
Source(s):
1. "Building Energy Efficiency Frontiers and Incubator Technologies (BENEFIT)," DE-FOA-0001027, 2014

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
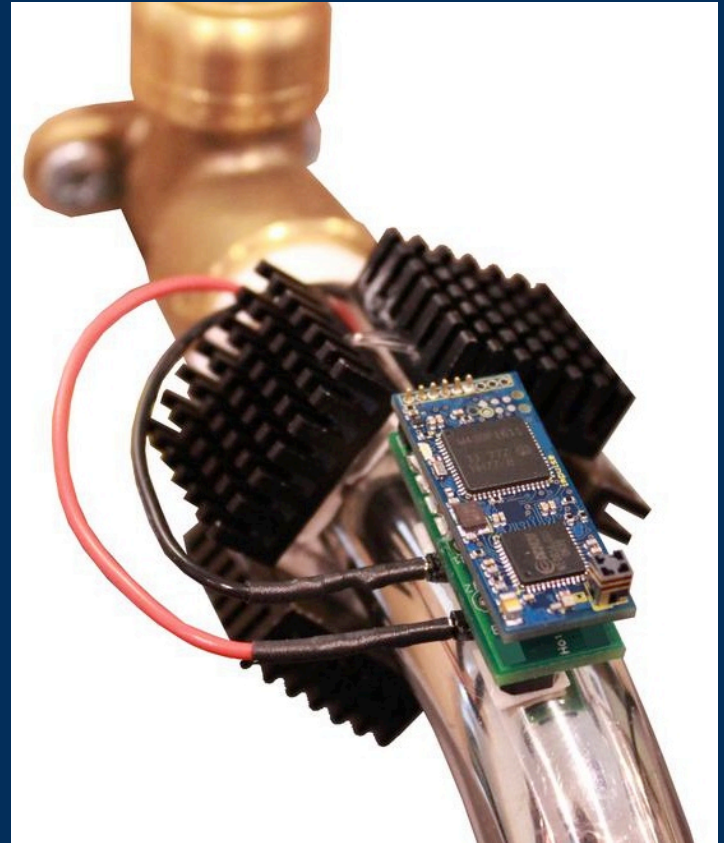
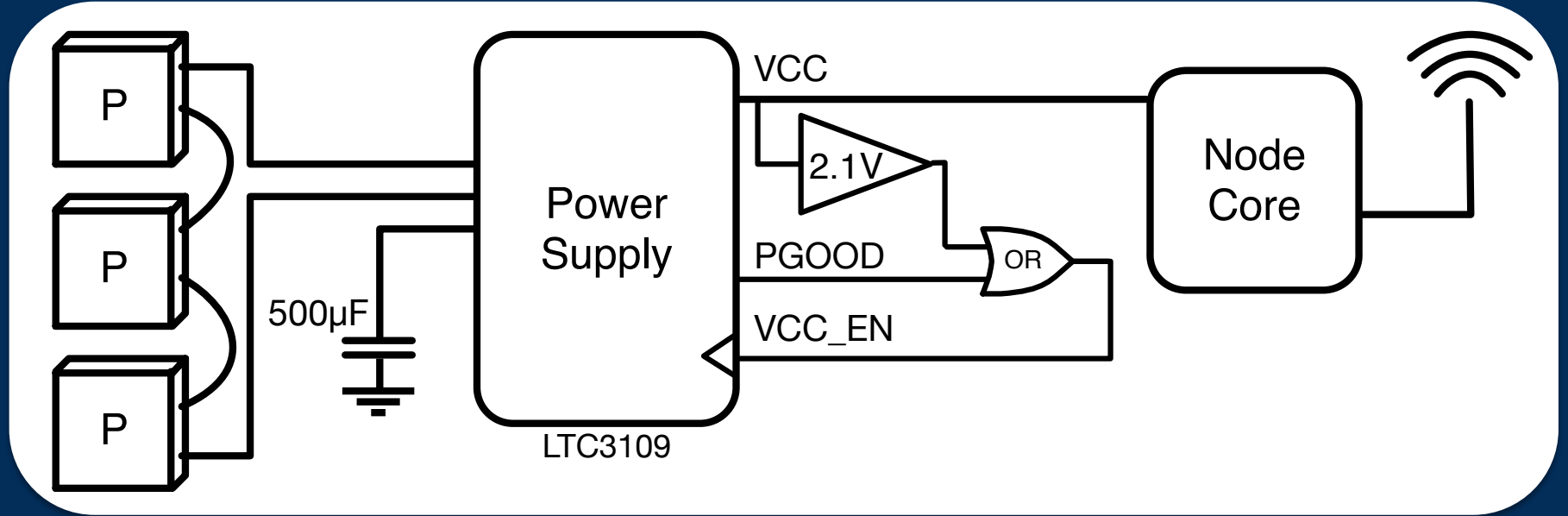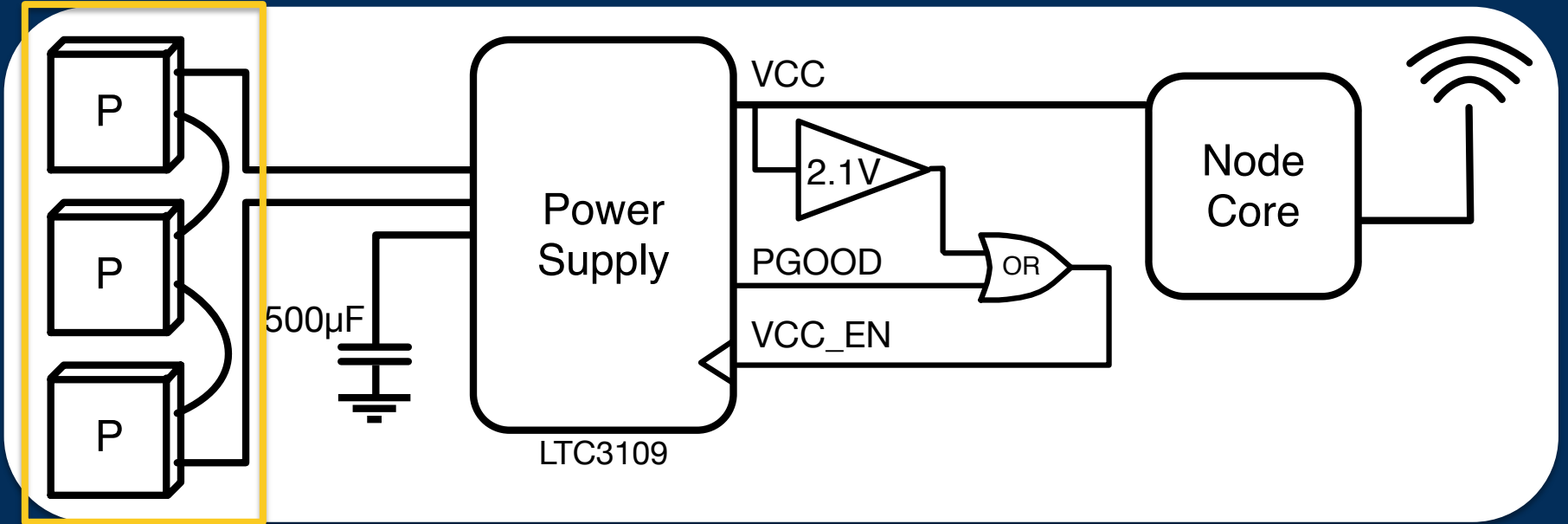The energy harvester *is* the sensor

Our System Design

Thermes

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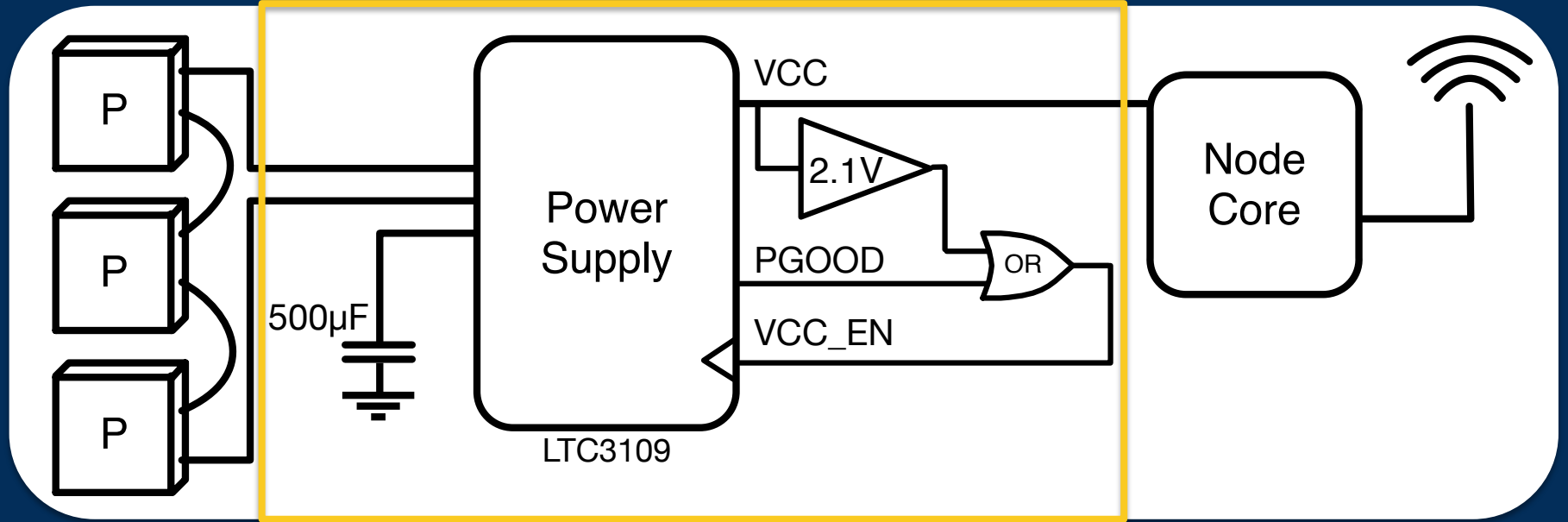- – Energy-neutral system
- – Wireless communication

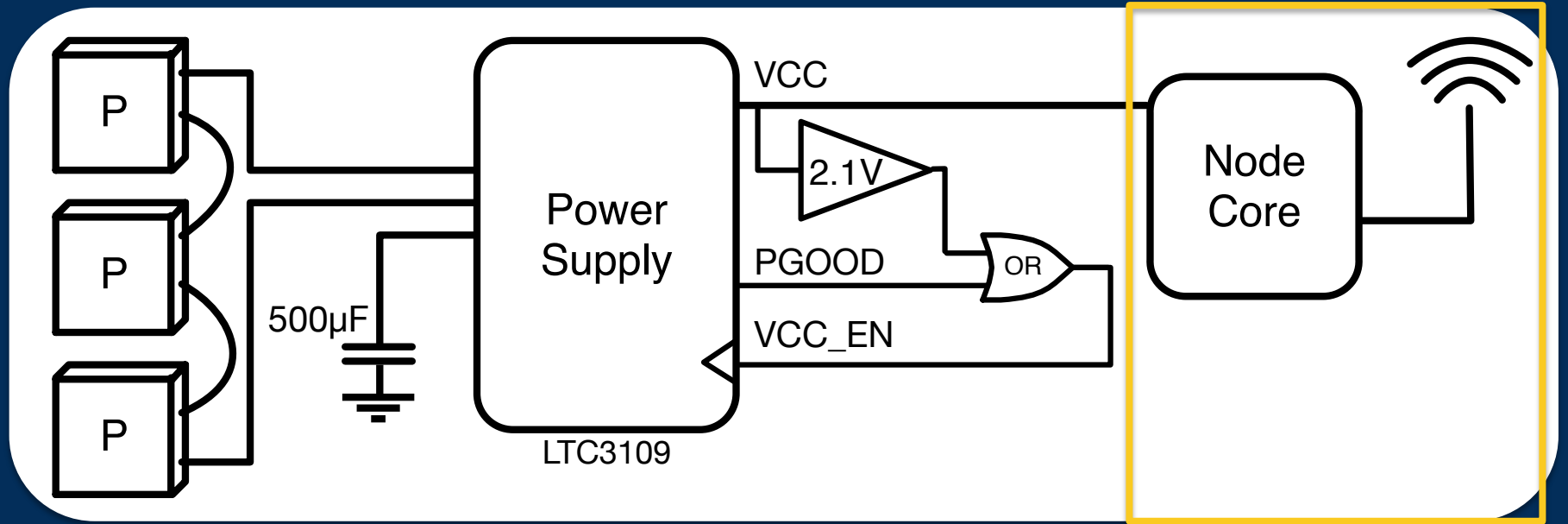# Thermes System Architecture

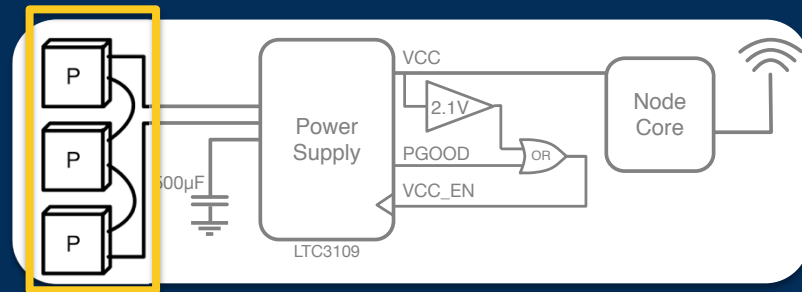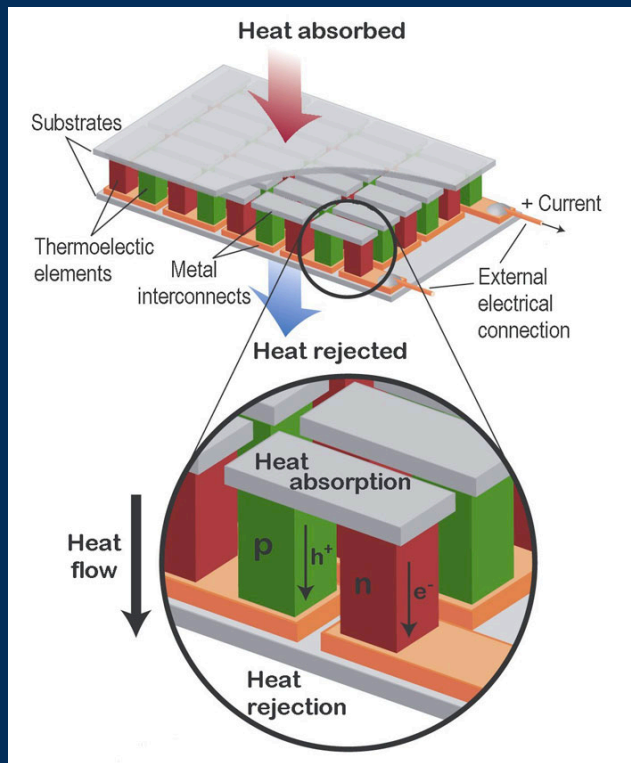# Thermes System Architecture

Thermes System Architecture

Thermes System Architecture

Harvesting Front End

Peltier junctions
- Temperature differential into current
- Low efficiency

Heat rejection is critical
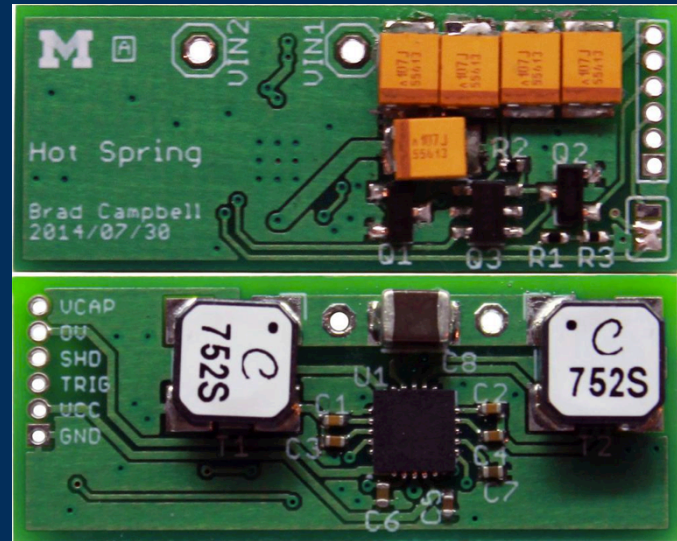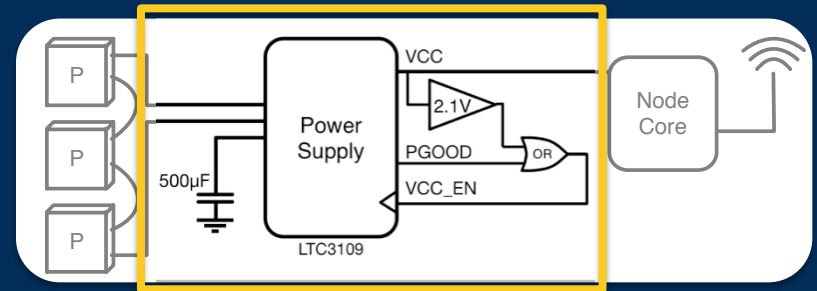
Multiple junctions in series for more voltage

Zoom into Power System

Power supply
- Auto-polarity
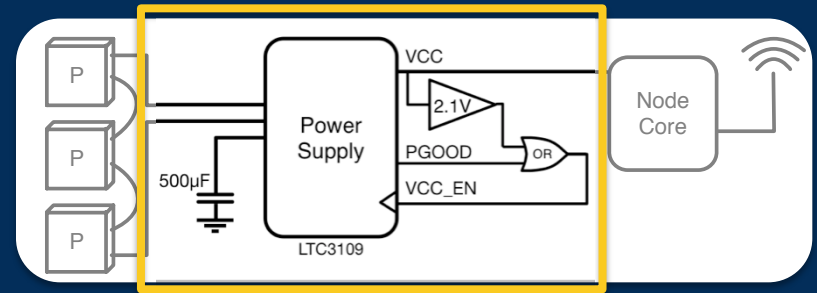- Harvesting begins at 30 mV

500 uF capacitor bank
- No battery

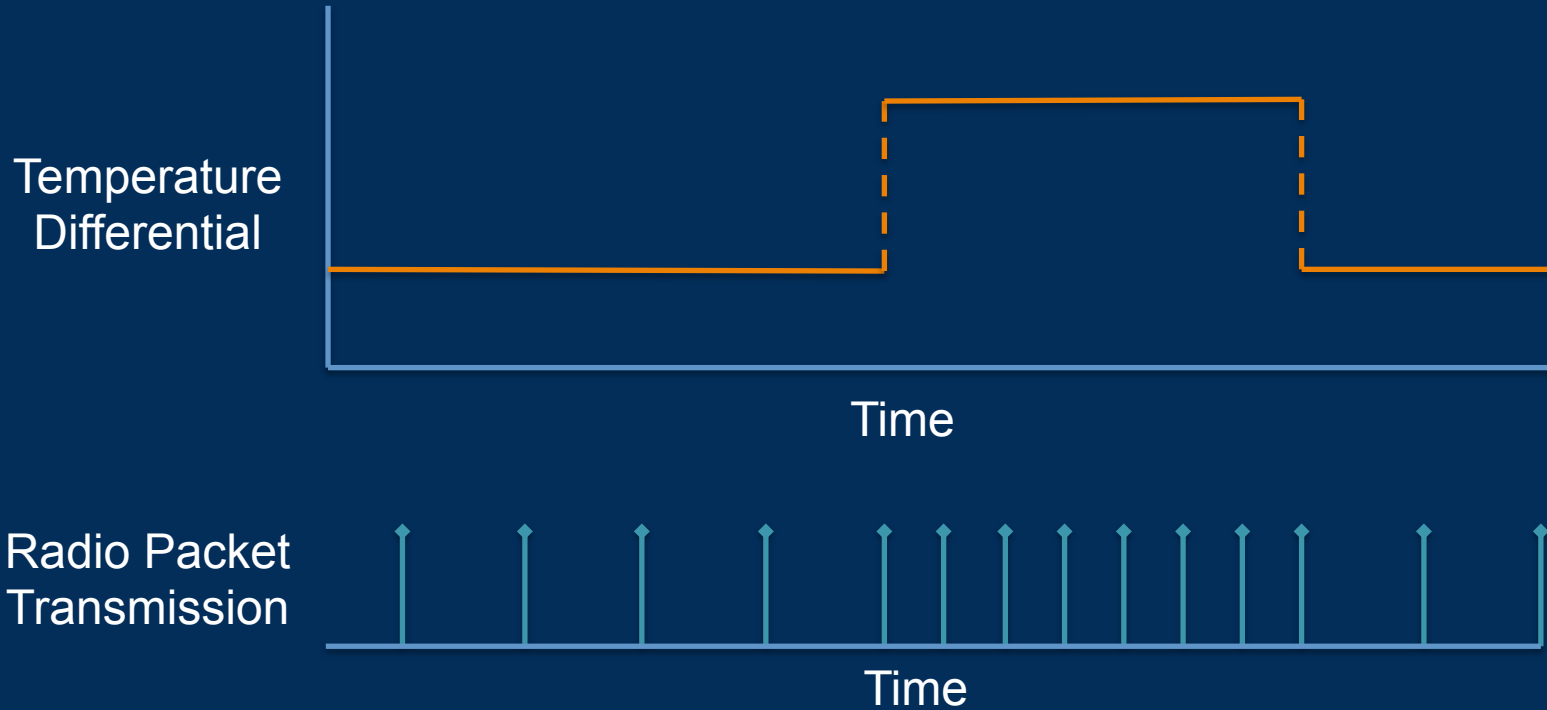

Top

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
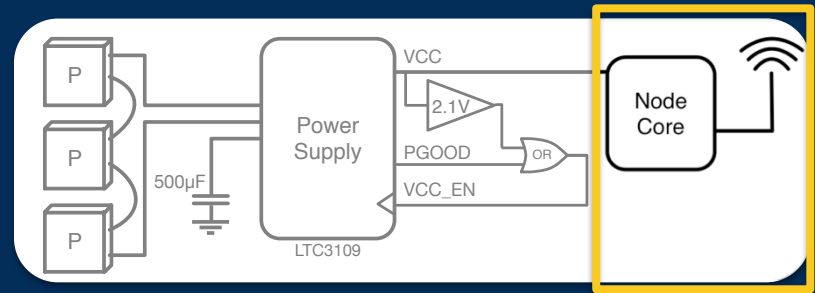   Translates to 1.3 mJ per activation

Transmission Rate Changes with Temperature
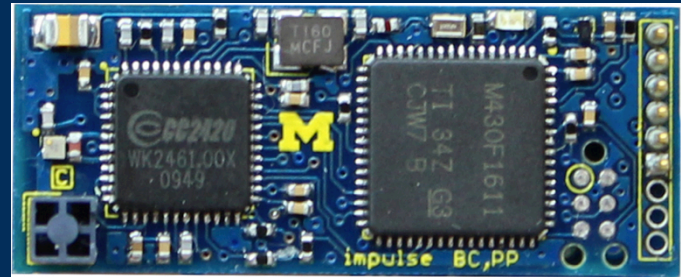
Zoom into Node Core

The classic node setup

MSP430
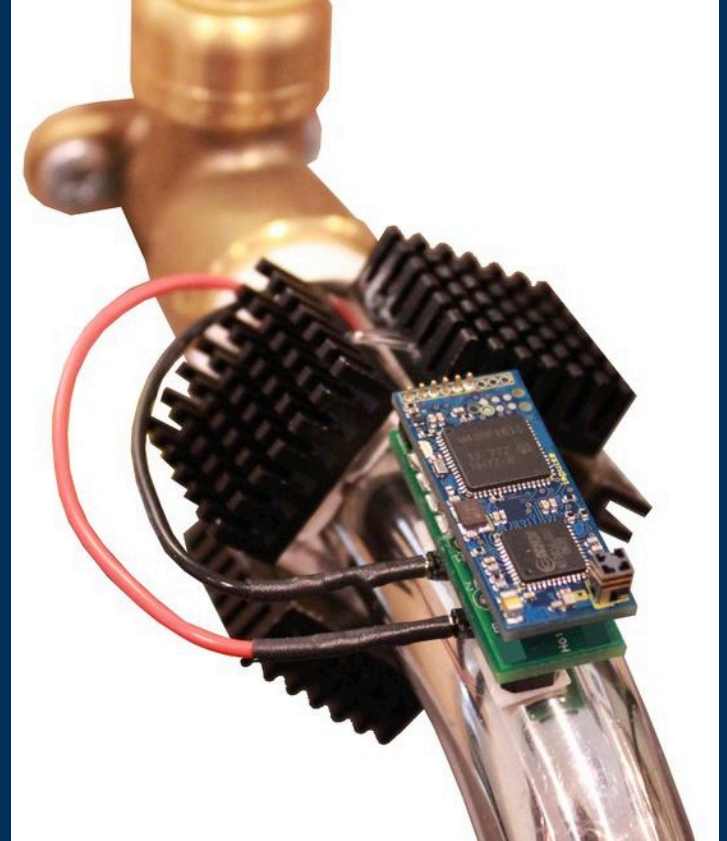- – TinyOS

CC2420
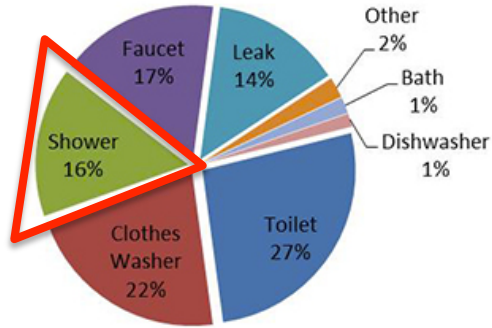- – 802.15.4 communications

Top

Our System Design

Thermes

Energy-Neutral Thermal Sensing
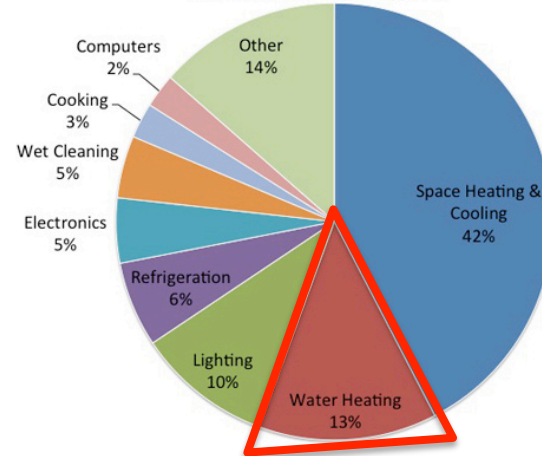
But what can you do with such a sensor?

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
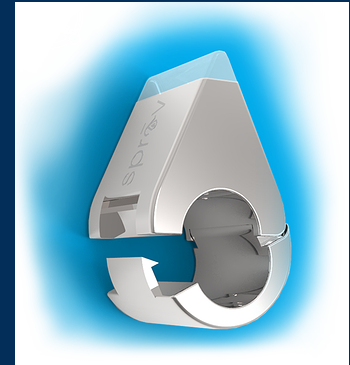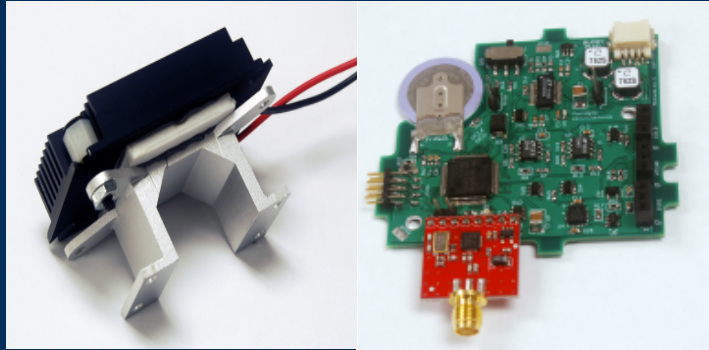

2010 Residential Energy Use

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

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

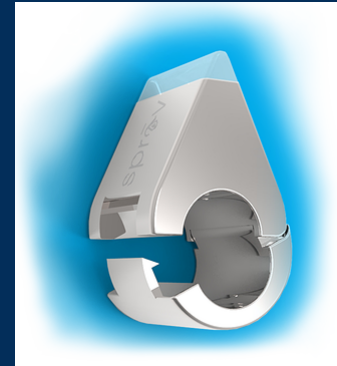# Existing Water Meters

Acoustic Water Meters

High powered sensing

– Lifetime limitation

Upstream

Sprav

Impeller-Based Water Meters

Amphiro

Impeller-based design

- – Good for energy harvesting
- – Difficult installation
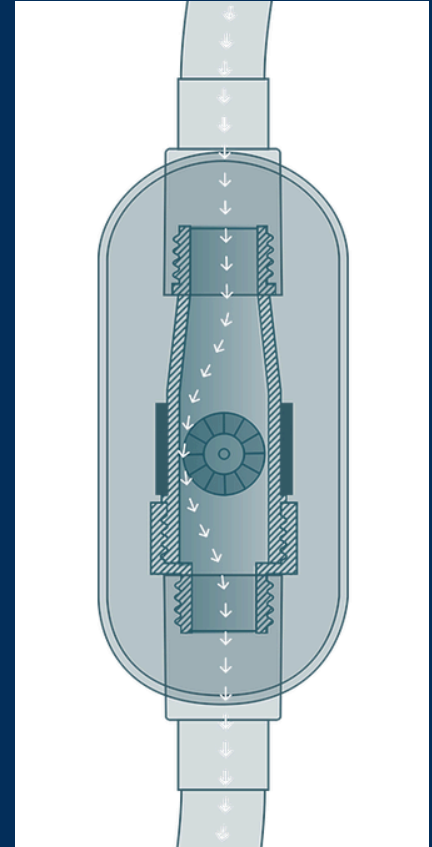
Thermal Harvesting Water Meters

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

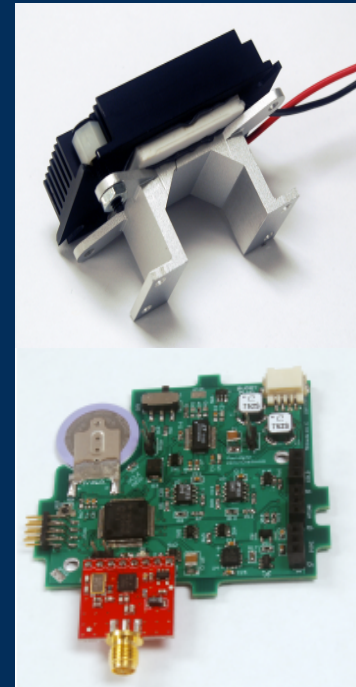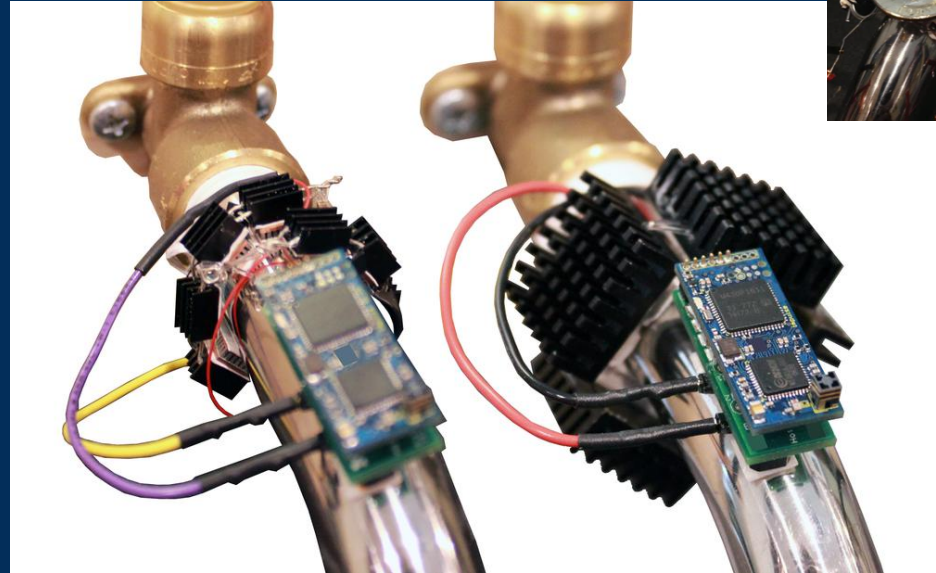# Thermes Implementations

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
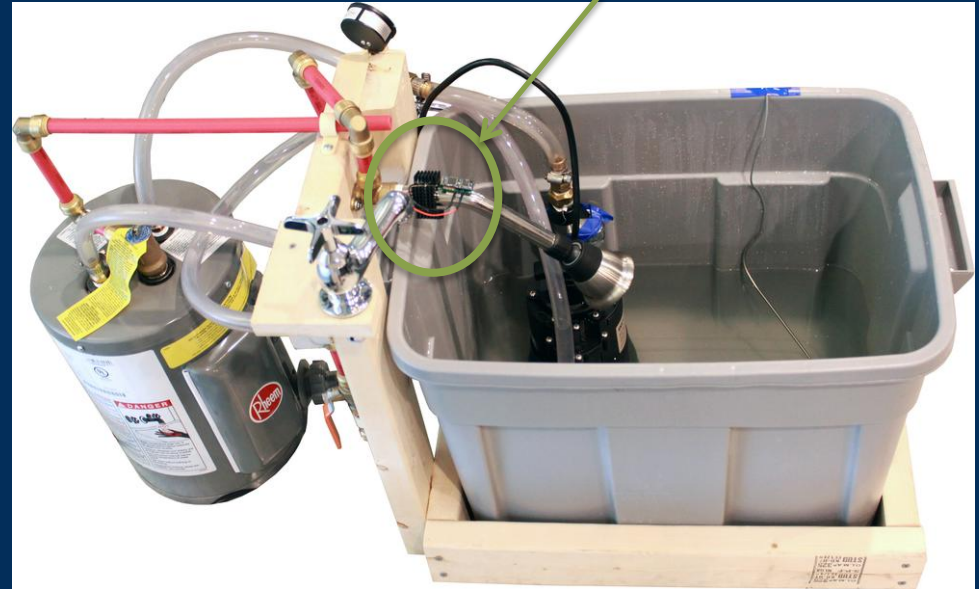
Ambient temperature remained
23° C for all tests

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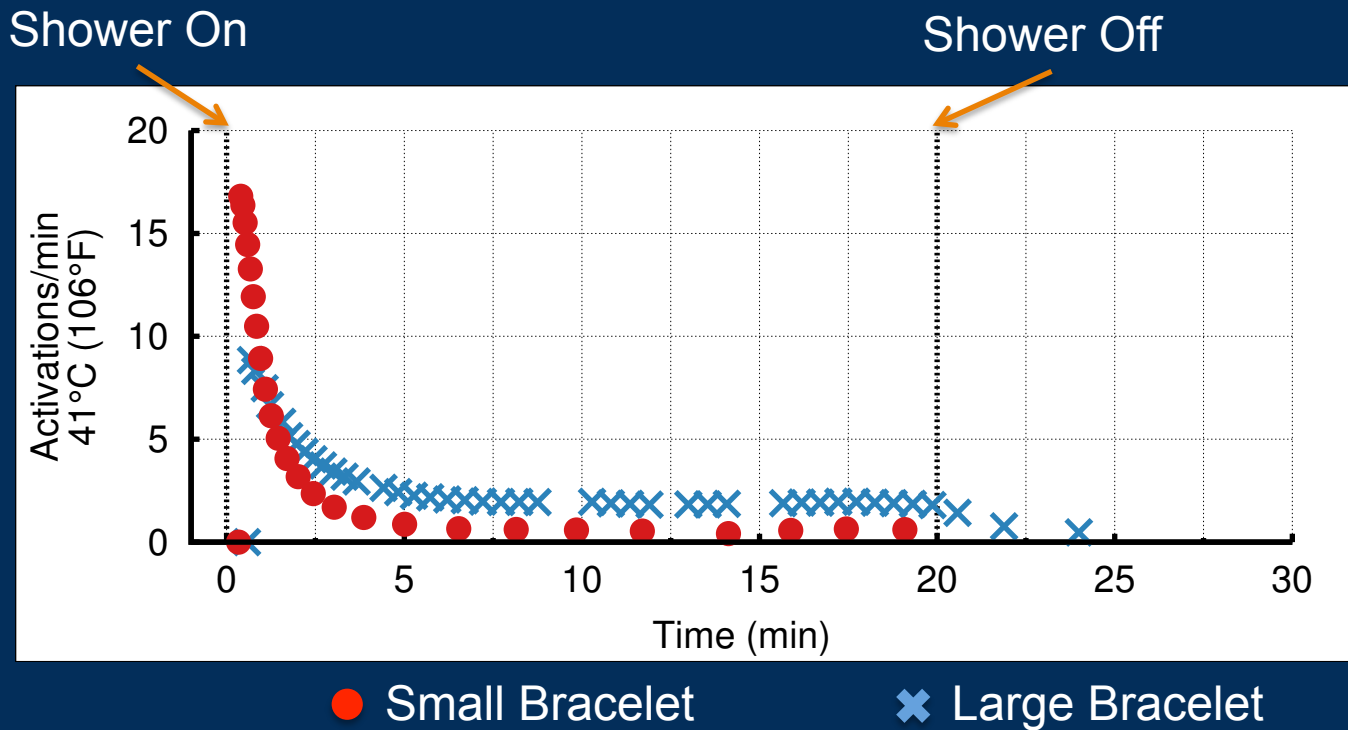constant water temperature

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Thermes

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Operation at Average Shower Temperature

Operation at Average Shower Temperature

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Operation at Average Shower Temperature

Operation at Average Shower Temperature

Equilibrium of the System

Temperature of Pipe

Time

Radio Packet Transmission

Time

Equilibrium of the System

Temperature of Pipe / Time

Radio Packet Transmission / Time
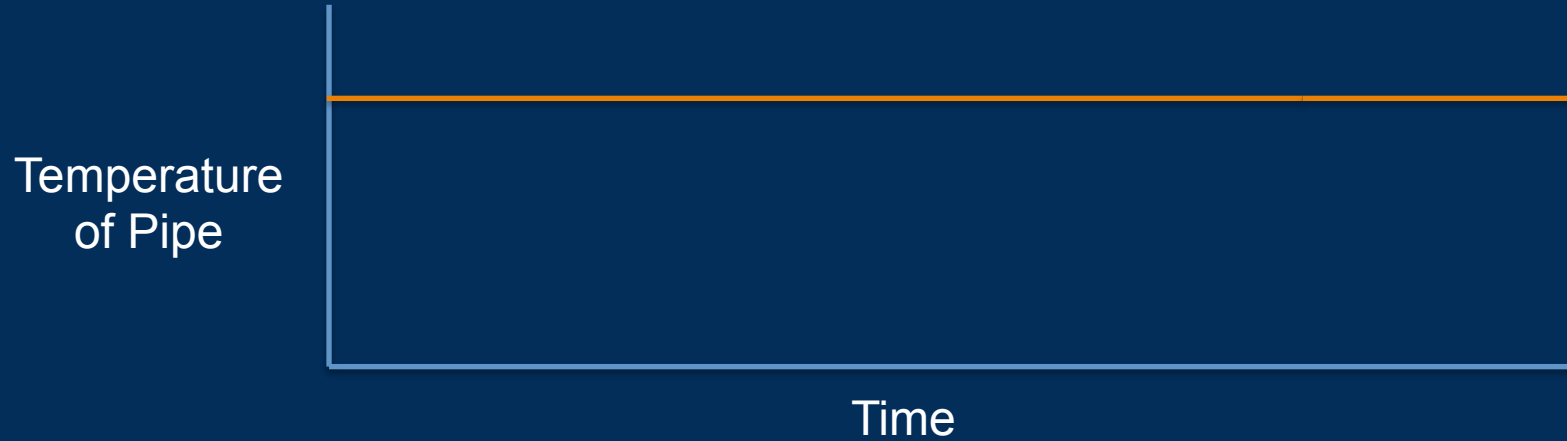
Lower Temperature Operation Is Troublesome
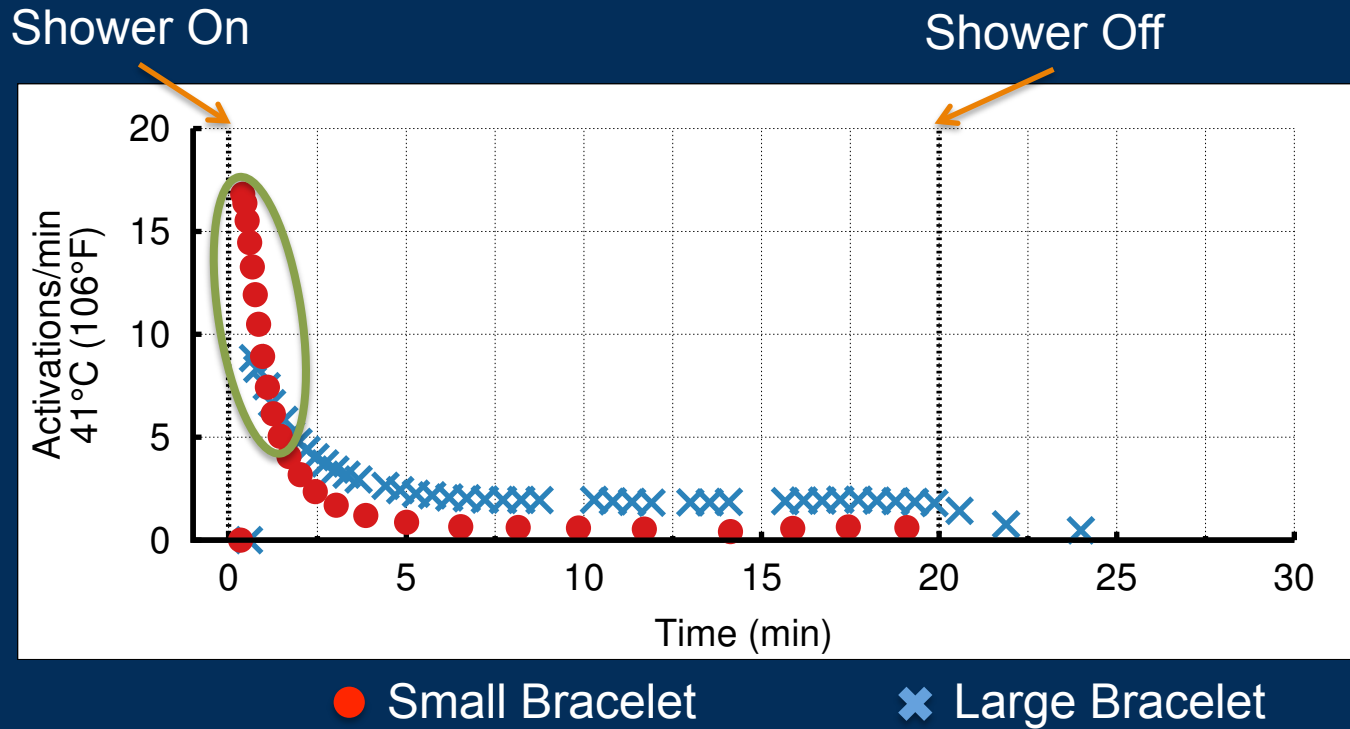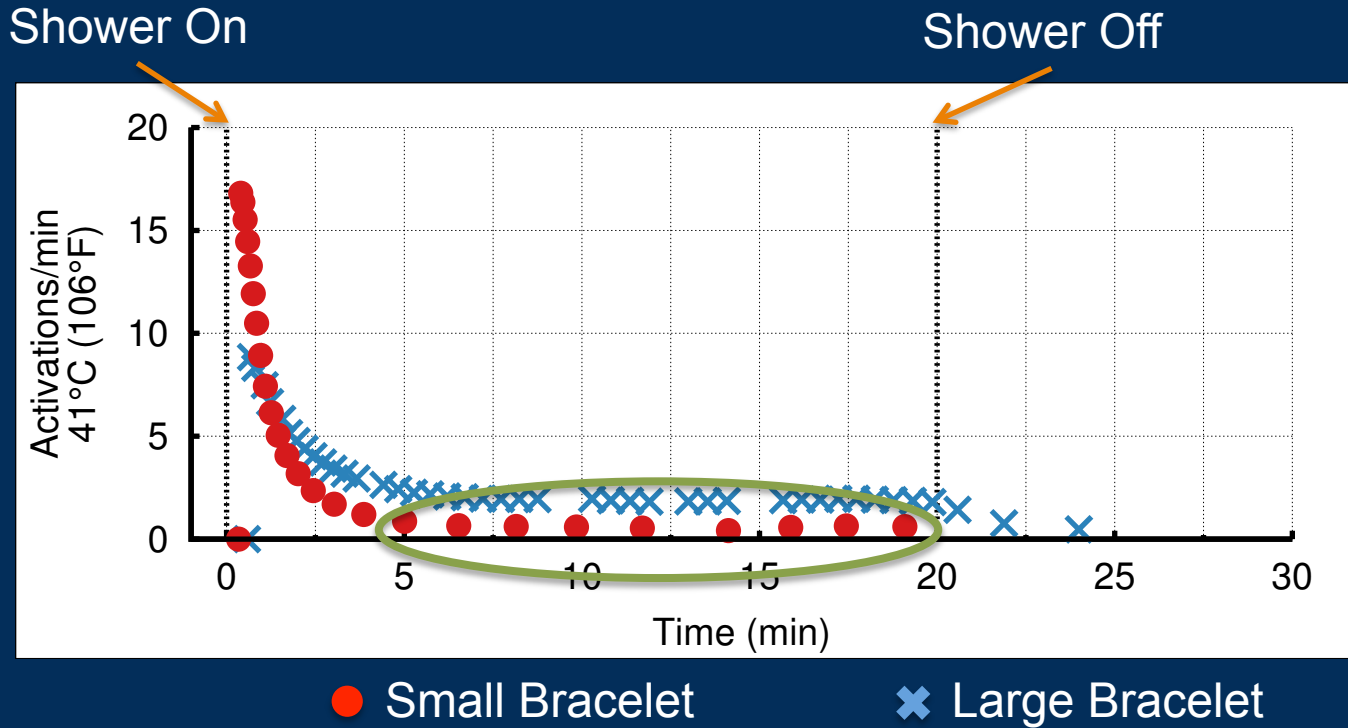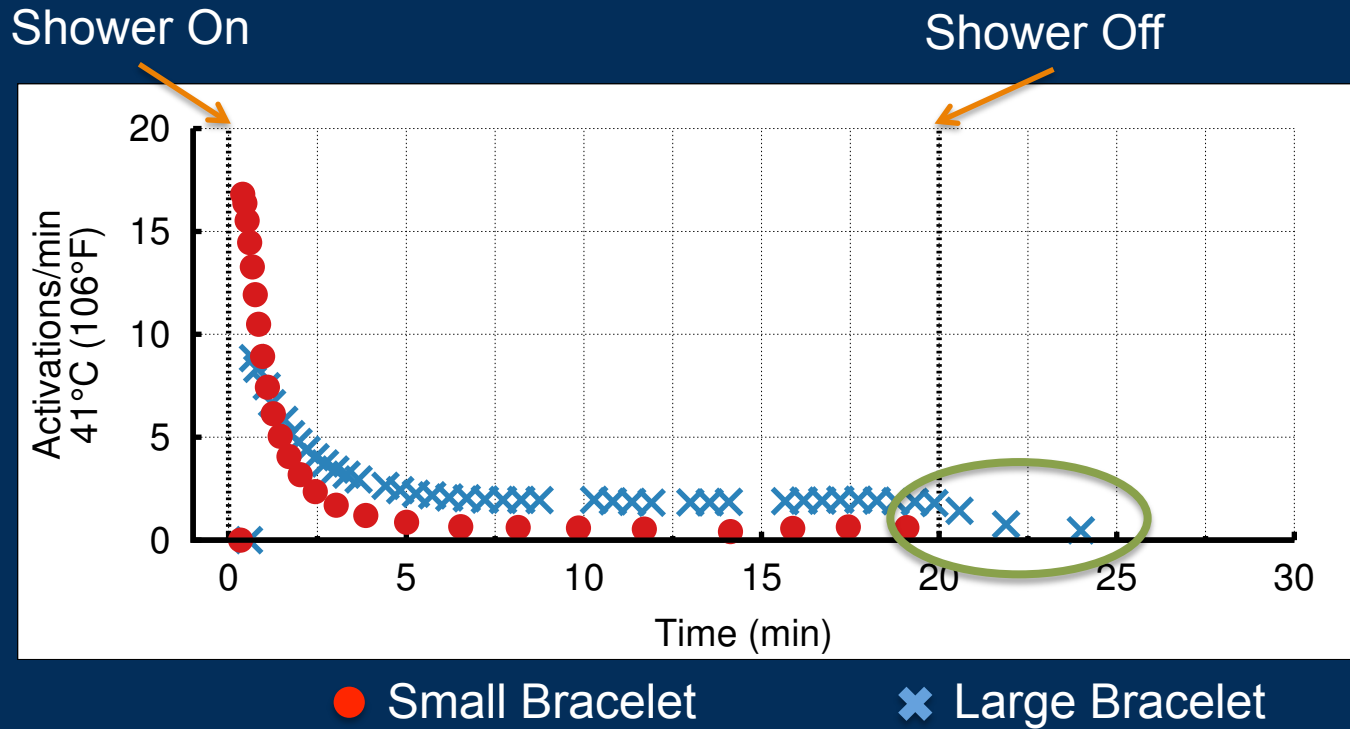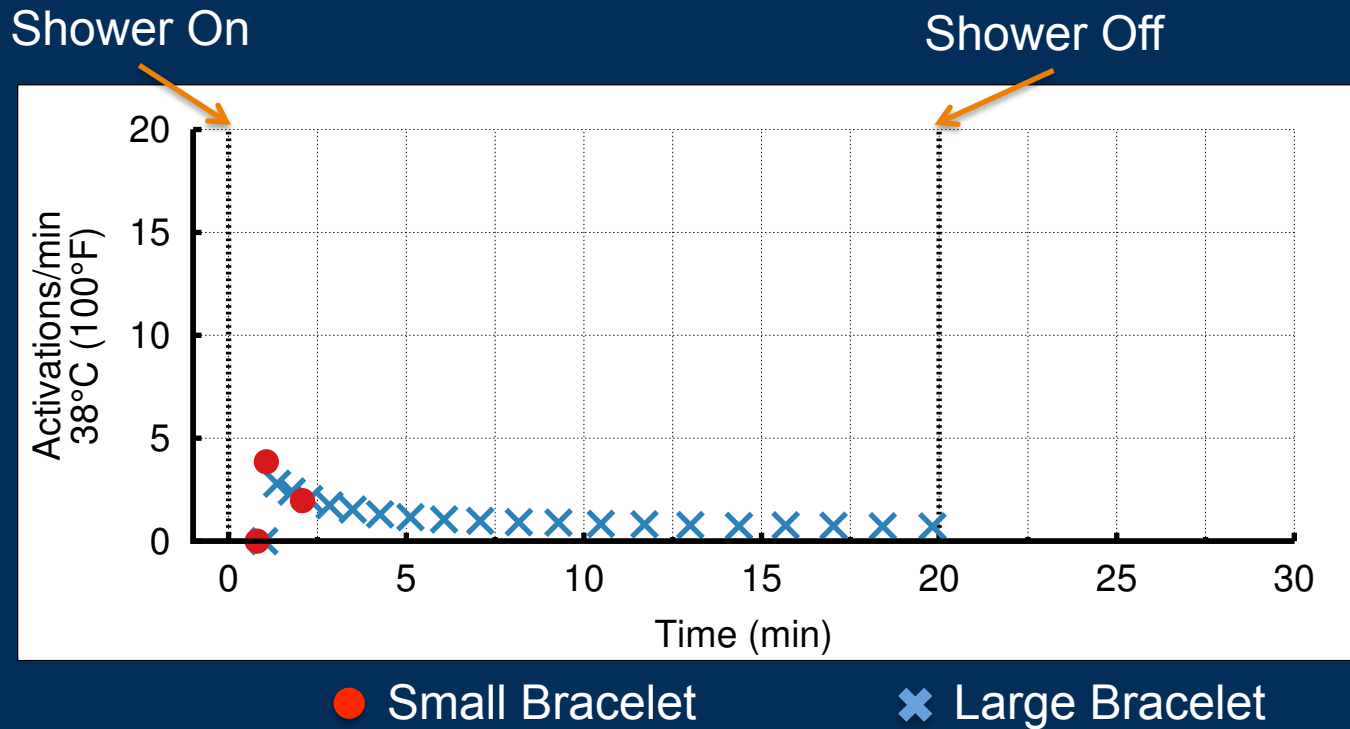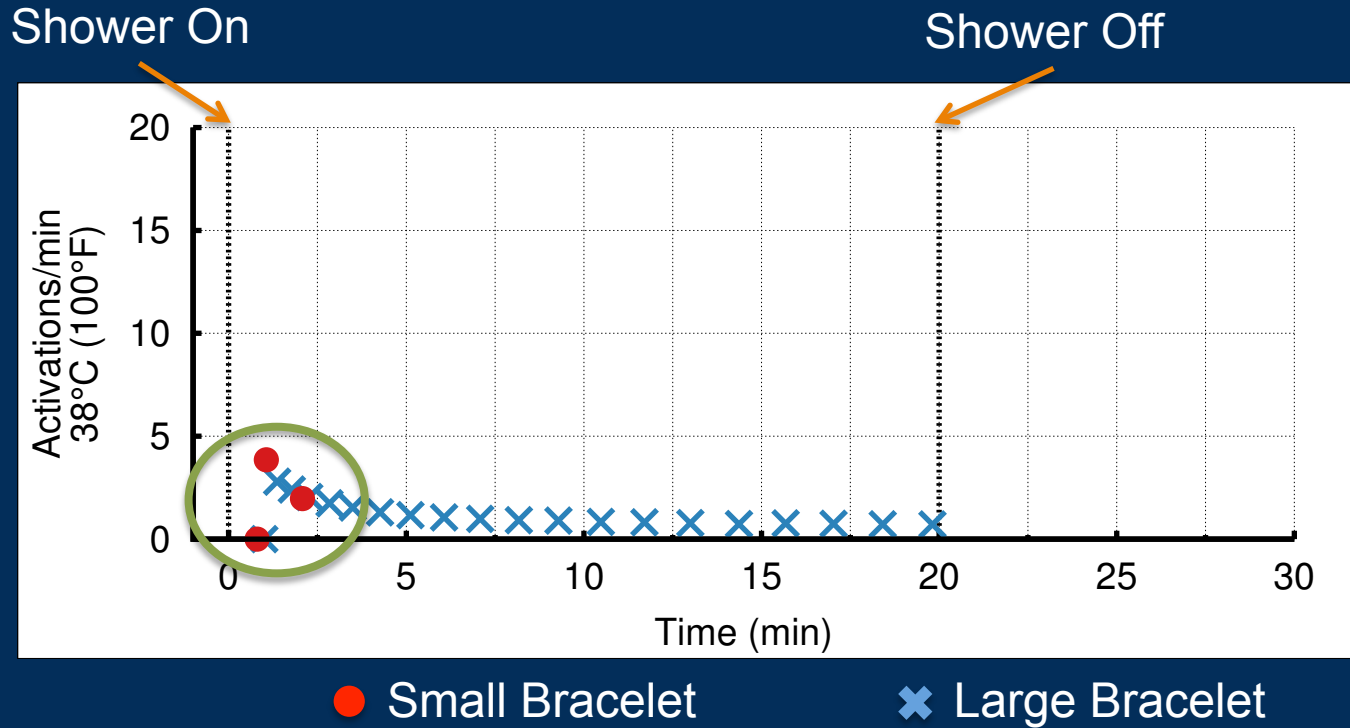
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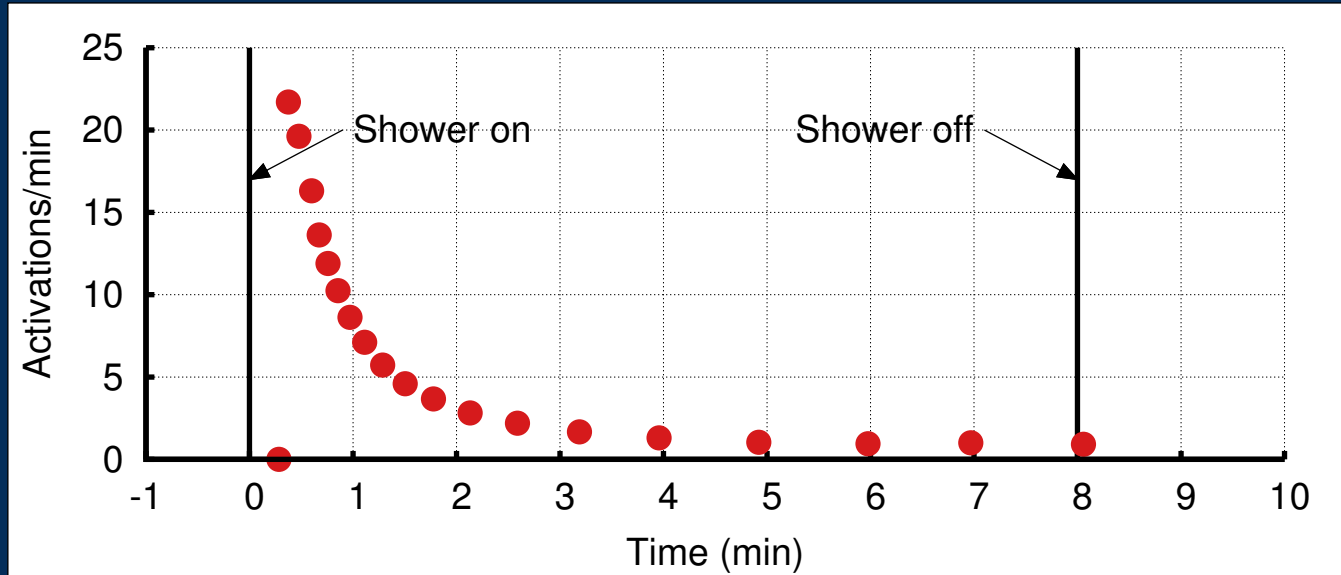
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Estimating Start and Stop Times

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
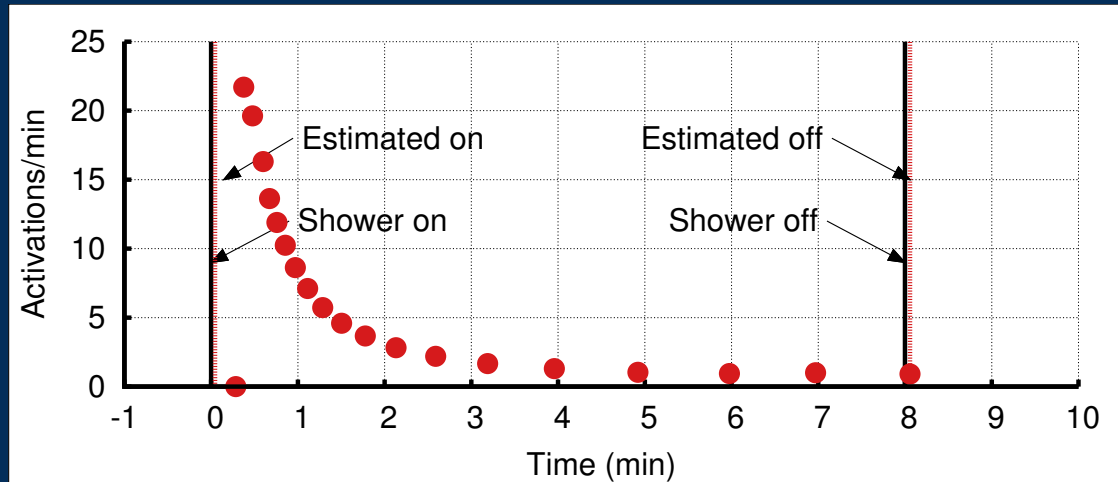
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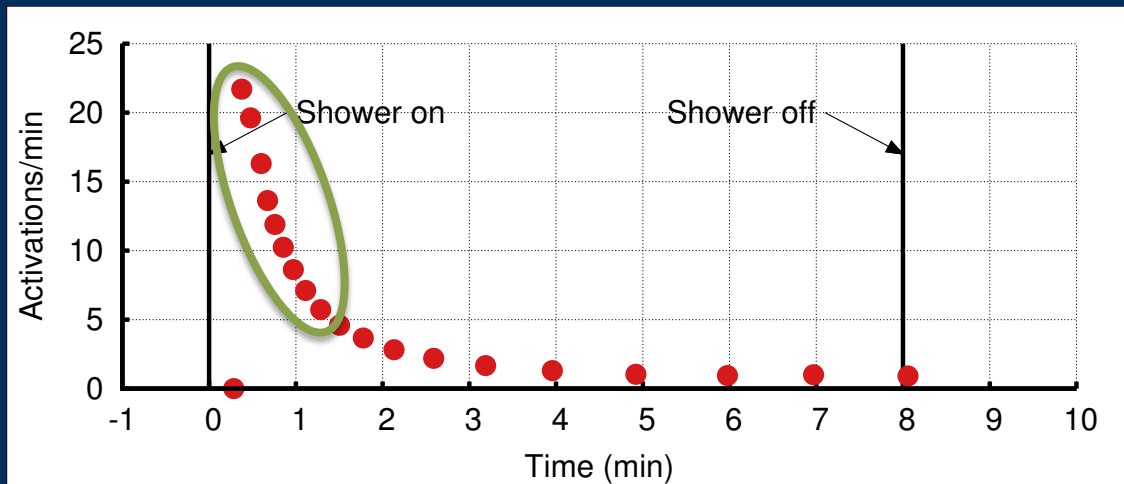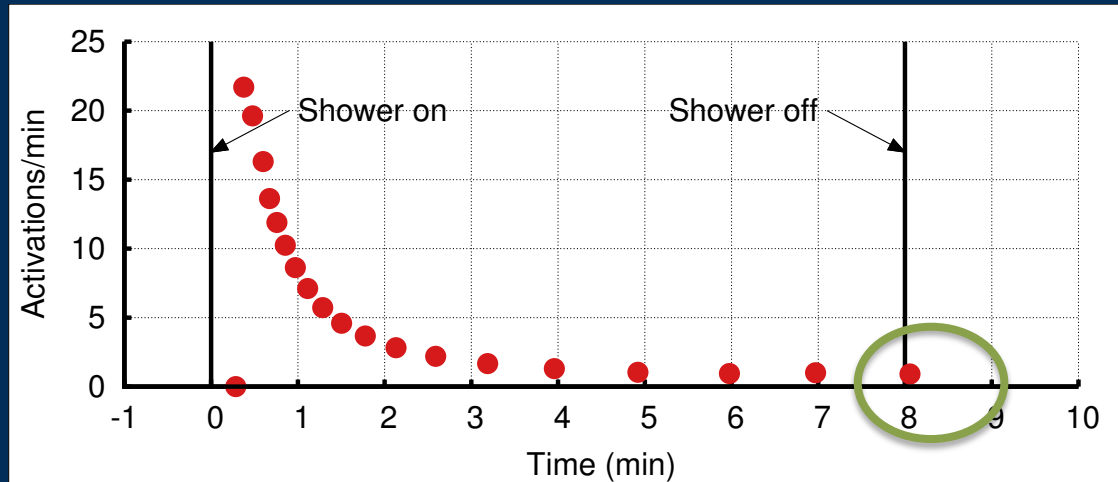
4) What other applications can it be used for?

Real Showers

Shower started at time zero and continued for over ten minutes

Small Bracelet

Real Showers

Real Showers
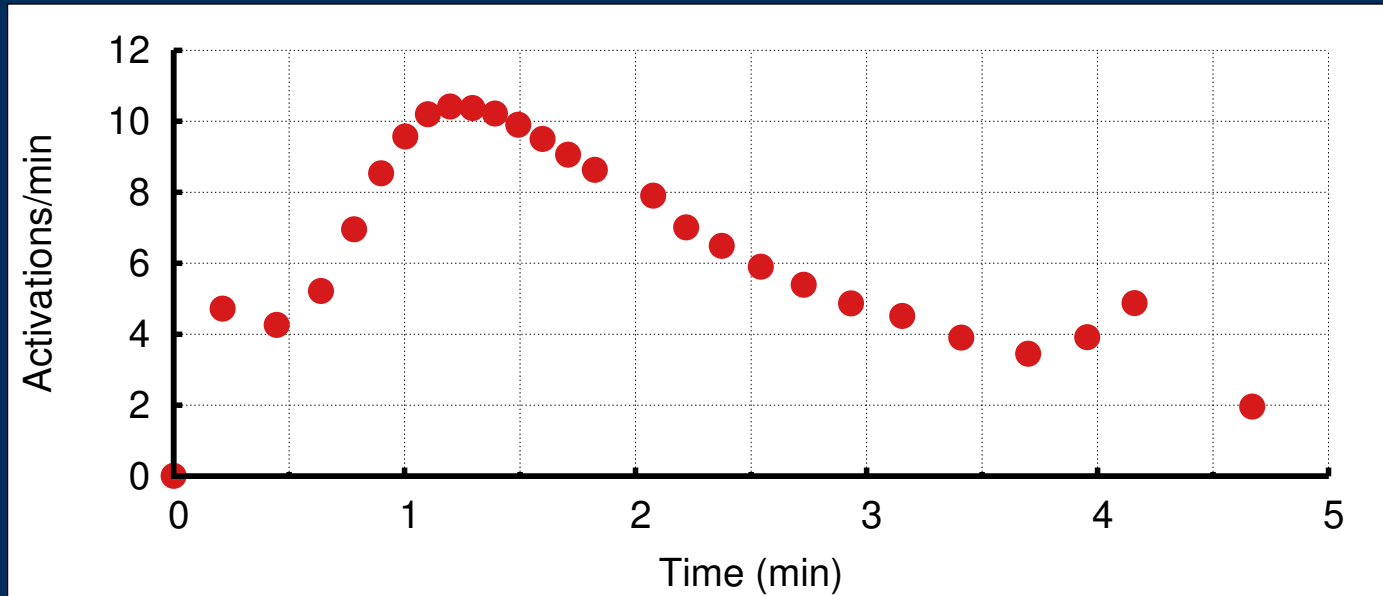
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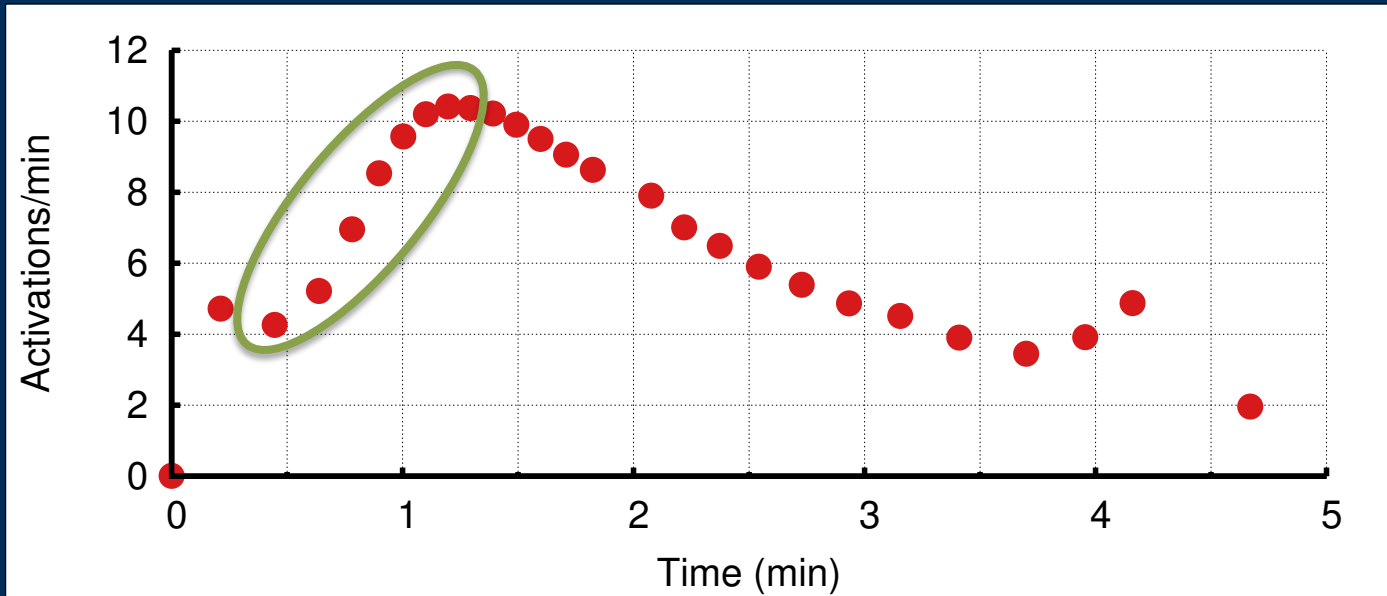
4) What other applications can it be used for?

Extending the Idea

Thermes can be used anywhere a temperature differential exists
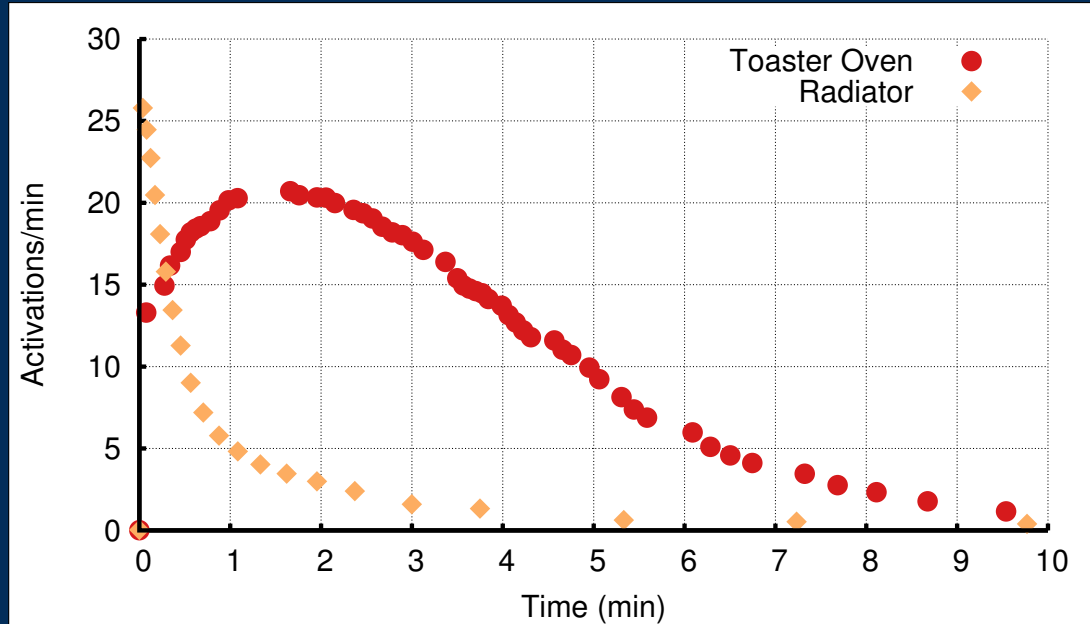
Future Work

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
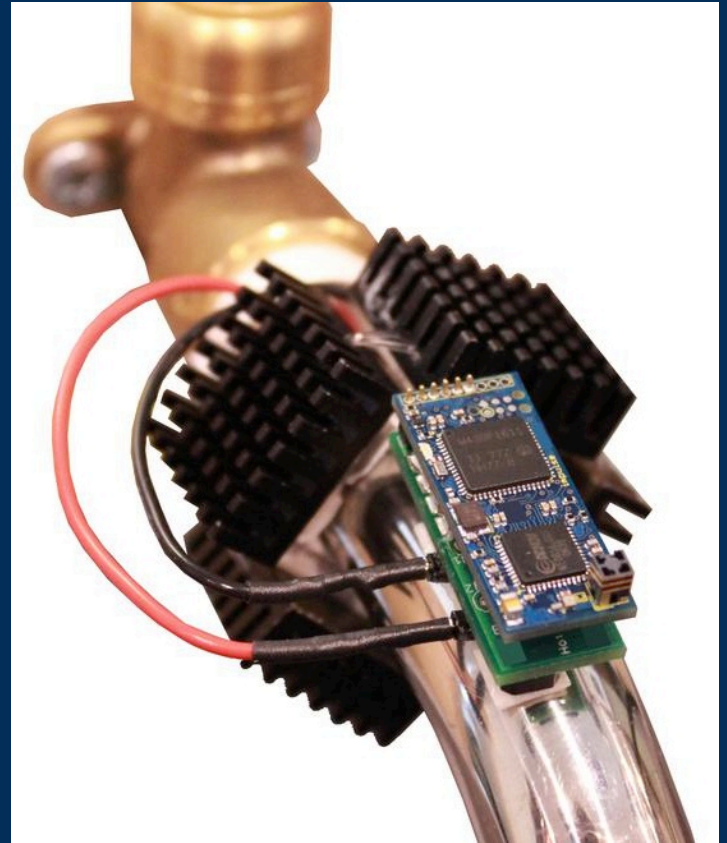
Questions?

Energy-Harvesting Thermoelectric Sensing for Unobtrusive Water and Appliance Metering

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http://github.com/lab11/monjolo

MICHIGAN ENGINEERING
UNIVERSITY OF MICHIGAN
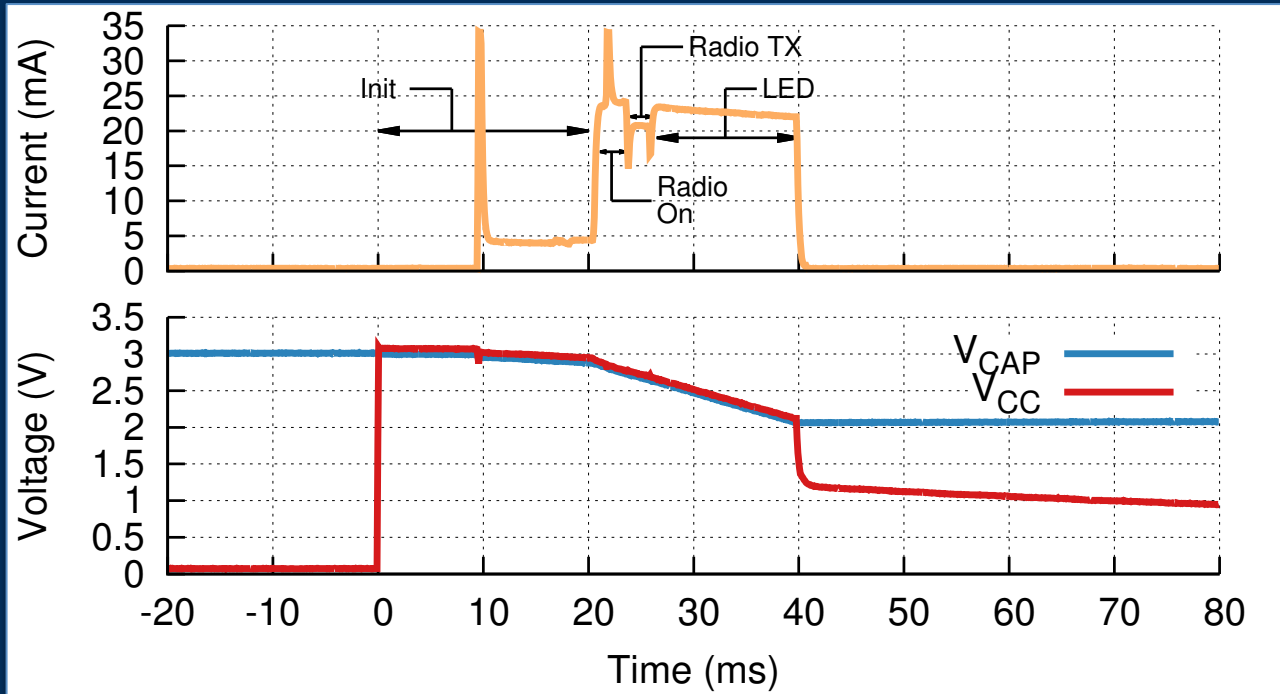
Bonus Slides

MICHIGAN ENGINEERING
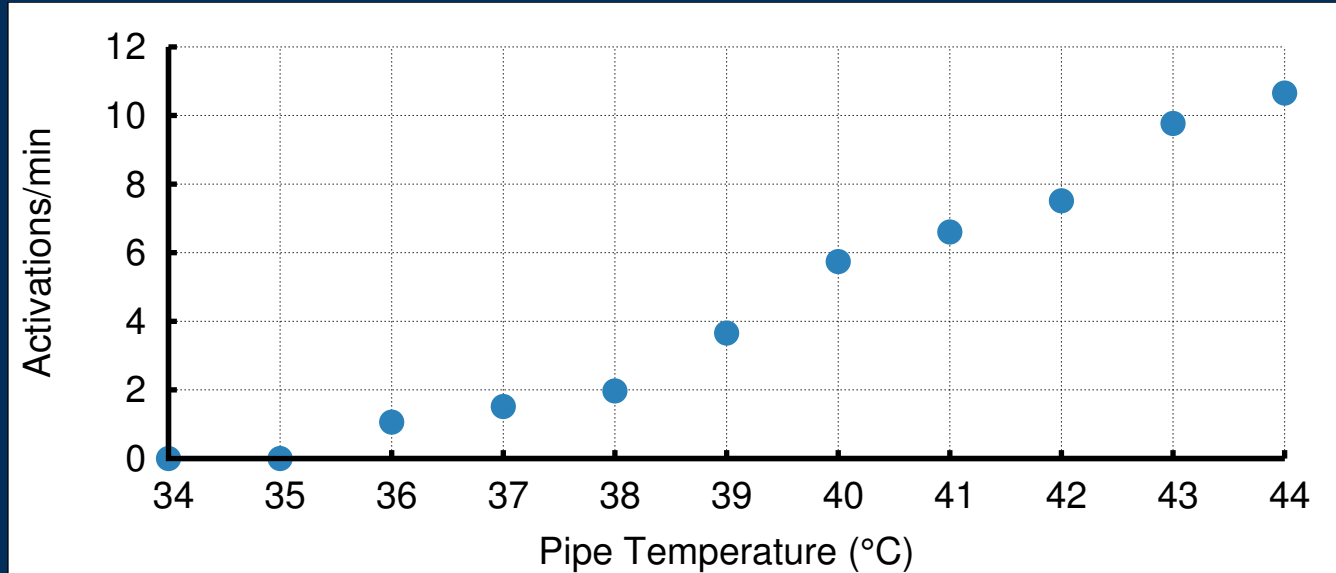UNIVERSITY OF MICHIGAN

Wired Water Meters

View of a Single Activation

Energy Harvester Performance
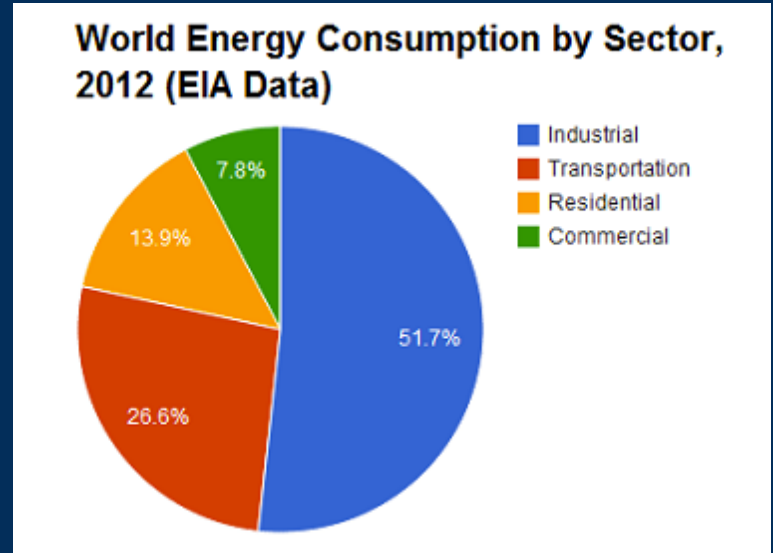
Activations/min are proportional to temperature
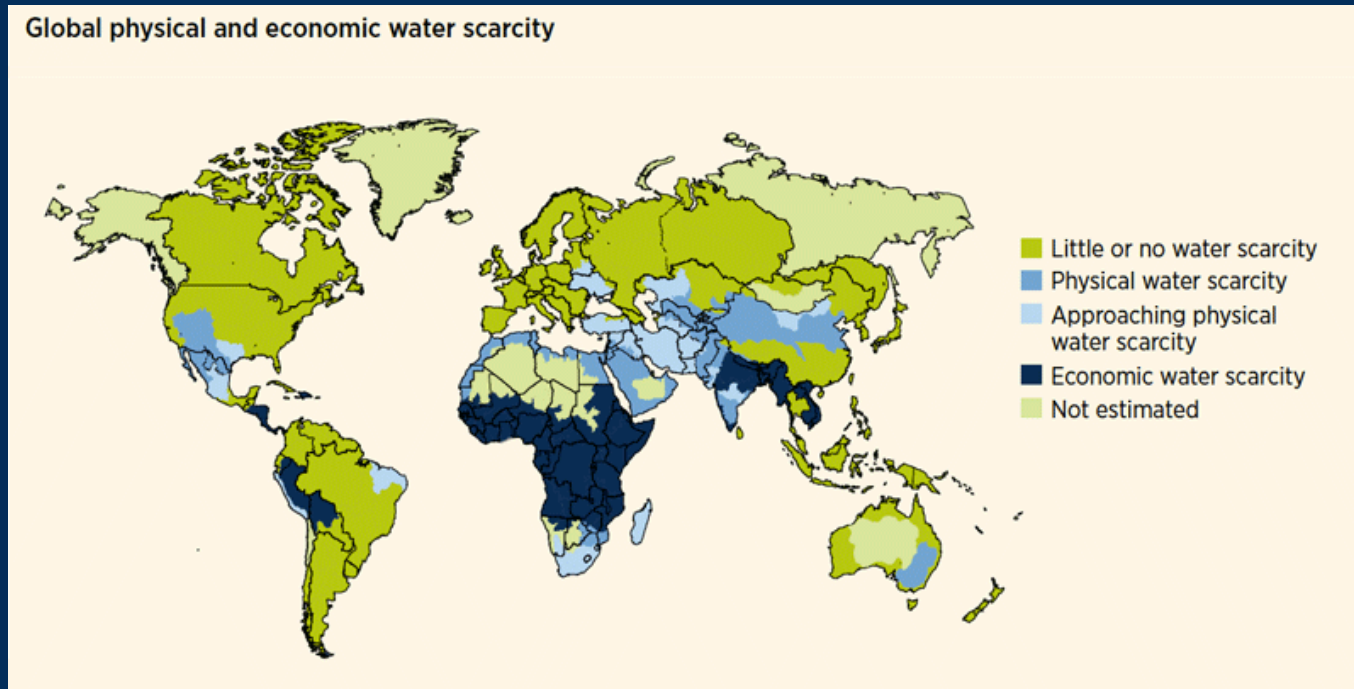
Energy Management is a Residential Problem

Energy use in the home is an important factor of total energy use

Water use is a significant portion of this problem.

World Energy Consumption by Sector, 2012 (EIA Data)

- Industrial
- Transportation
- Residential
- Commercial

7.8%
13.9%
51.7%
26.6%

US Energy Information Administration. 2012

Water Is Becoming Scarce

Global physical and economic water scarcity

Legend:
- Little or no water scarcity
- Physical water scarcity
- Approaching physical water scarcity
- Economic water scarcity
- Not estimated

- "Water scarcity is among the main problems to be faced by many societies and the World in the XXIst century."
  - *Human Development Report 2006*, UN
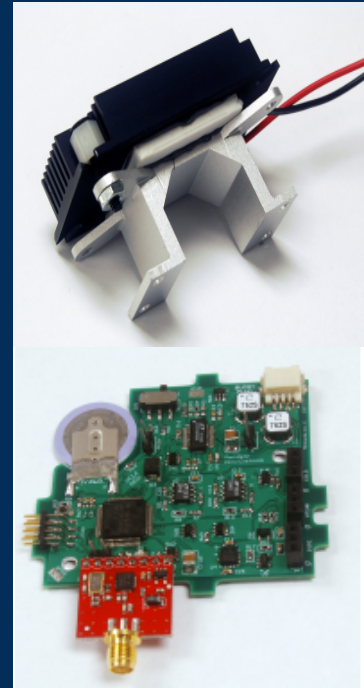
Current Systems Fail to Maximize Usability

DoubleDip senses flow with an accelerometer

– Increases energy needs

DoubleDip board is 58 cm^2 (9 in^2)

– More obtrusive installation

These problems limit usability

DoubleDip

DOE's call for "open architecture sensors"

"BTO [Building Technologies Office] is developing **open-architecture sensors** and sensor systems that **easily share data** to enable building operators and owners to cost effectively **capture energy** and **cost savings** through the use of new and existing control system applications. The objective is to **take to market** new sensors and sensor configurations that allow **easy application** to building operation, easy and **open access to the data** from the sensors, and novel application of sensor data to building management systems. BTO 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.**), **open-source** sensor packages that allow for data acquisition and transmission with **increased lifespan** between manual calibrations, **"virtual sensors"** enabled by innovative combinations of hardware and software, and **easily installed "plug and play"** sensor packages in which sensors would be **automatically recognized** by building energy management systems, in a manner similar to how conventional printers are easily recognized by an existing computer network."
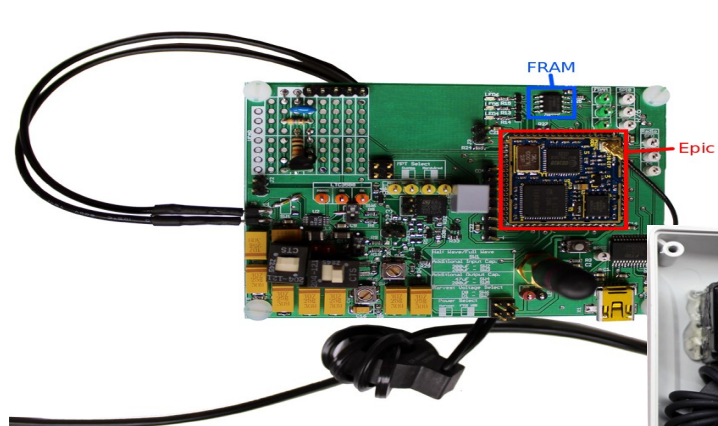
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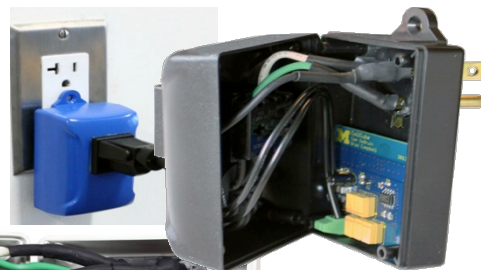# Measuring energy consuming activities
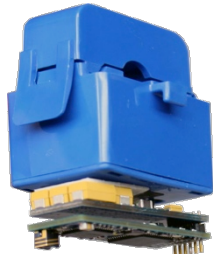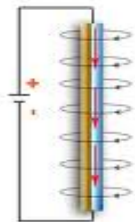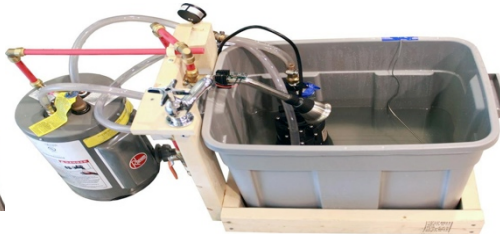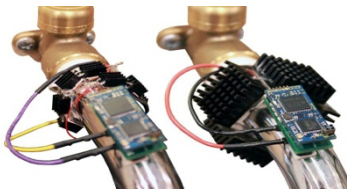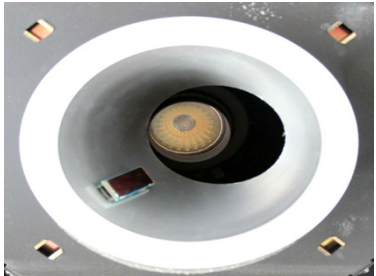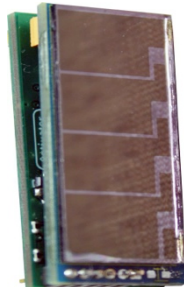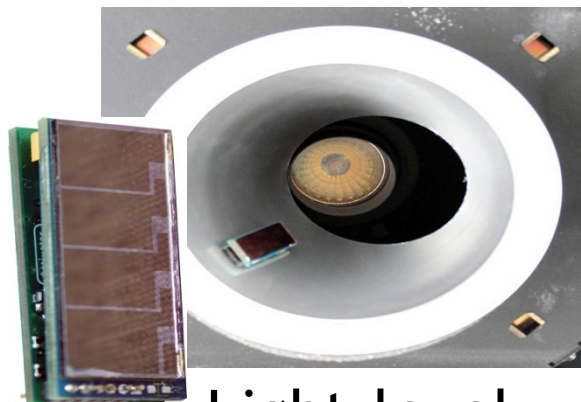

Monjolo: A Portuguese
water hammer

Monjolo meter realizations

Test board

Plug-load

Light-level

Panel-mount