



OPEN SOURCE BUILDING SCIENCE SENSORS

Advisory Board Meeting, January 27, 2015

Akram Ali, Torkan Fazli, and Brent Stephens

Civil, Architectural and Environmental Engineering

Illinois Institute of Technology, Chicago, IL



The Built Environment Research Group

advancing energy, environmental, and sustainability
research within the built environment
at Illinois Institute of Technology



web www.built-envi.com **email** brent@iit.edu **twitter** @built_envi

Today's agenda



OSBSS

Open Source
Building Science Sensors

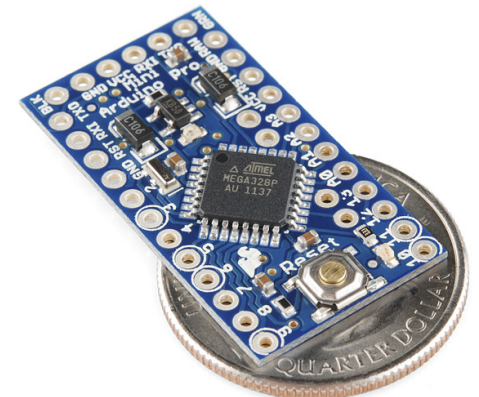
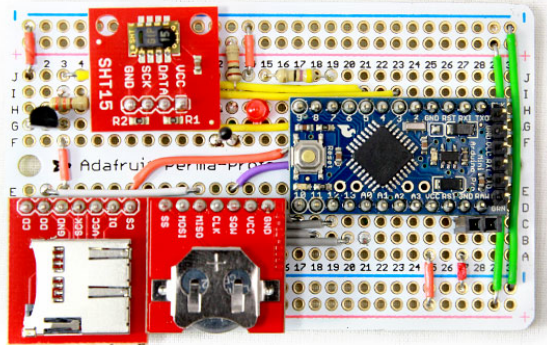
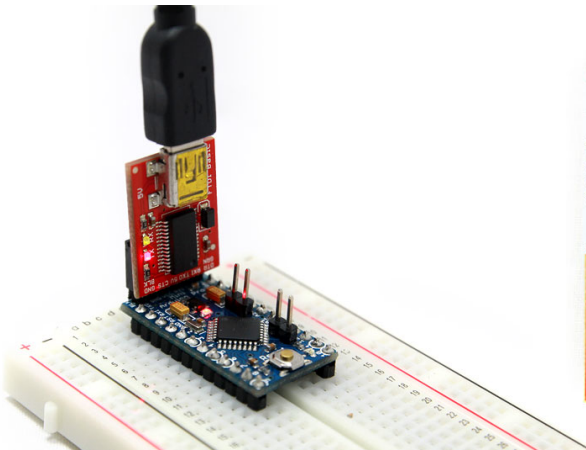
- | | |
|----------|---|
| 9:00 am | Introductions |
| 9:15 am | OSBSS progress update, product demonstration, and group discussion <ul style="list-style-type: none">• Led by Brent Stephens, Akram Ali, and Torkan Fazli |
| 11:00 am | OSBSS future plans <ul style="list-style-type: none">• New/revised capabilities (wireless, PCB versions, GUI, new sensors)• Solicitation of advisory board suggestions for future• Develop plan of action |
| 12:00 pm | Adjourn |

(lunch next door – optional)



OPEN SOURCE BUILDING SCIENCE SENSORS

The **Open Source Building Science Sensors (OSBSS)** project is designing and demonstrating how to build a network of inexpensive building environmental and operational sensors for long-term studies of the indoor environment using open source hardware and software



Acknowledgements

- Funding from the **Alfred P. Sloan Foundation program on the Microbiology of the Built Environment**
 - Paula Olsiewski



Akram Ali



Torkan Fazli



Boyang "Bobo" Dong



Zack Zanzinger



Deion Debose



Joseph Chee Poh Huan



OPEN SOURCE BUILDING SCIENCE SENSORS

Four tasks outlined in the original proposal:

1. Literature review
2. Sensor development
3. Online documentation
4. Protocol development and publication

Timeline:

November 1, 2013 – May 1, 2015 (~80% complete)

Questions to be thinking about:

1. How is this helpful to your respective communities?
2. Do you have suggestions for improvements?
 - Types of measurements
 - Usability of the platform
3. What would you imagine the next phase(s) of this project to look like?
4. Is the example tutorial missing any important information or steps?
 - What kind of tutorial would you be most likely to use?
 - e.g., PDF/HTML

Motivation for OSBSS

- Recent studies have greatly increased our knowledge of microbial ecology of the indoor environments in which we live and work

Summarized in Kelley and Gilbert **2013** *Genome Biol* 14:202;
Konya and Scott **2014** *Curr Sustain Energy Rep* 1:35-42

- Limited collection of long-term building science data to date
- Insufficiently described built environmental data can limit our ability to compare microbial ecology results from one indoor environment to another
 - Or assess how best to control indoor microbial communities



Building science to advance research in the microbiology of the built environment (MoBE)

Supported by the Alfred P. Sloan Foundation

May 22-23, 2014 | Illinois Institute of Technology | Chicago, IL



**ALFRED P. SLOAN
FOUNDATION**



**ILLINOIS INSTITUTE
OF TECHNOLOGY**

Full meeting report and transcript available for download:
<http://built-envi.com/portfolio/mobe-building-science-workshop/>

“Tools to improve built environment data collection for indoor microbial ecology investigations”

Suggestions for built environment measurements

1. Measure detailed building characteristics and long-term indoor environmental conditions
 - Building surveys, T, RH, W, light, others
2. Measure human occupancy and activity
 - Proximity, trip wires, CO₂, RFID, acoustic, Bluetooth, video
3. Characterize HVAC systems and measure ventilation rates (and sources of air)
4. Characterize surfaces
 - T, a_w (ERH), pH, porosity, qualitative details, frequency of cleaning
5. Standardize air sampling and quantifying aerosol dynamics

A few references on environmental conditions and microbial communities:

Tang **2009** *J R Soc Interface*; Noyce et al **2006** *J Hosp Infect*; Mbithi et al **1991** *Appl Environ Microbiol*;
Baughman, Arens **1996** *ASHRAE Trans*; Jawad et al **1996** *J Clin Microbiol*; McElDowney, Fletcher **1988** *Lett Appl Microbiol*;
Coughenour et al **2011** *Microb Drug Resist*; Hobday, Dancer **2013** *J Hosp Infect*

“Tools to improve built environment data collection for indoor microbial ecology investigations”

Long list of measurement types and techniques

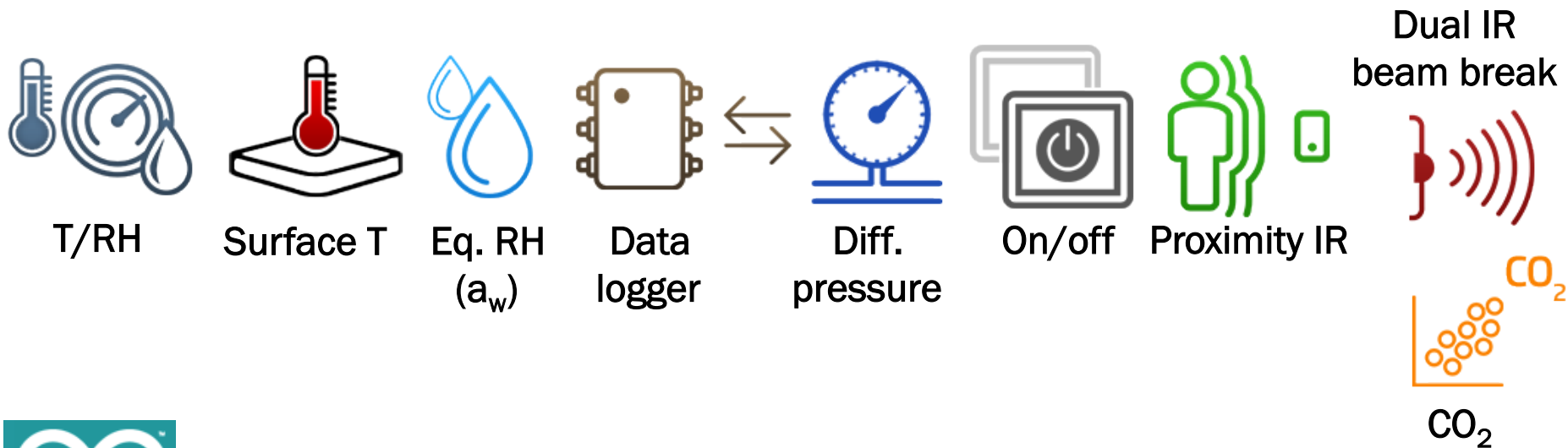
Parameter(s)	Measurement/collection method	Important considerations	Reference
1. Building characteristics and environmental conditions			
Basic building characteristics	Surveys, visual assessments	Age of construction, floor areas and volumes, material descriptions, type of use, typical occupancy, history of water damage, occupant complaints, HVAC system type and operation, ventilation method and source, the use of humidifiers, etc.	[19,45,49,174]
Indoor T/RH, absolute humidity, and artificial/natural light	Portable, off-the-shelf, battery-powered sensors with data loggers	Storage capacity, accuracy, precision, battery power	[175–178]
Outdoor T/RH, absolute humidity, and light	Publicly available meteorological data or local weather station installations	Data availability, installation location	[179–181]
2. HVAC system characteristics and ventilation rates			
Spot measurements of airflow rates at AHU	Correlate pressure readings to fan curve data by the fan manufacturer	Requires knowledge of fan manufacturer and in-situ verification	[182]
	Traverse velocity with pitot tubes or hot-wire anemometers (multiplied by duct area)	Requires knowledge of duct areas, high uncertainty	[96,105,160]
	Pressure matching with powered, calibrated fan	Typically greater accuracy than capture hood, limited to smaller systems, requires clear access to AHU	[97,106,183,184]
	Airflow metering plates	Requires modifications for larger AHUs	[98,107,109,185,186]
Spot measurements of airflow rates at individual supply diffusers or return grilles	Airflow capture hood	Limited accuracy under some conditions	[105,187,188]
	Air velocity or pressure readings correlated to diffuser characteristics	May not accurately reflect in-situ performance, requires knowledge of specific manufacturer	[189]
	Traverse velocity with pitot tubes or hot-wire anemometers (multiplied by duct area)	Requires knowledge of duct areas, high uncertainty	[96,105,160]
	Pressure matching with powered, calibrated fan operating as flow hood	Typically greater accuracy than capture hood	[97,105,106,183,184]
Continuous flow measurements	Flow meters installed directly into HVAC system (e.g. venturi meters, flow nozzles, orifice meters, rotameters)	Invasive, requires HVAC access, data logger, and power	[96,190]

SENSOR DEVELOPMENT AND DOCUMENTATION



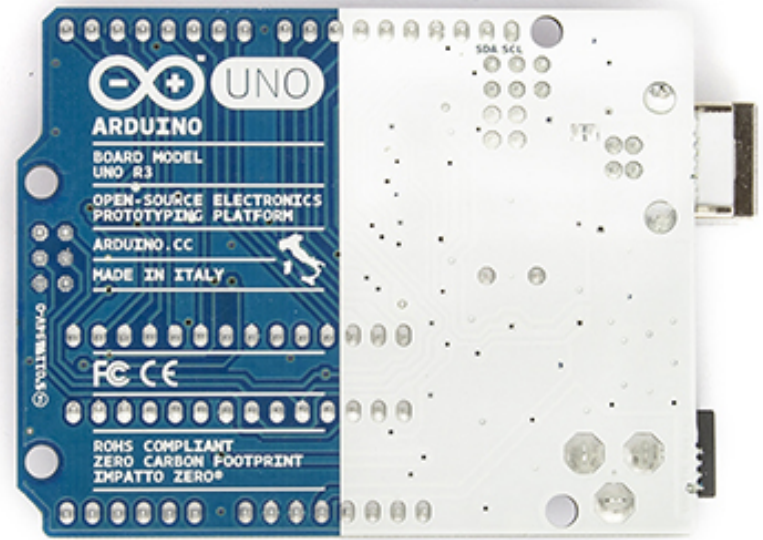
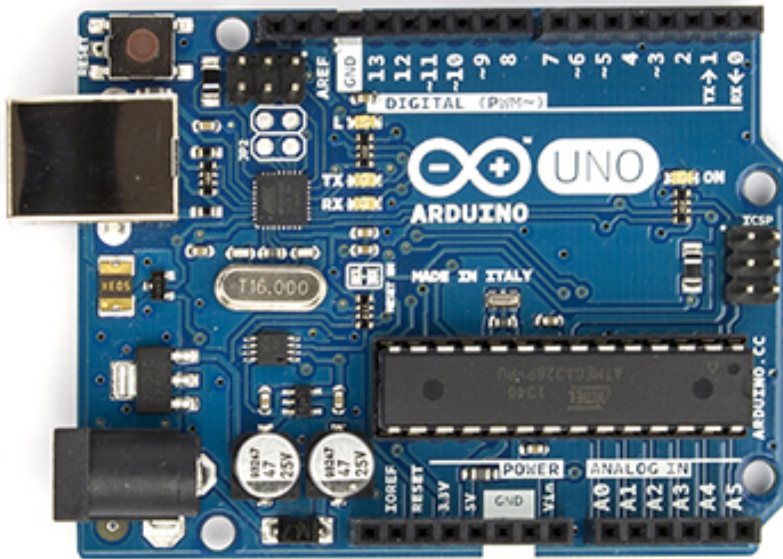
OPEN SOURCE BUILDING SCIENCE SENSORS

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Why Arduino?

- Arduino is an open-source electronics platform based on easy-to-use hardware and software
 - Large array of options
 - Huge global user community



Arduino Uno

Why Arduino?

- There are dozens of official and unofficial boards
 - Variety of shapes, sizes, power, memory, number of I/O pins, etc.



Arduino Uno



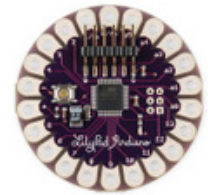
Arduino Leonardo



Arduino Mega 2560



Arduino Robot



LilyPad Arduino



Arduino Due



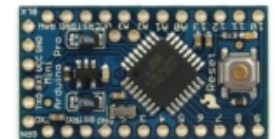
Arduino Yún



Arduino Mini



Arduino Nano



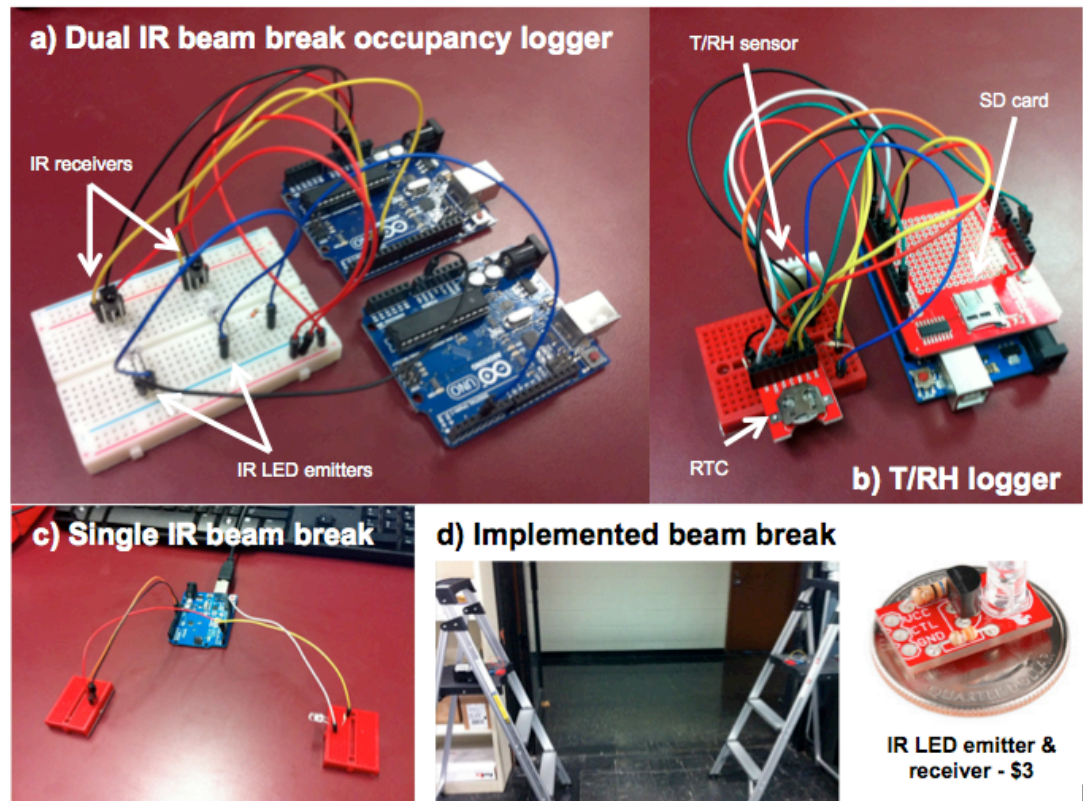
Arduino Pro Mini

Why Arduino?

Name	Processor	Operating Voltage/Input Voltage	CPU Speed	Analog In/Out	Digital IO/PWM	EEPROM [KB]	SRAM [KB]	Flash [KB]	USB	UART
Uno	ATmega328	5 V/7-12 V	16MHz	6/0	14/6	1	2	32	Regular	1
Due	AT91SAM3X8E	3.3 V/7-12 V	84 MHz	12/2	54/12	-	96	512	2 Micro	4
Leonardo	ATmega32u4	5 V/7-12 V	16MHz	12/0	20/7	1	2.5	32	Micro	1
Mega 2560	ATmega2560	5 V/7-12 V	16MHz	16/0	54/15	4	8	256	Regular	4
Mega ADK	ATmega2560	5 V/7-12 V	16MHz	16/0	54/15	4	8	256	Regular	4
Micro	ATmega32u4	5 V/7-12 V	16MHz	12/0	20/7	1	2.5	32	Micro	1
Mini	ATmega328	5 V/7-9 V	16MHz	8/0	14/6	1	2	32	-	-
Nano	ATmega168	5 V/7-9 V	16MHz	8/0	14/6	0.512	1	16	Mini-B	1
	ATmega328					1	2	32		
Ethernet	ATmega328	5 V/7-12 V	16MHz	6/0	14/4	1	2	32	Regular	-
Esplora	ATmega32u4	5 V/7-12 V	16MHz	-	-	1	2.5	32	Micro	-
ArduinoBT	ATmega328	5 V/2.5-12 V	16MHz	6/0	14/6	1	2	32	-	1
Fio	ATmega328P	3.3 V/3.7-7 V	8MHz	8/0	14/6	1	2	32	Mini	1
Pro (168)	ATmega168	3.3 V/3.35-12 V	8MHz	6/0	14/6	0.512	1	16	-	1

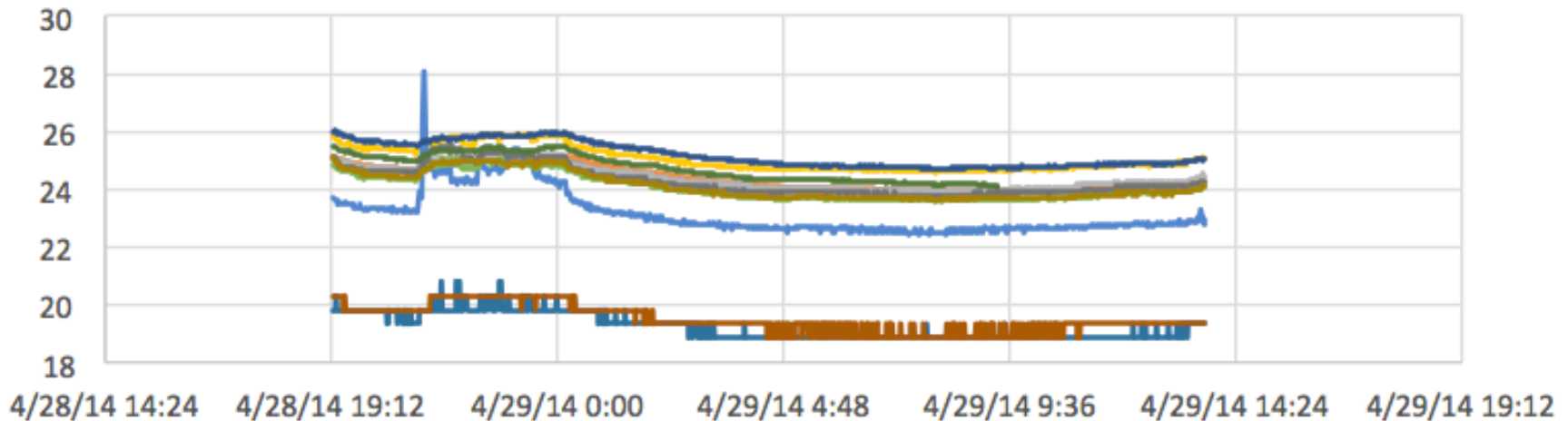
Development process: Stage 1 (**Concept**)

- Begin with breadboard (solder-less) concept development on **Arduino Uno** controllers with off-the-shelf sensors
 - Allows for testing basic functionality, accuracy, and developing code
- Issues at this stage:
 - High power draw
 - Real time clock (RTC)
 - Data storage
 - Durability
 - Aesthetics

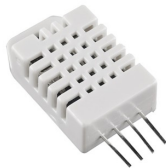


Development process: Stage 1 (Concept)

All Temperature

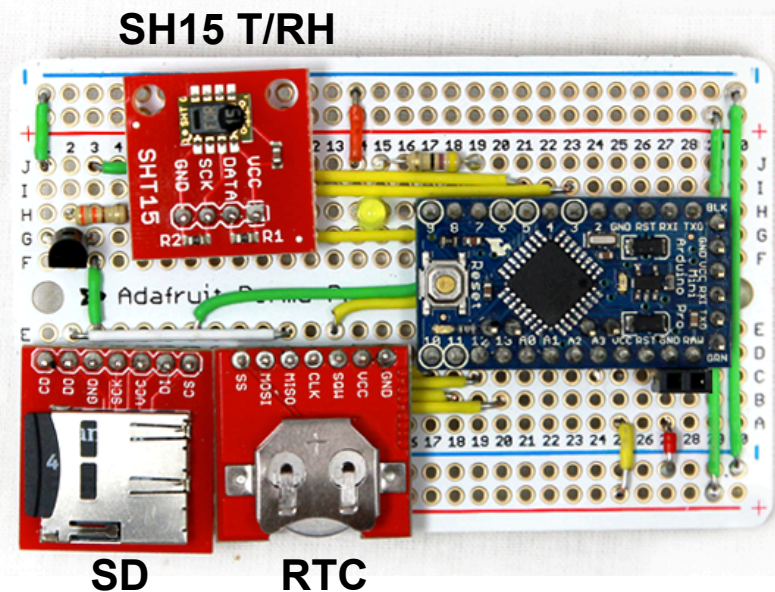


- HOBO 1 - Temp
- HOBO 2 - Temp
- Black Thermistor 1 (C)
- Black Thermistor 2 (C)
- Gold Thermistor 1 (C)
- Gold Thermistor 2 (C)
- TMP36 1 (C)
- TMP36 2 (C)
- White Temp 1 (C)
- White Temp 2 (C)
- SHT15 Temp
- TMP102 Temp



Development process: Stage 2 (**Prototype**)

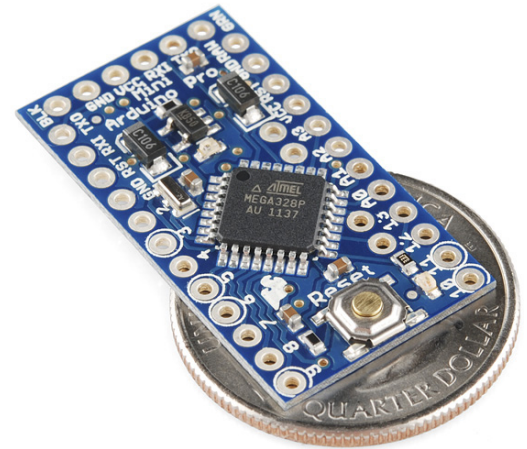
- Select most promising sensor(s)
- Move from Arduino Uno to **Arduino Pro Mini** (or knock-off versions for \$3)
 - Large reductions in power draw with custom libraries
 - Use of sleep mode functions
- Upgrade to solder-able breadboard
 - Improves durability
- Upgrade to custom enclosures
 - Improves aesthetics
- Provides base low-power logger



Development process: Stage 2 (**Prototype**)

Why the Arduino Pro Mini 328?

- Can use either 3.3V or 5V DC
- 8 MHz (3.3V) or 16 MHz (5V) processor
- Small footprint (0.7x1.3")
- 8 analog pins
- 14 digital I/Os
- 16 kB flash memory (2 kB used by bootloader)



Original Apple Macintosh

Released: Jan 24, 1984

Intro price: \$2,495

Clock speed: 7.8 MHz

Memory: 128 kB RAM

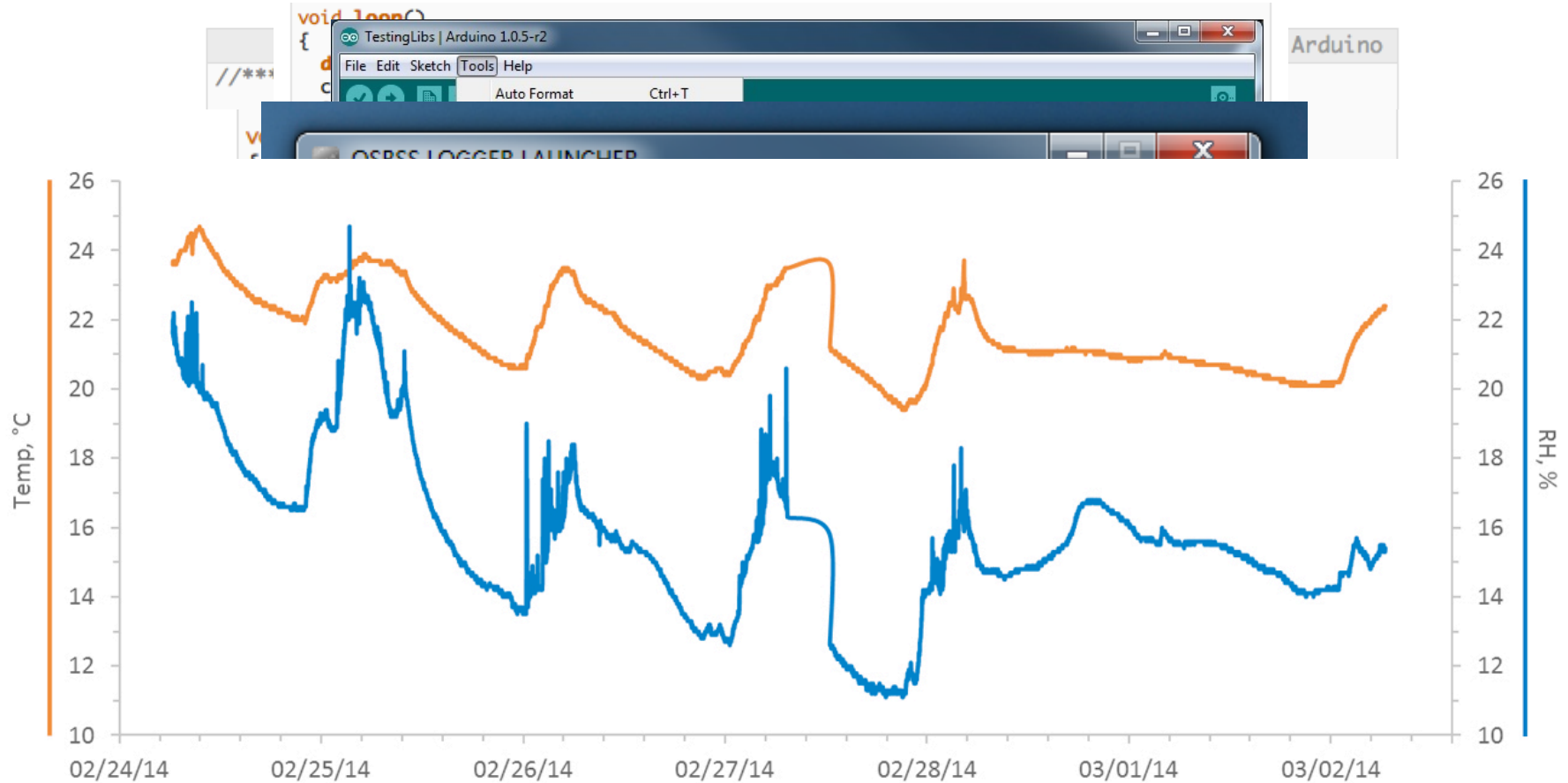
Pro Mini power draw:

From ~20 mA resting (Uno)

To ~0.2 mA resting (Mini + code)

From ~4 days to ~400 days on AA

Development process: Stage 3 (Tutorials)



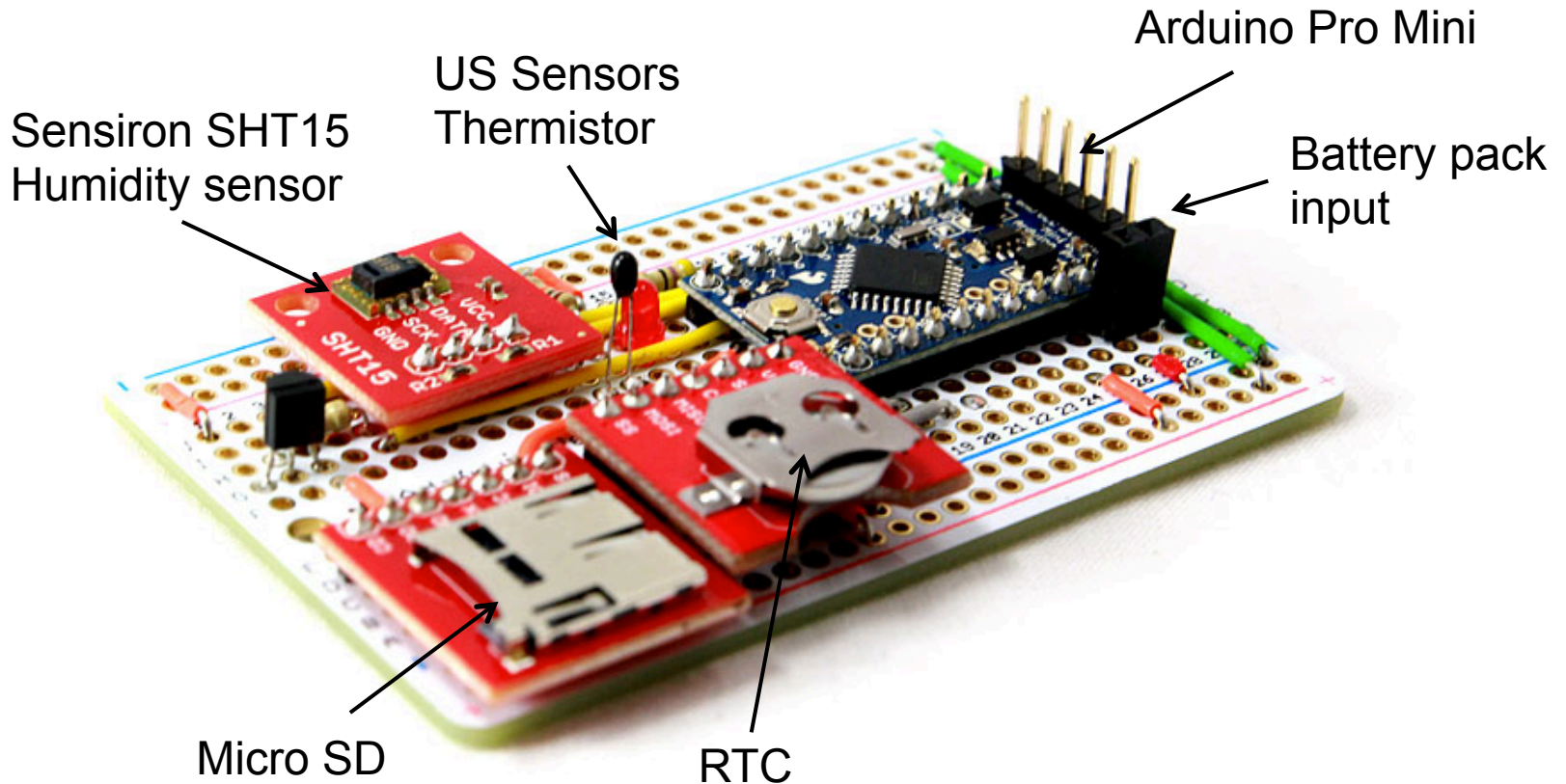
Total hardware cost: ~\$95 USD

PROGRESS UPDATE

Individual sensors

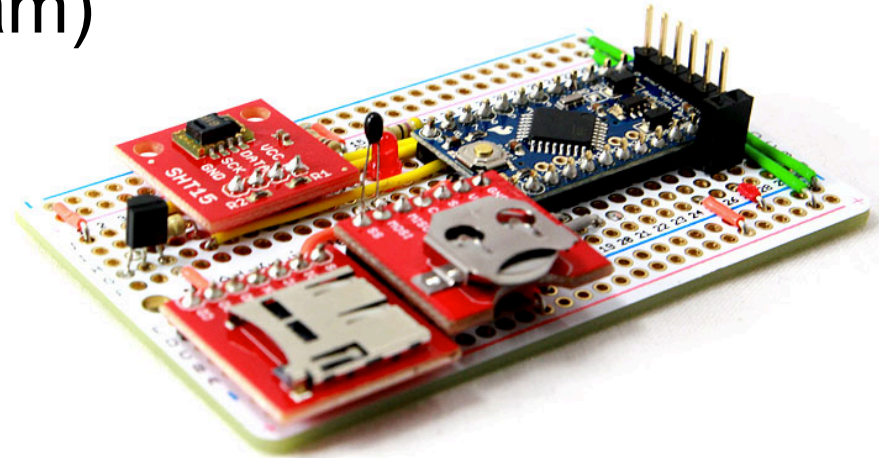
Temperature and RH

- Provided the base for our core long-term battery powered data logger
- Currently the only full tutorial online

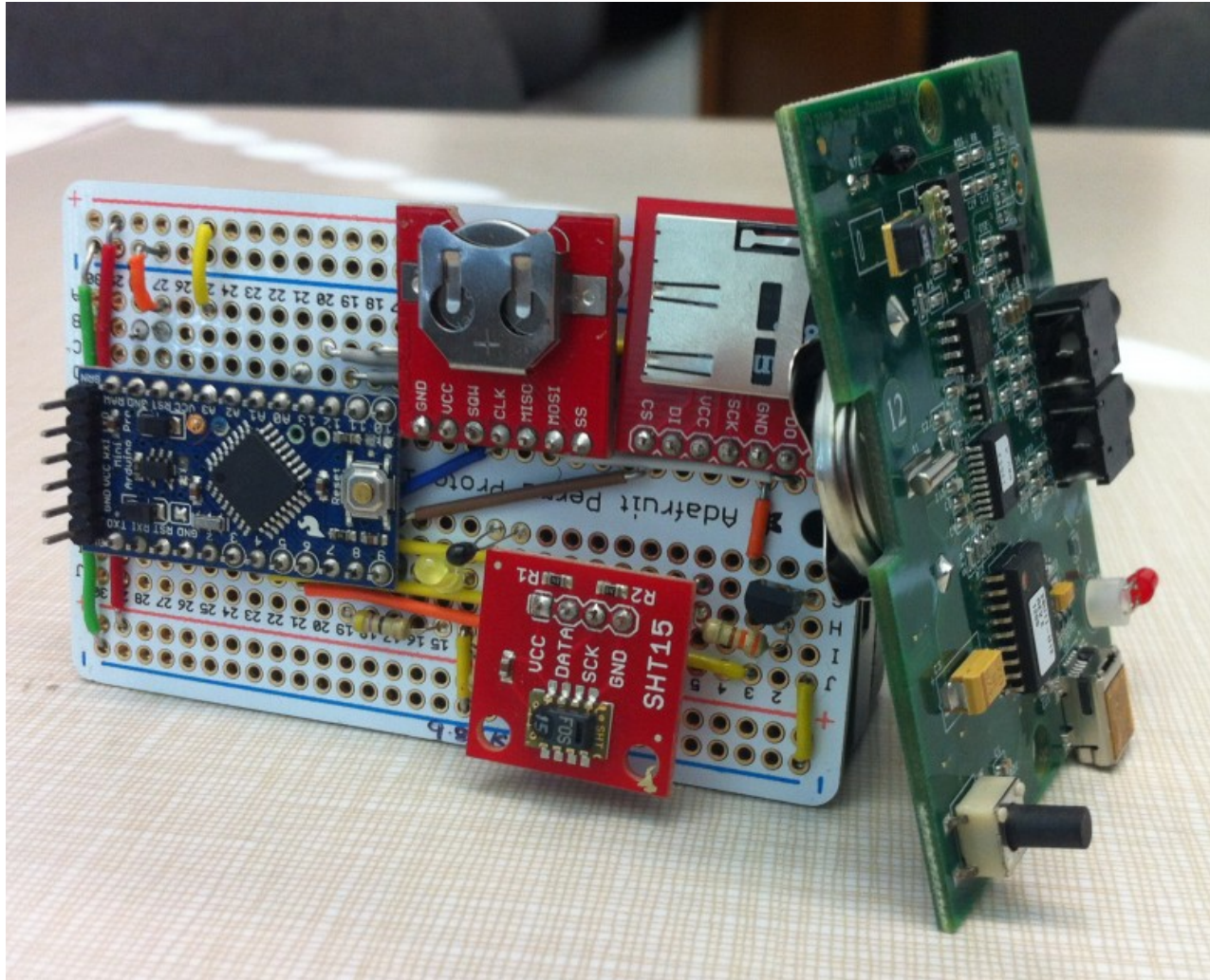


Temperature and RH

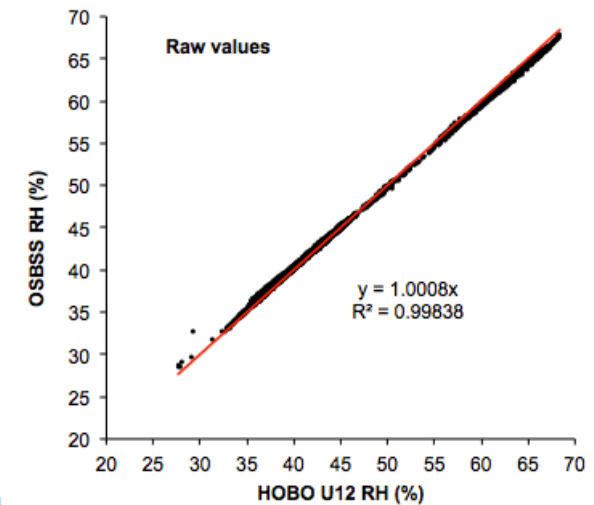
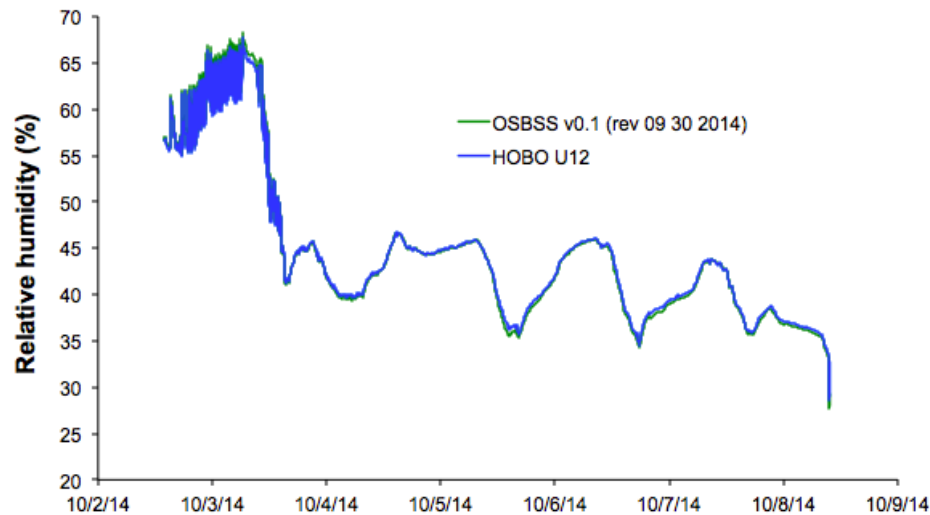
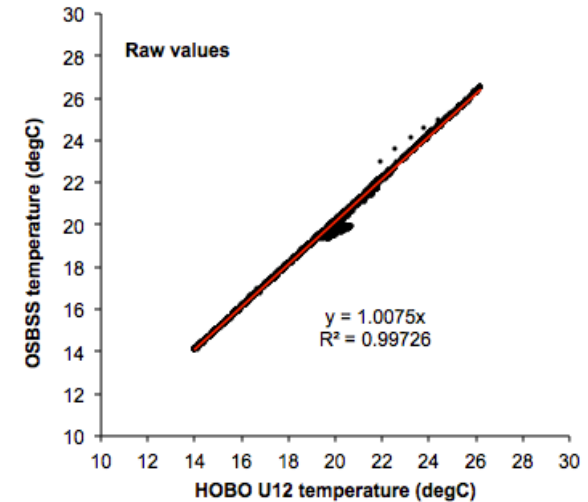
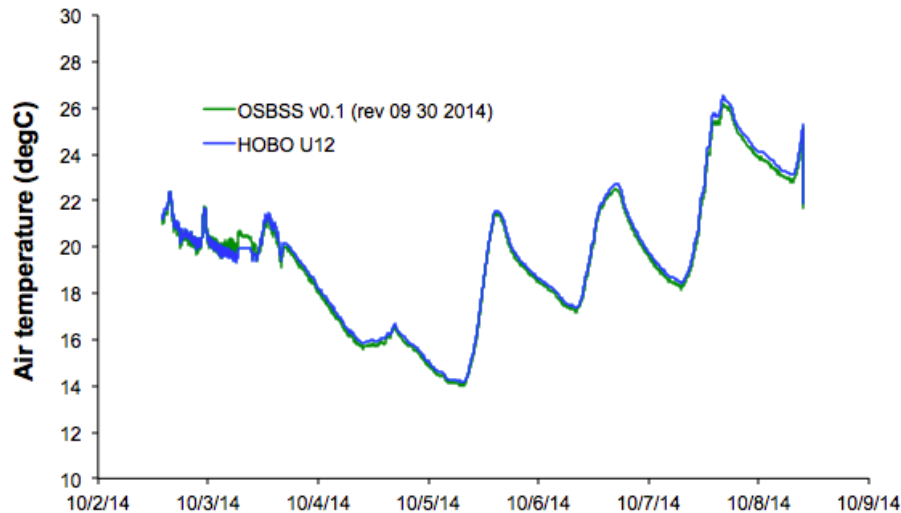
- T/RH demonstration (Akram)
 - Describe code sections
 - Set interval to 5 minutes
 - Change filename
 - Log T/RH
 - Download data and display



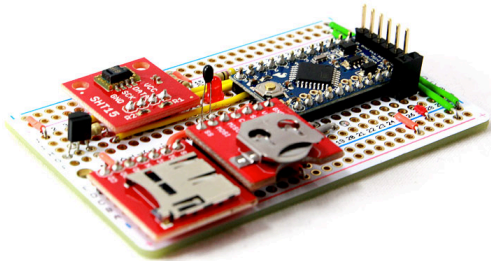
T/RH verification: OSBSS vs. HOBO



T/RH verification: OSBSS vs. HOBO



T/RH verification: OSBSS long-term

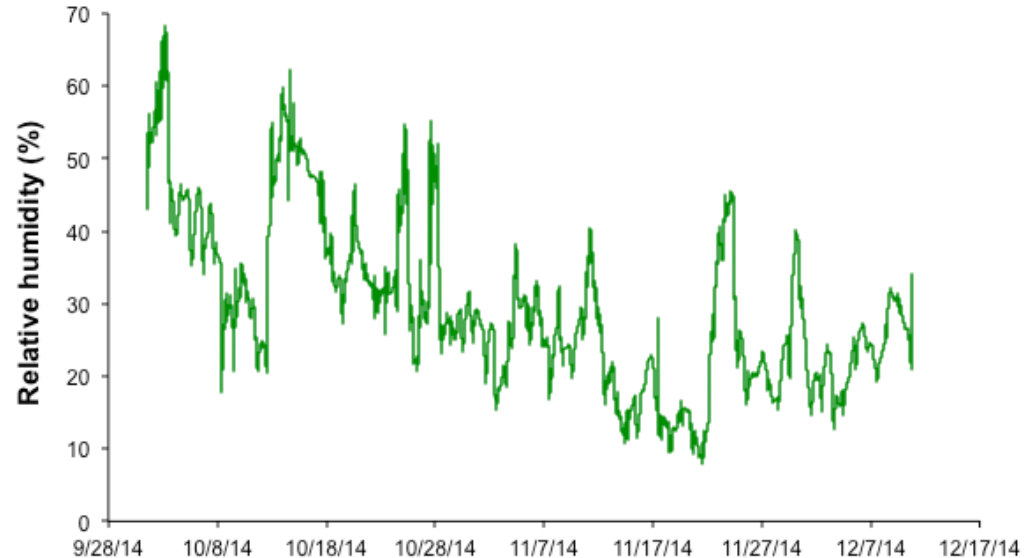
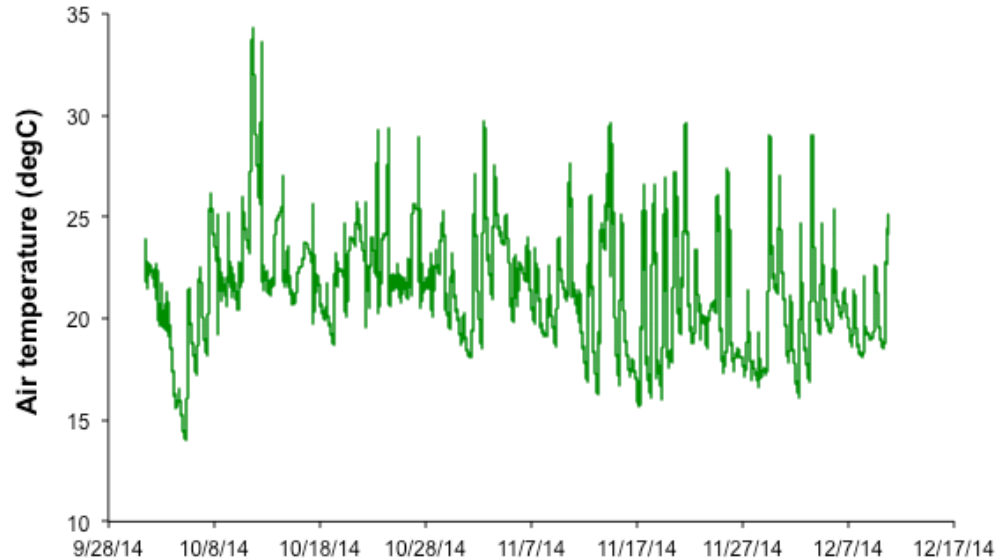


My office: ~90 days

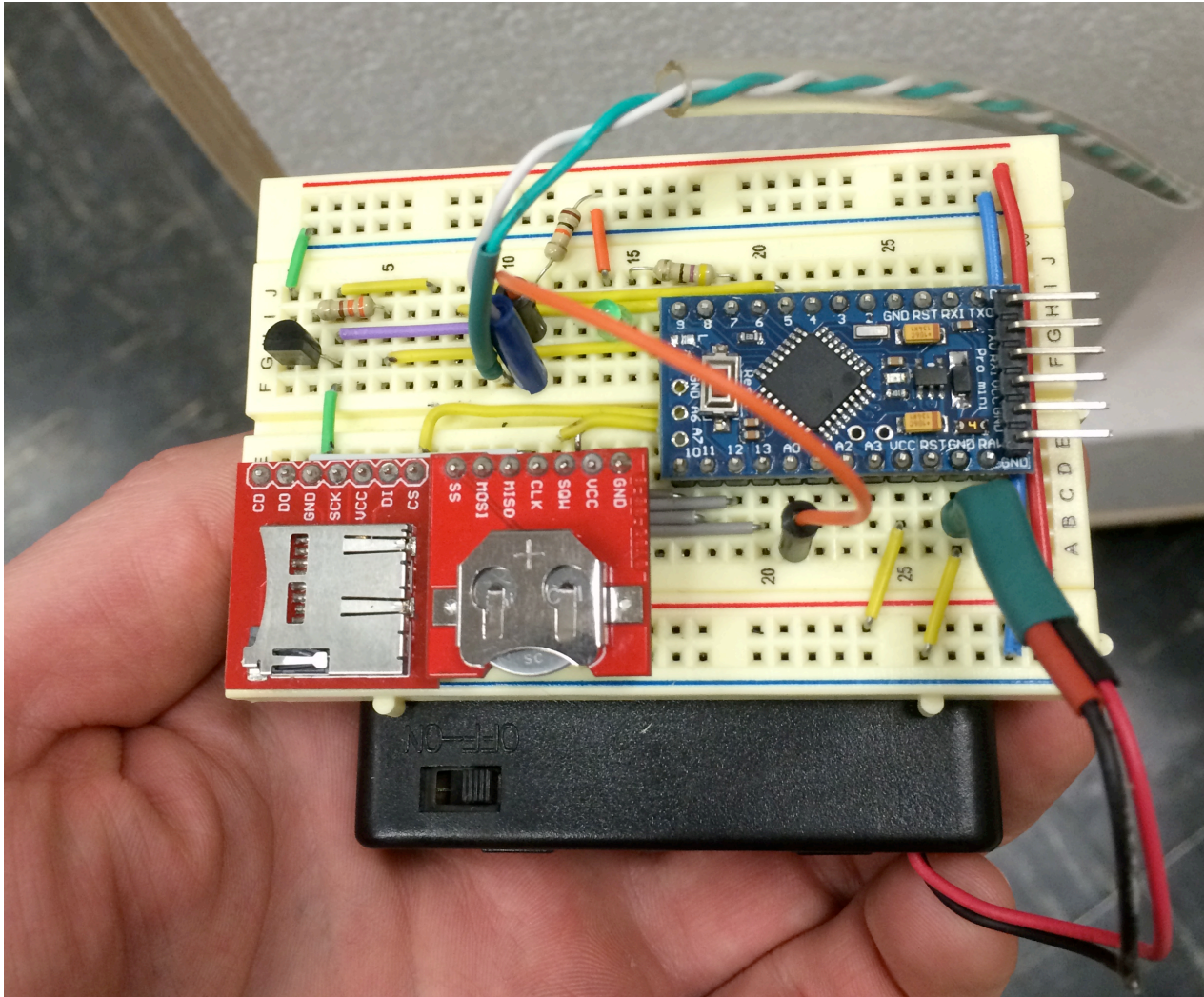
- Battery failure
(Issues w/ AA in series)

Akram's: Still going

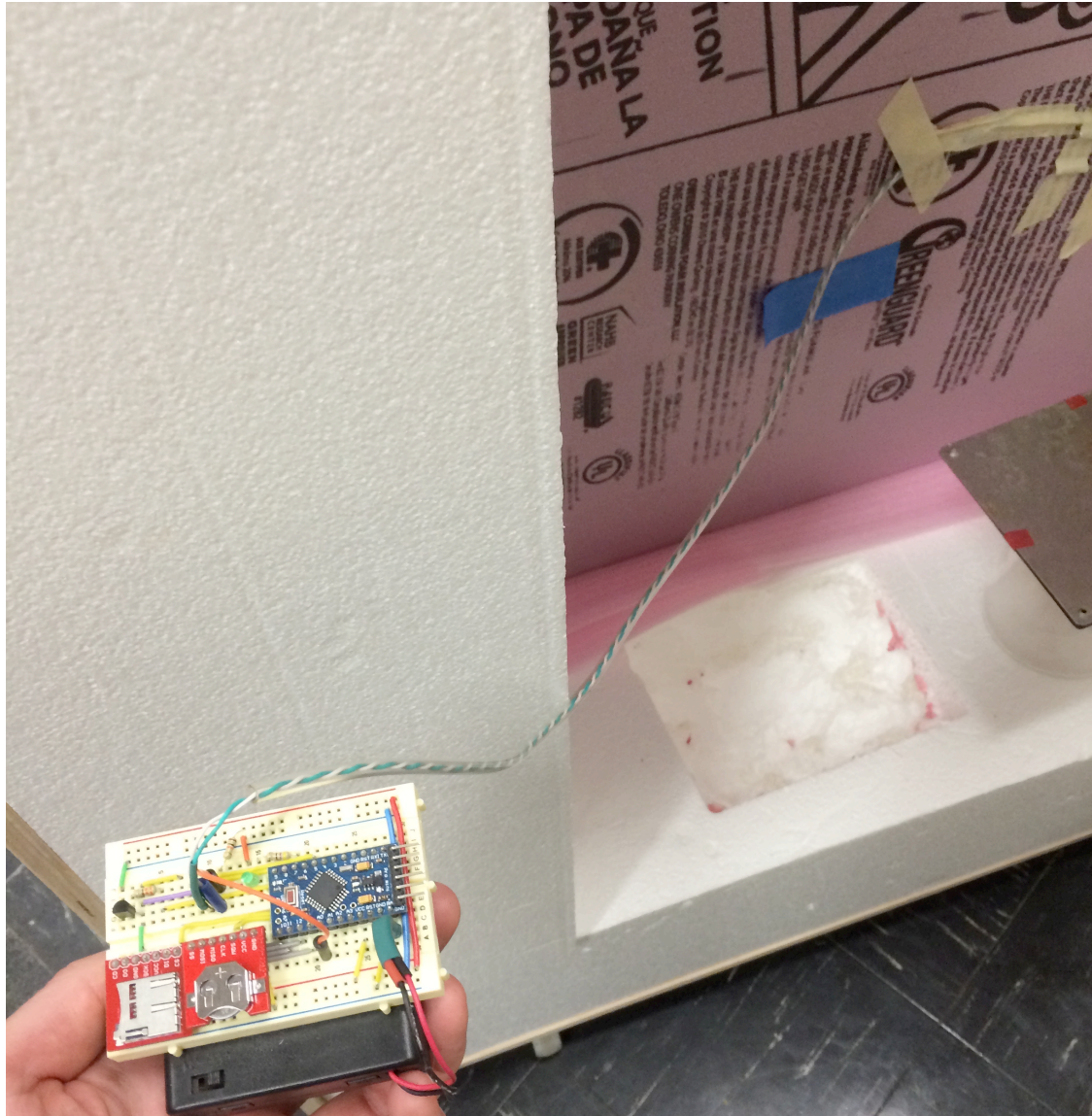
- Since Oct 2014
(Lithium ion batteries)



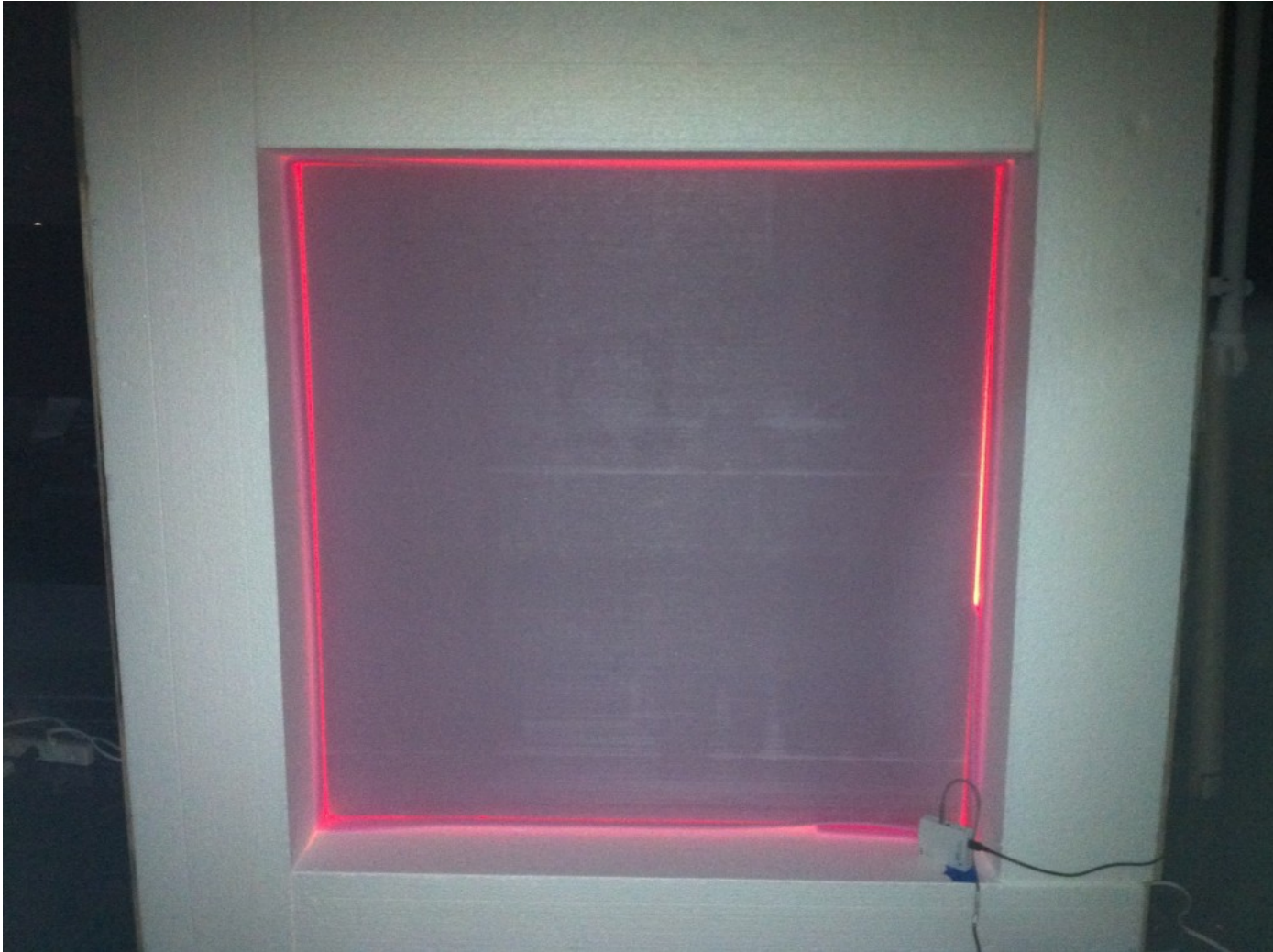
Surface temperature



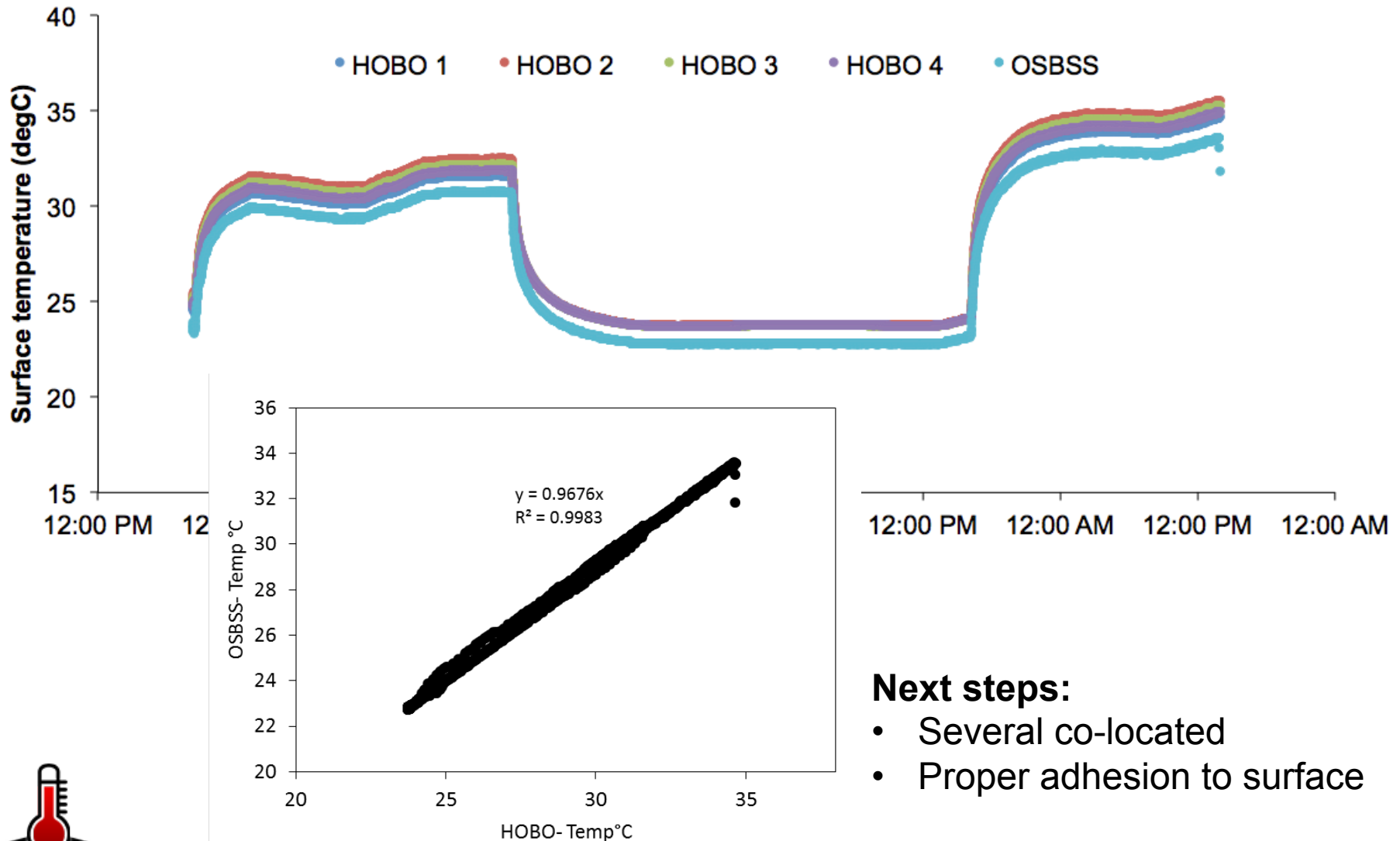
Surface temperature



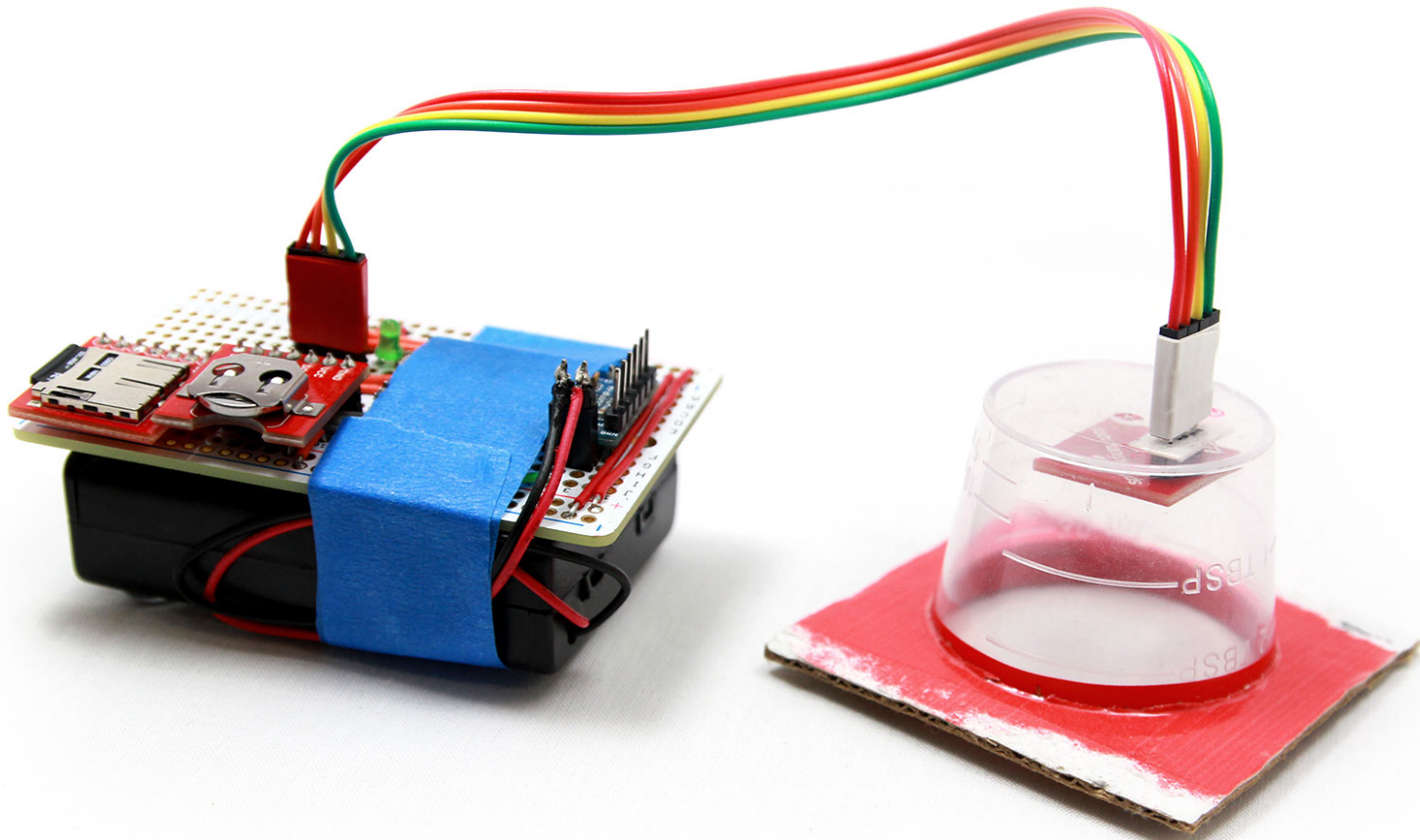
Surface temperature



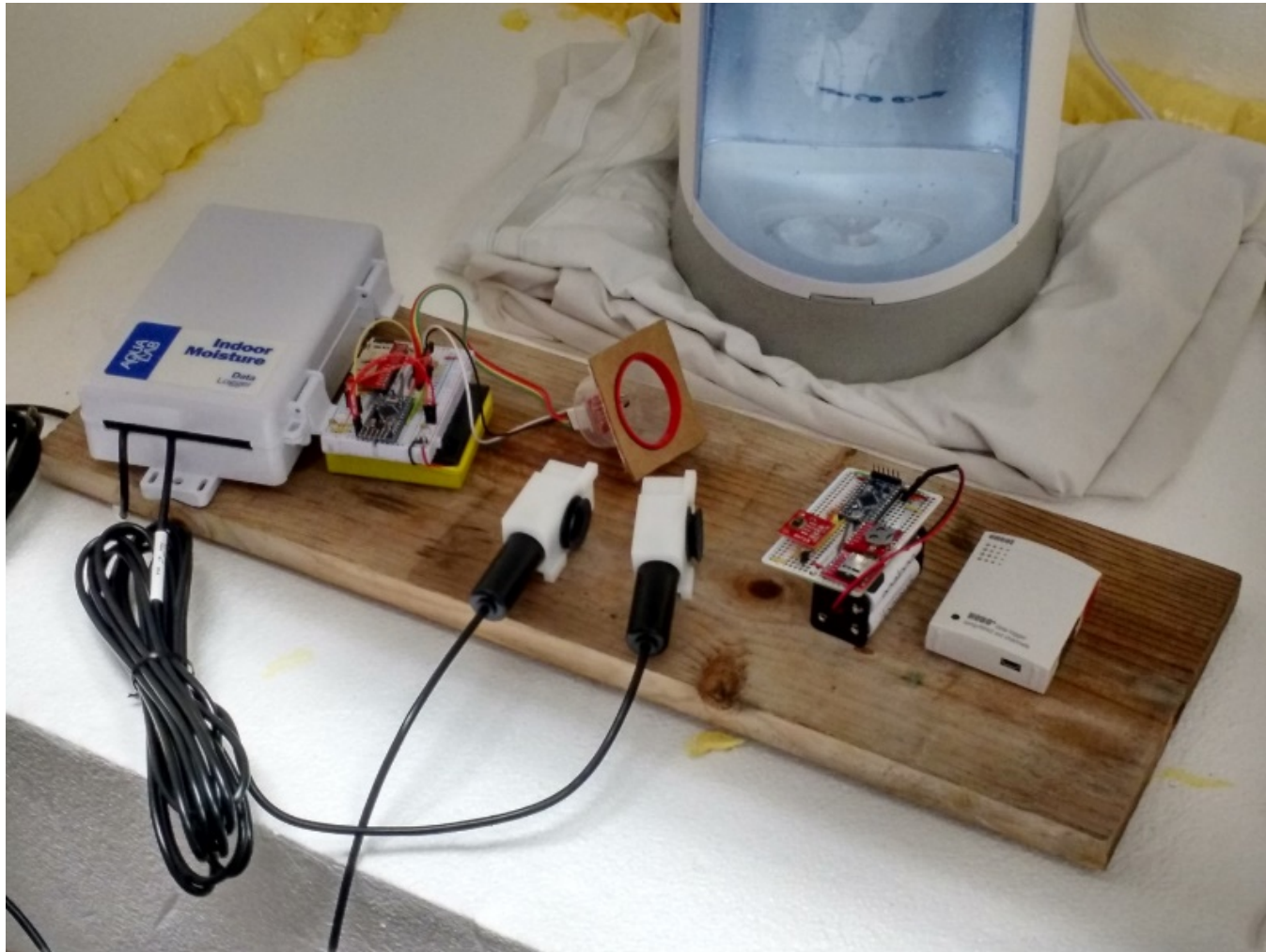
Surface temperature verification vs. HOBO



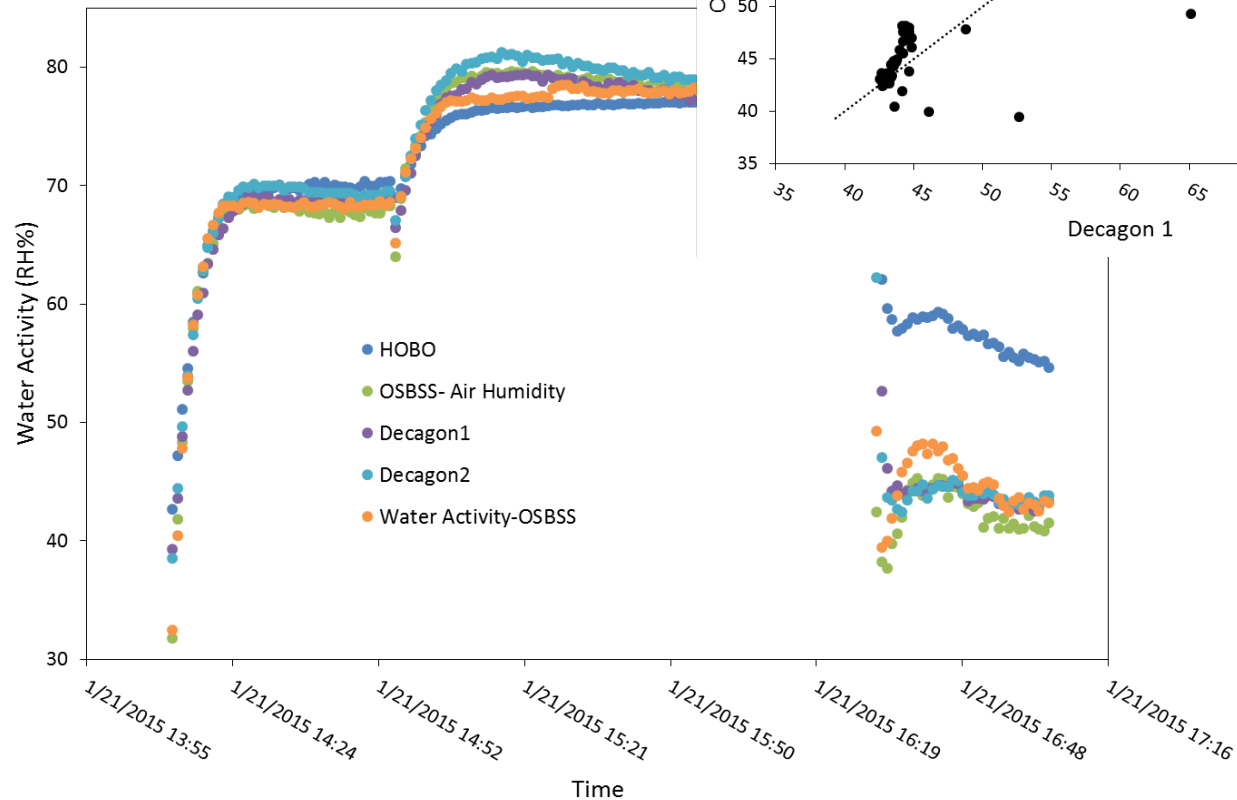
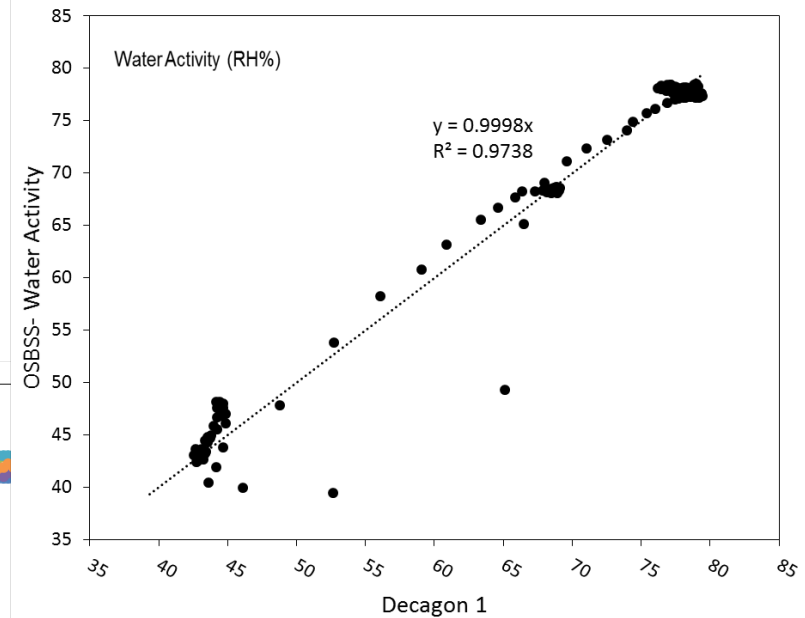
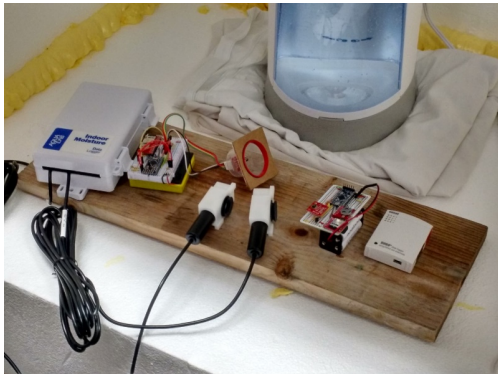
Equilibrium relative humidity (ERH)



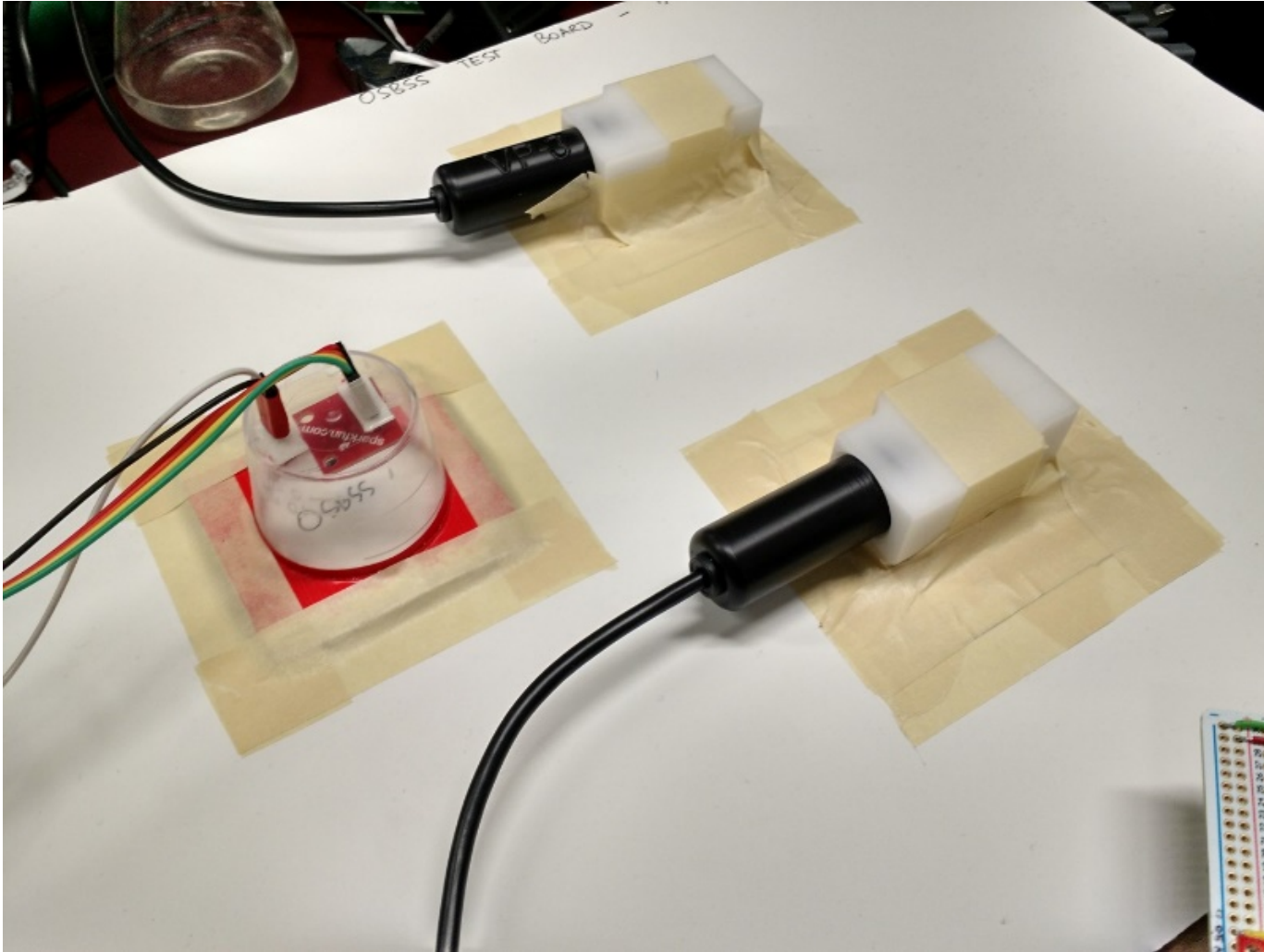
ERH: OSBSS verification vs. Decagon (open air)



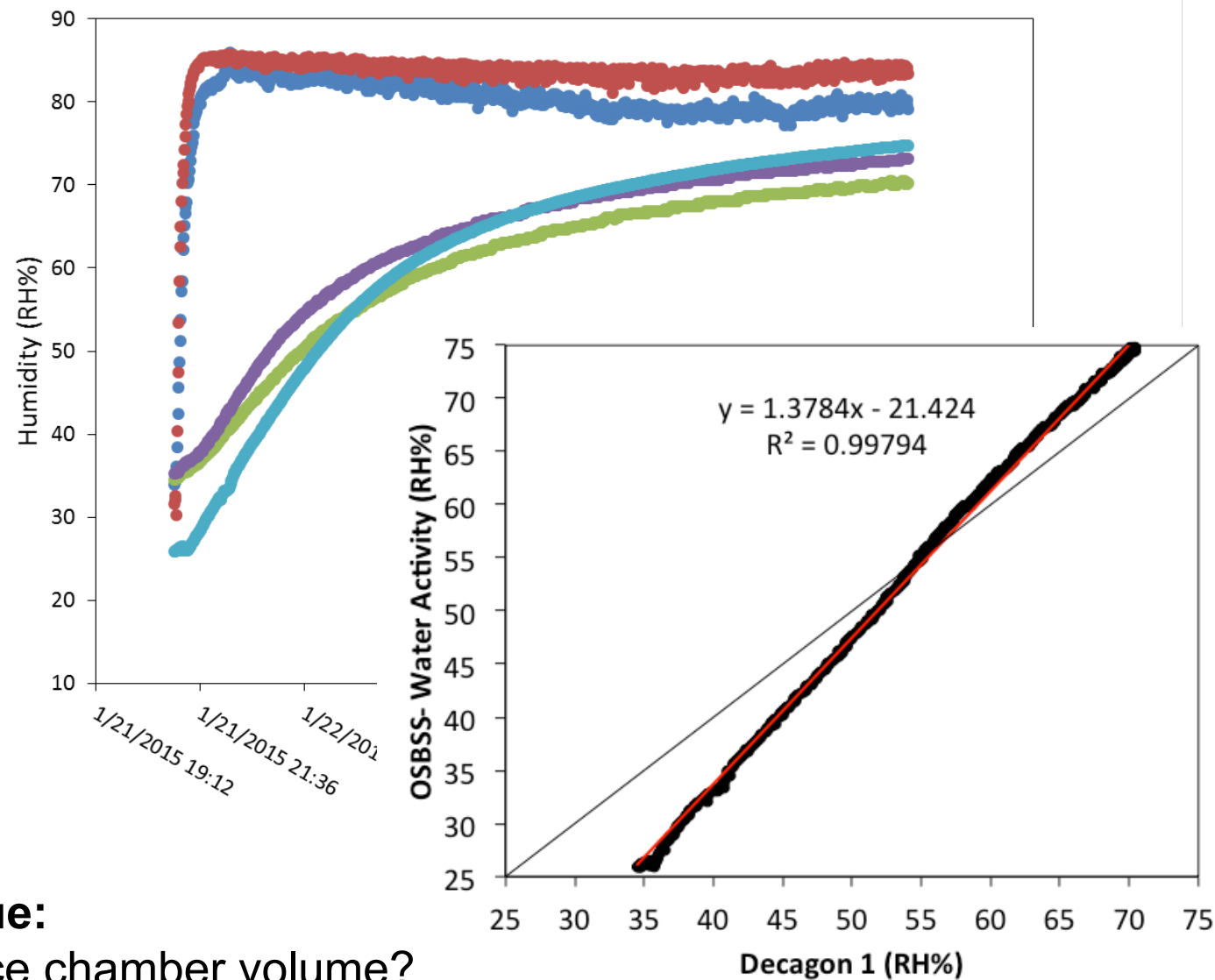
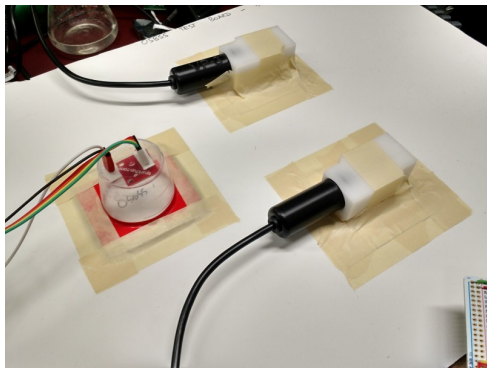
ERH: OSBSS verification vs. Decagon (open air)



ERH: OSBSS verification vs. Decagon (surface-attached)



ERH: OSBSS verification vs. Decagon (surface-attached)



Lag issue:

- Reduce chamber volume?

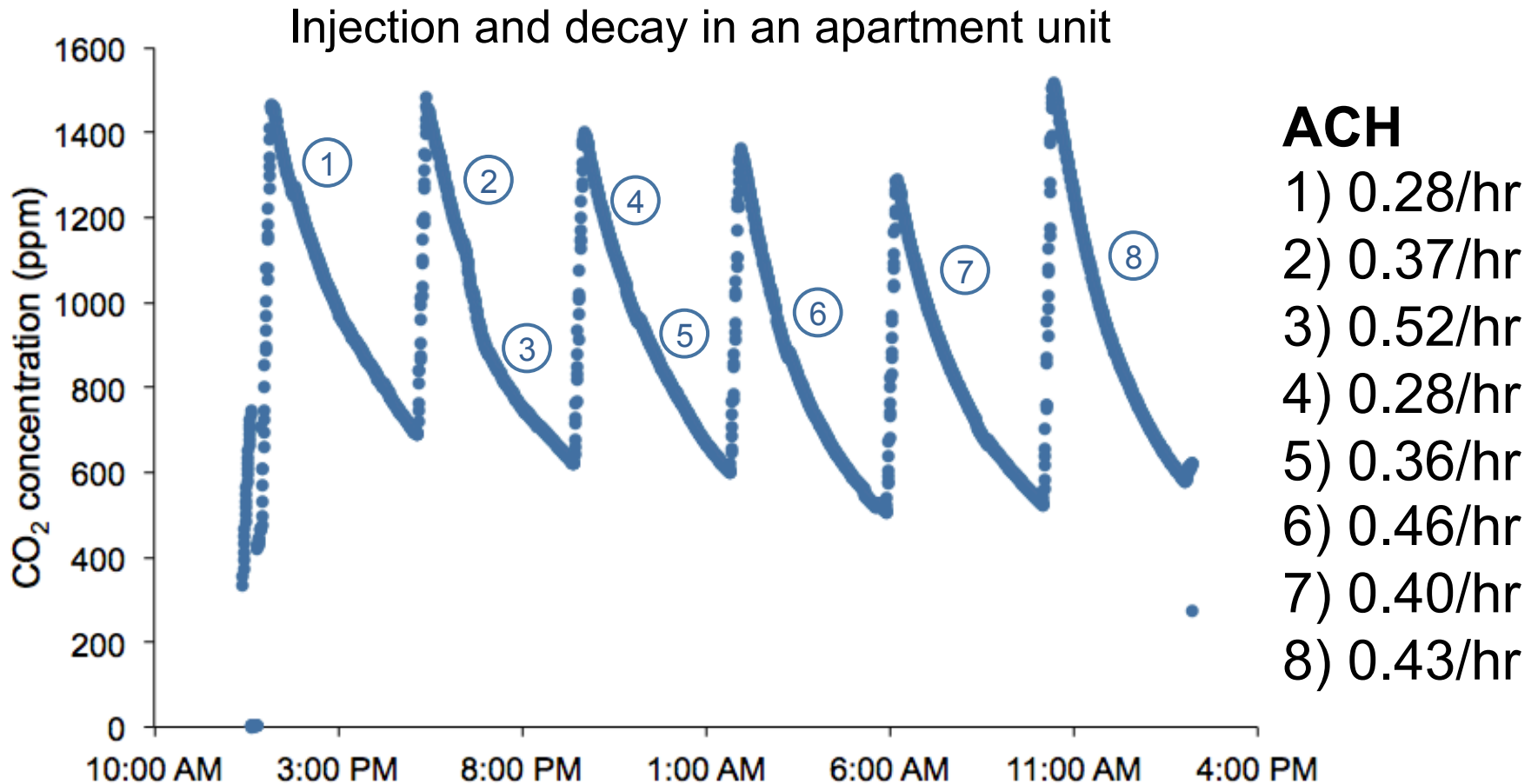
CO₂ injection and decay system

Sestos
timer

Grow
house
regulator



CO₂ injection and decay system demonstration



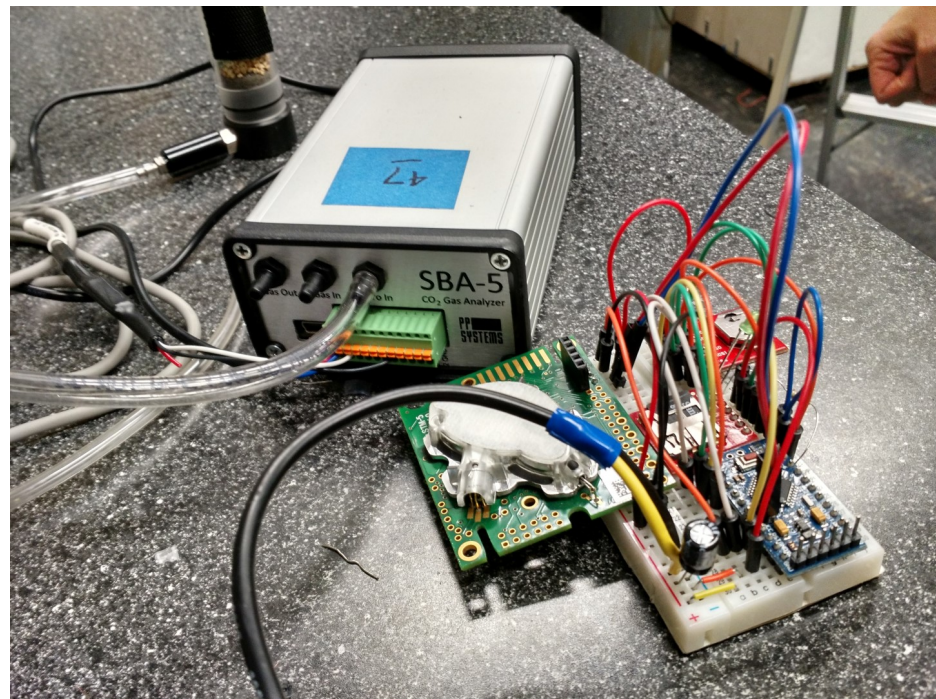
CO₂ measured w/ PP Systems SBA-5



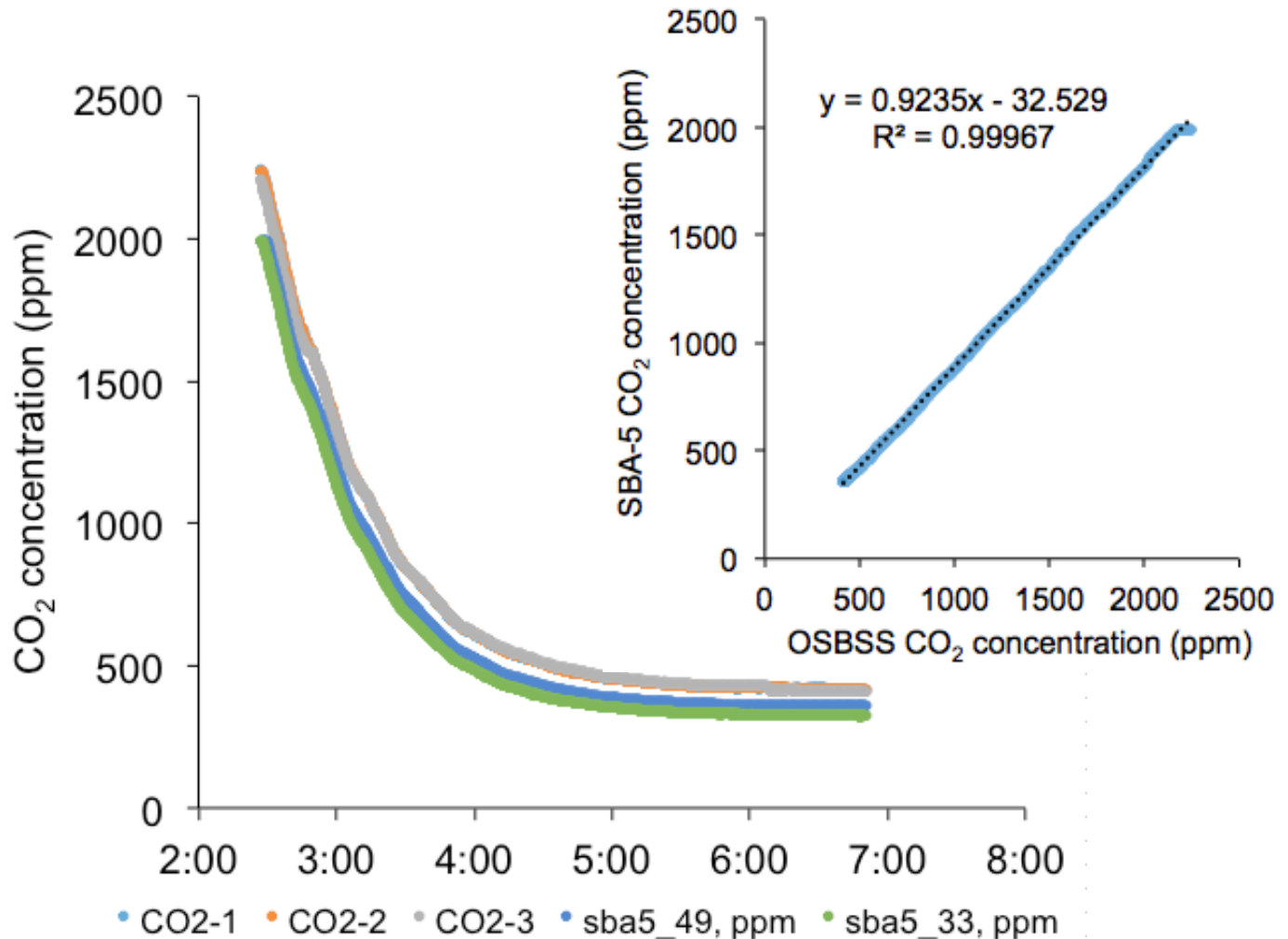
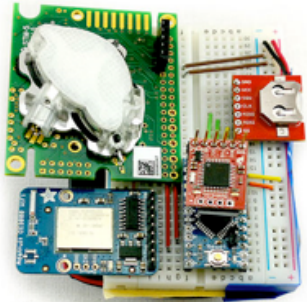
CO₂: OSBSS sensor/logger development



CO2meter.com - \$85



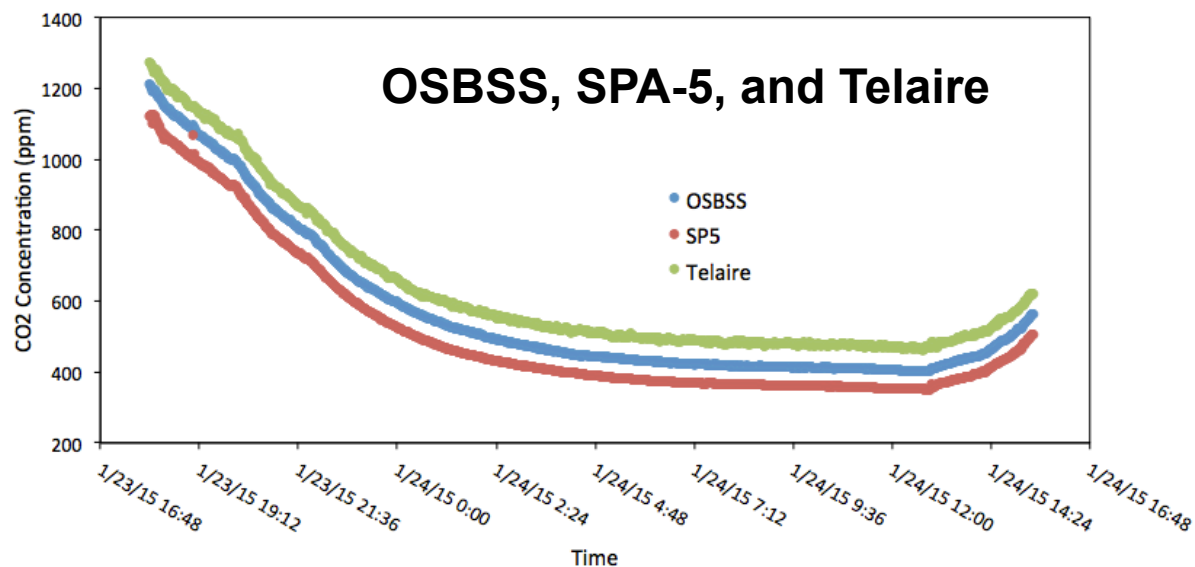
CO₂: OSBSS sensor/logger verification



Issues:

- Power draw relatively high (150-300 mA) at constant 5 VDC
- Periodic drops must be dealt with in code or post-processed

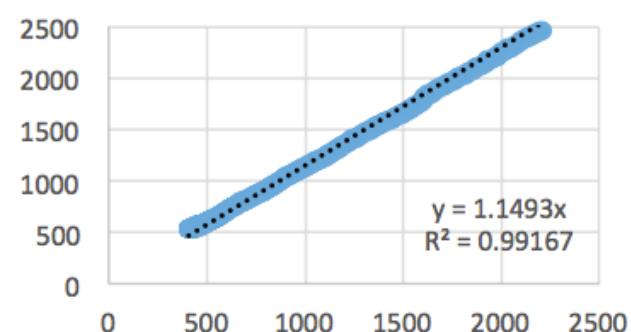
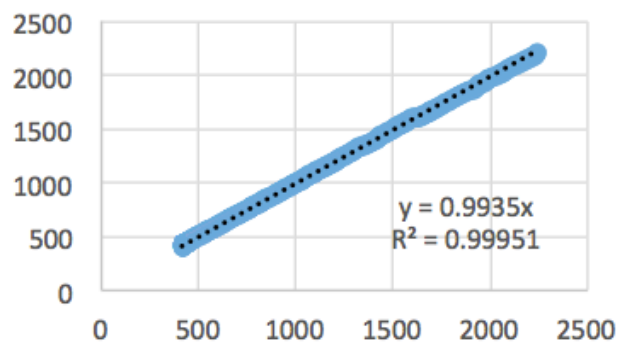
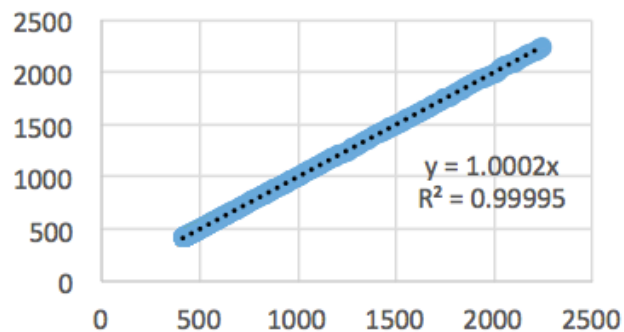
CO₂: OSBSS sensor/logger co-location



CO2-1 VS CO2-2

CO2-2 VS CO2-3

CO2-3 VS CO2-4

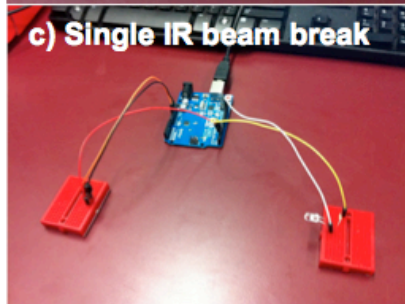
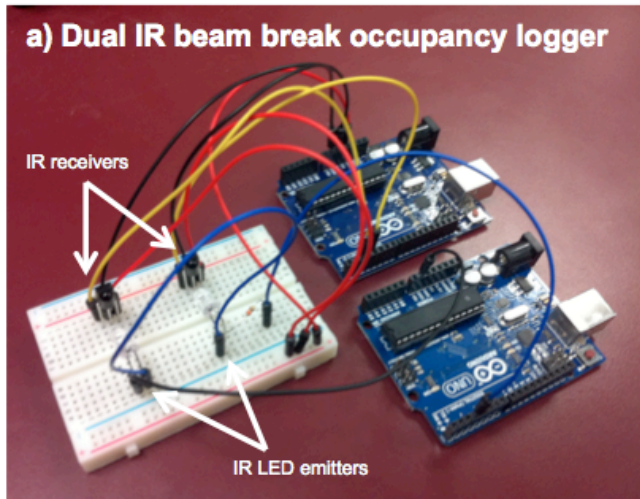


OSBSS vs. each other



Dual beam break occupancy

Prototype #1



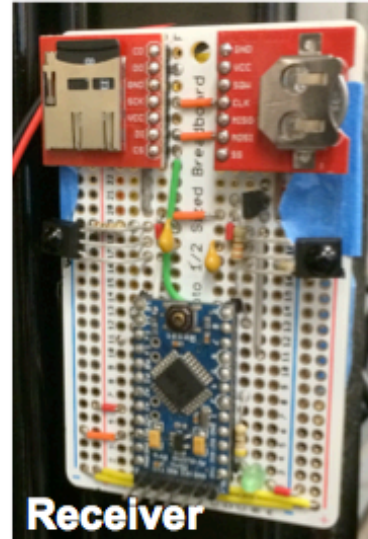
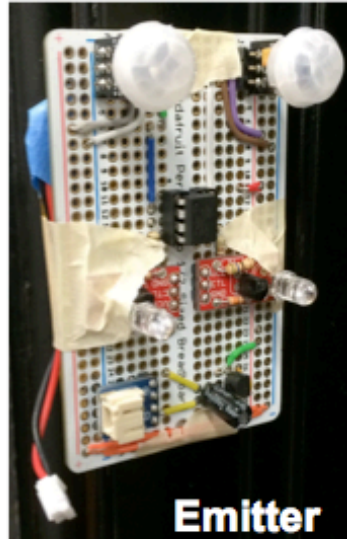
IR LED emitter & receiver - \$3

Prototype #2



Dual beam break occupancy

Prototype #3



Dual doorway beam break



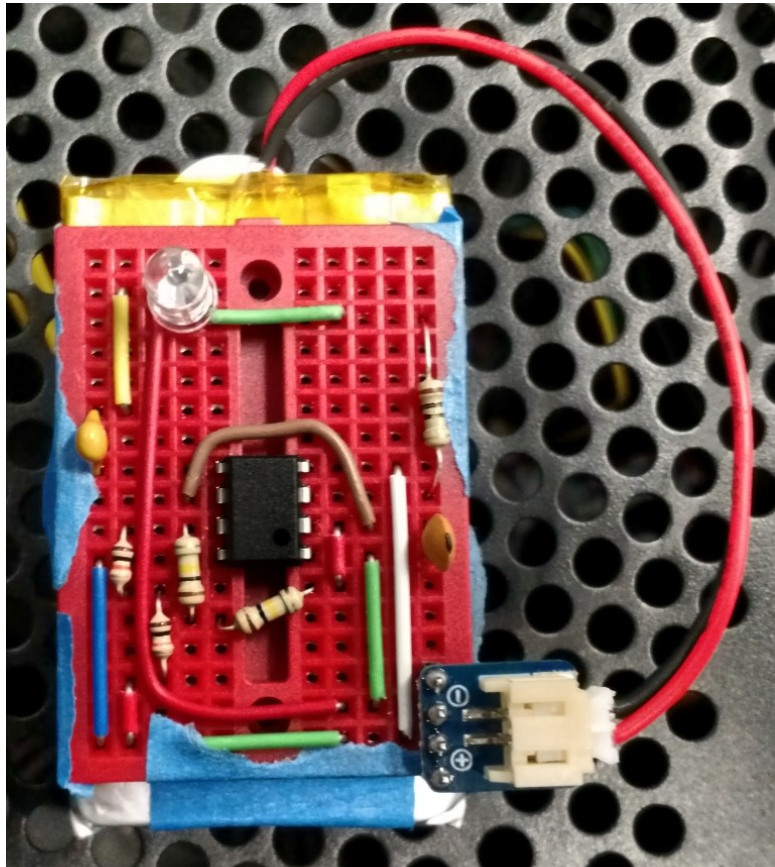
- Integrates passive IR to wake up
- Estimated battery life: 6-12 months



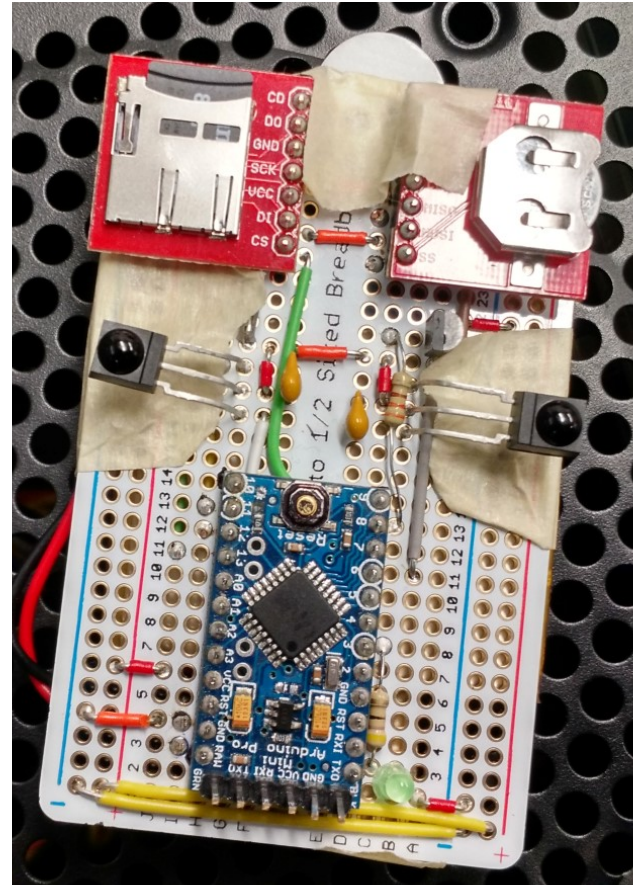
Dual beam break occupancy

Prototype #4

Estimated battery life: 1-2 months

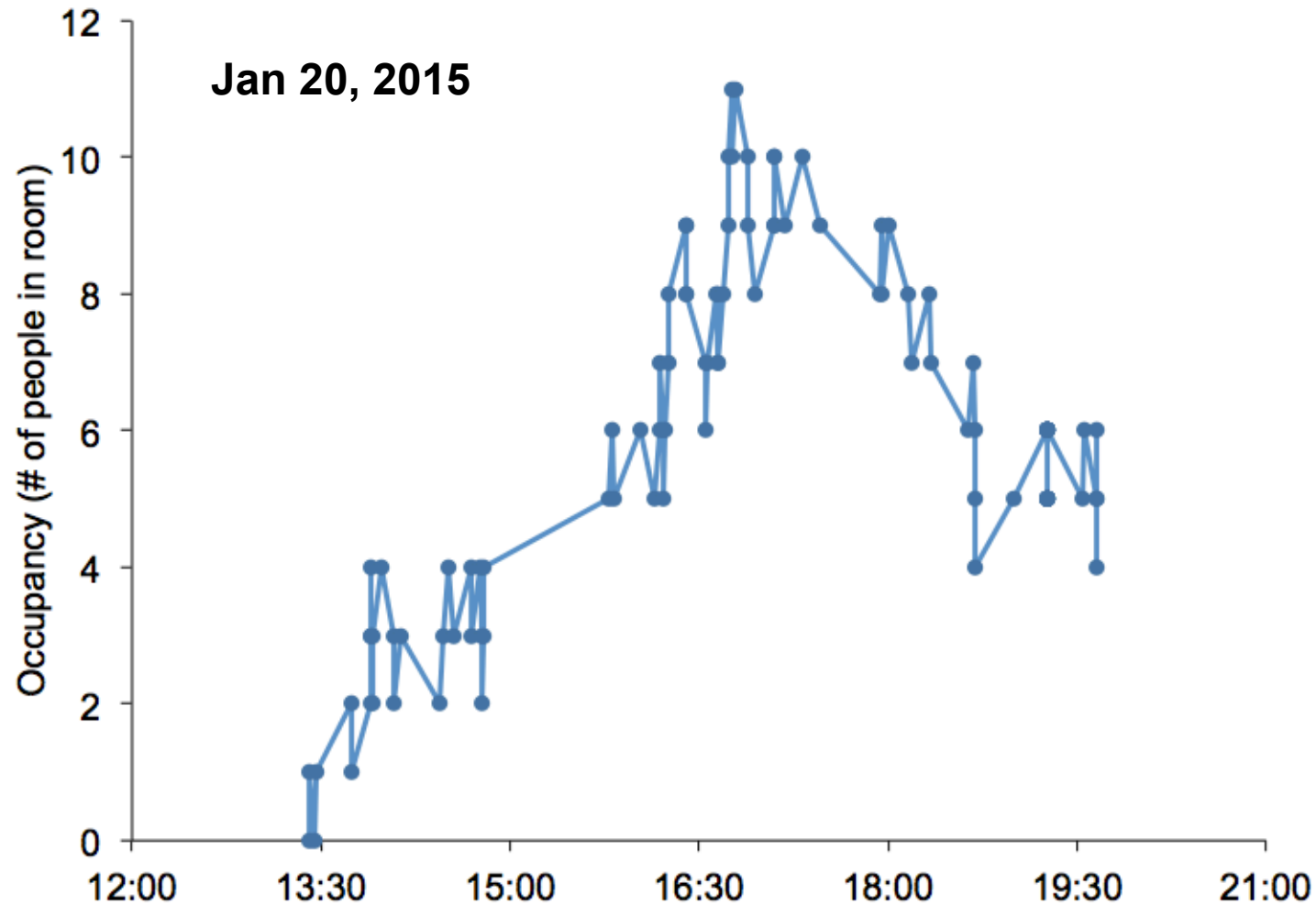


Emitter (555 timer IC)

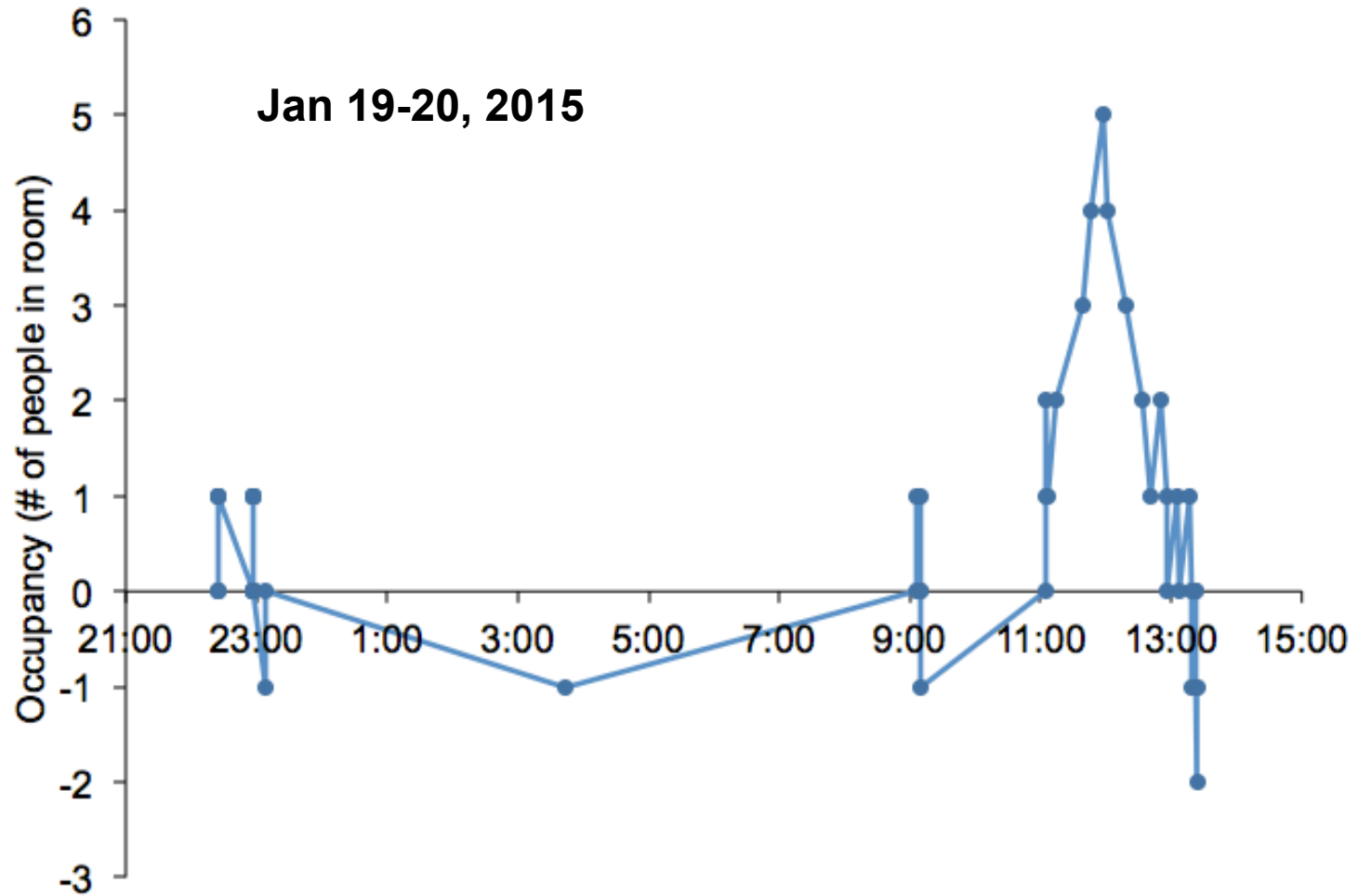


Receiver

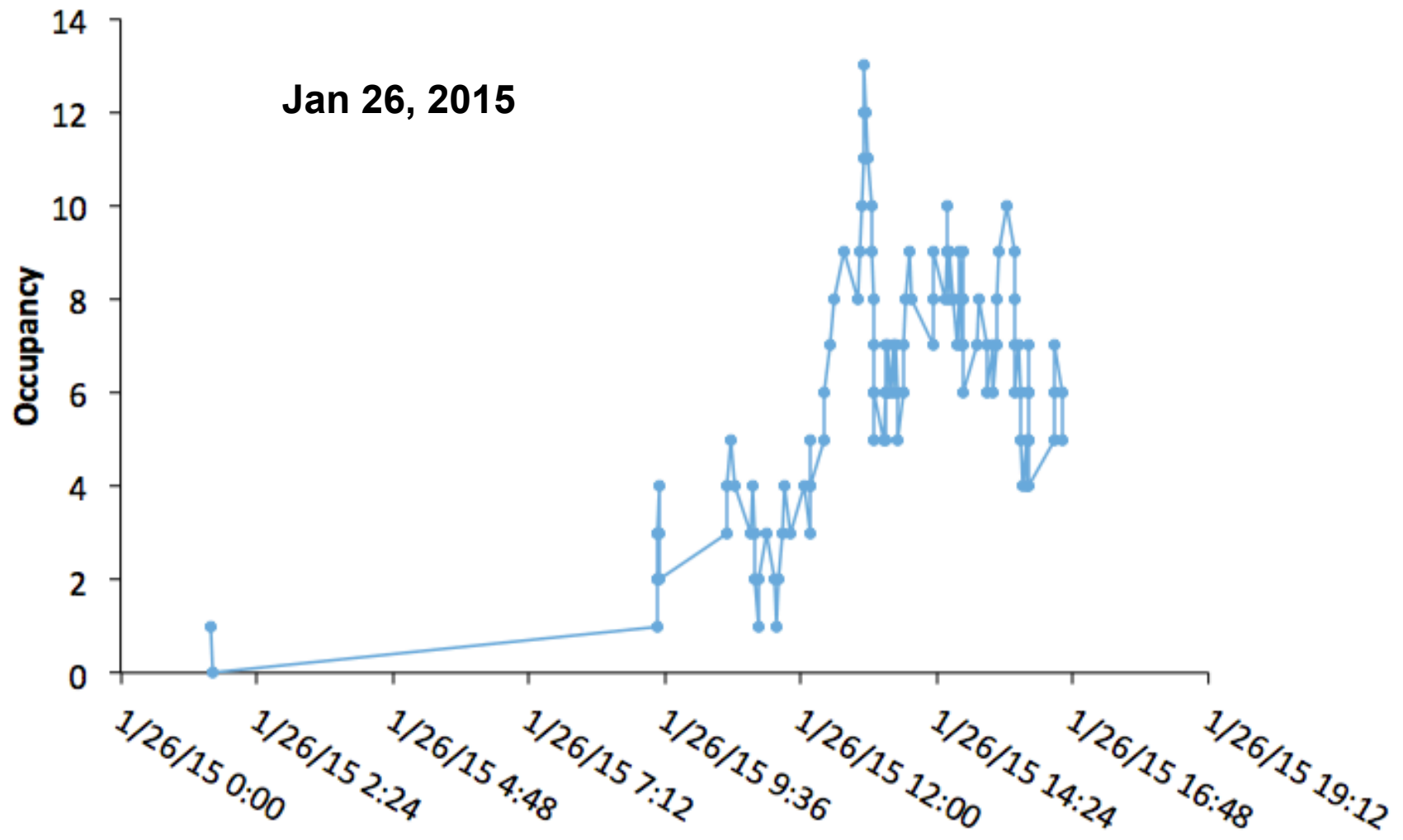
Data: Dual beam break occupancy counts (Prototype #3)



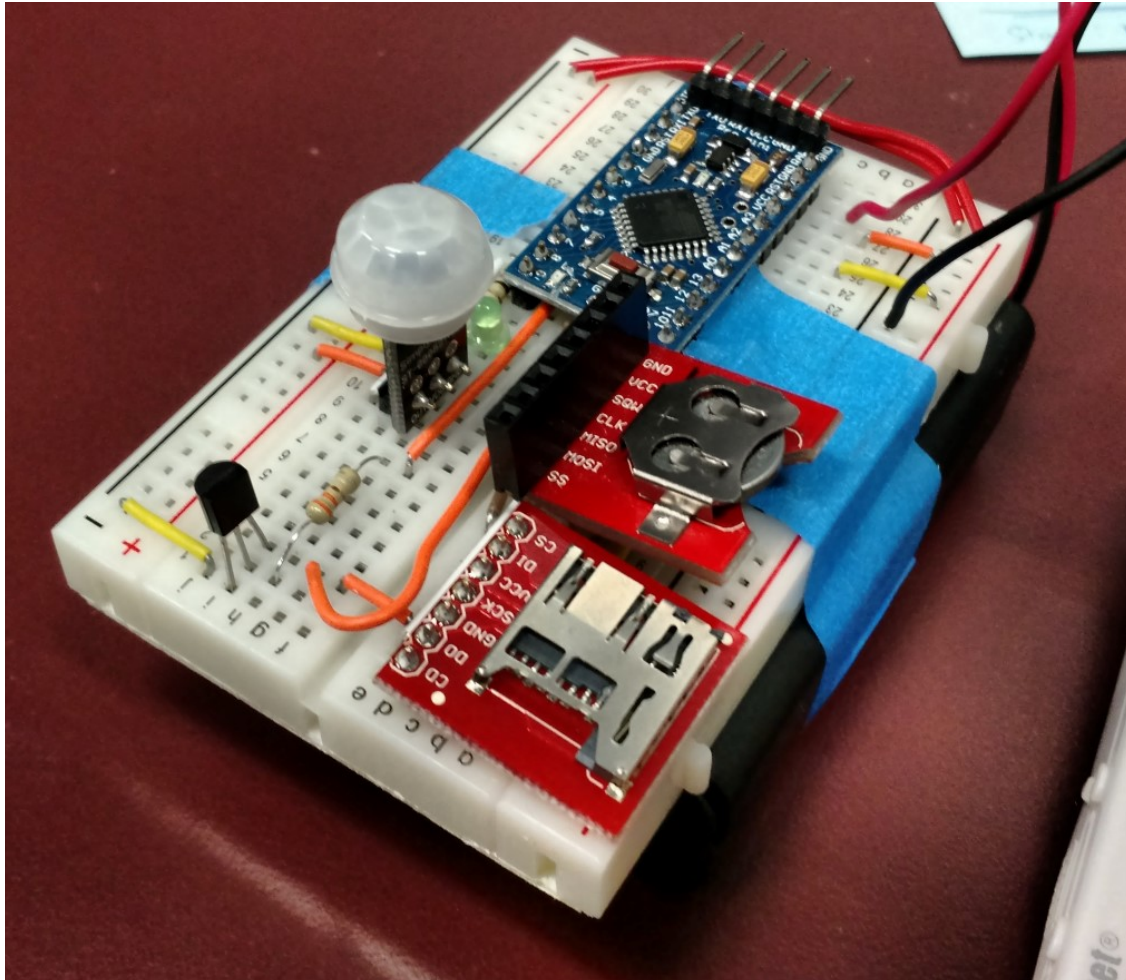
Data: Dual beam break occupancy counts (Prototype #3)



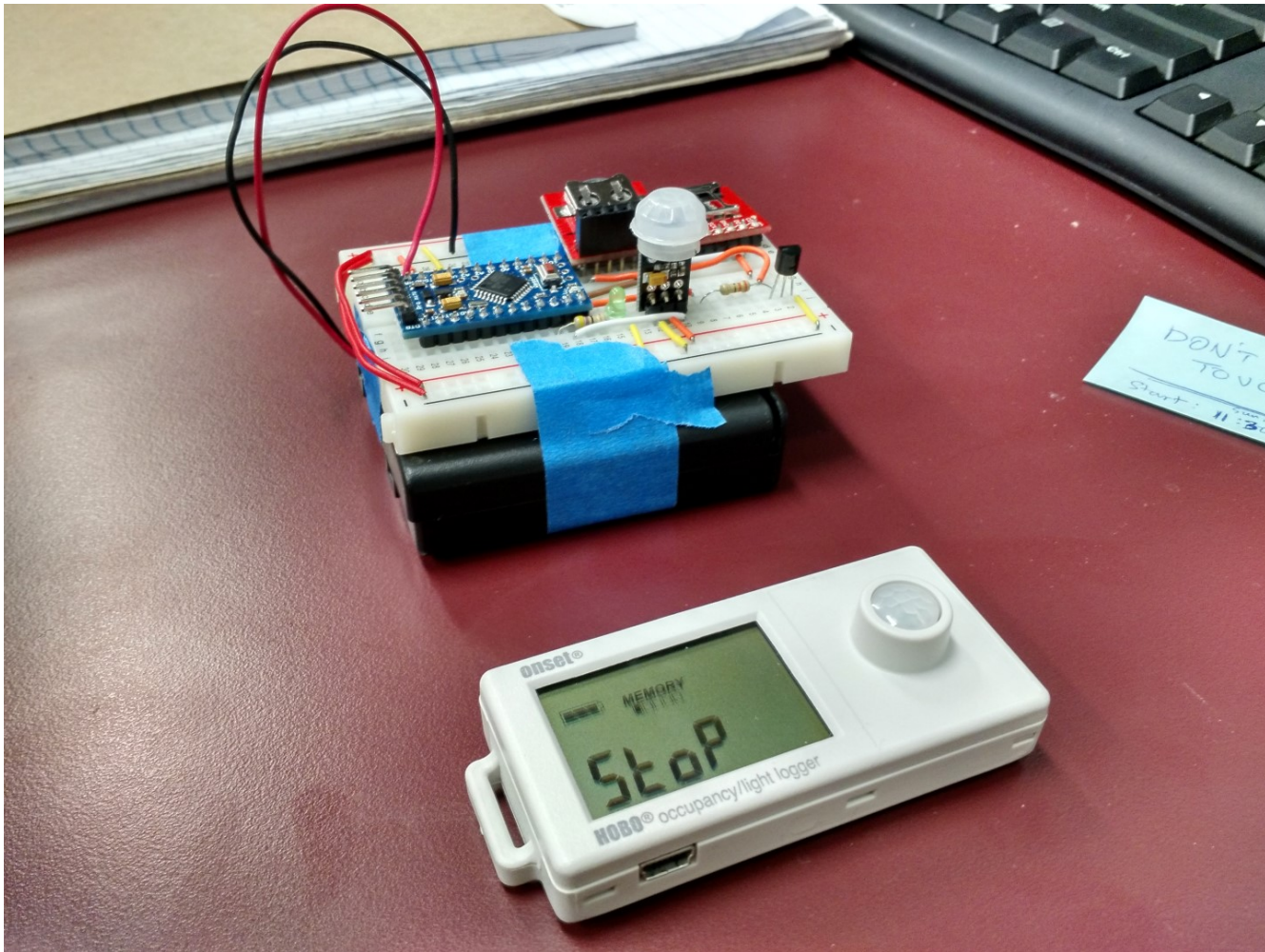
Data: Dual bream w/ 555 timer (Prototype #4)



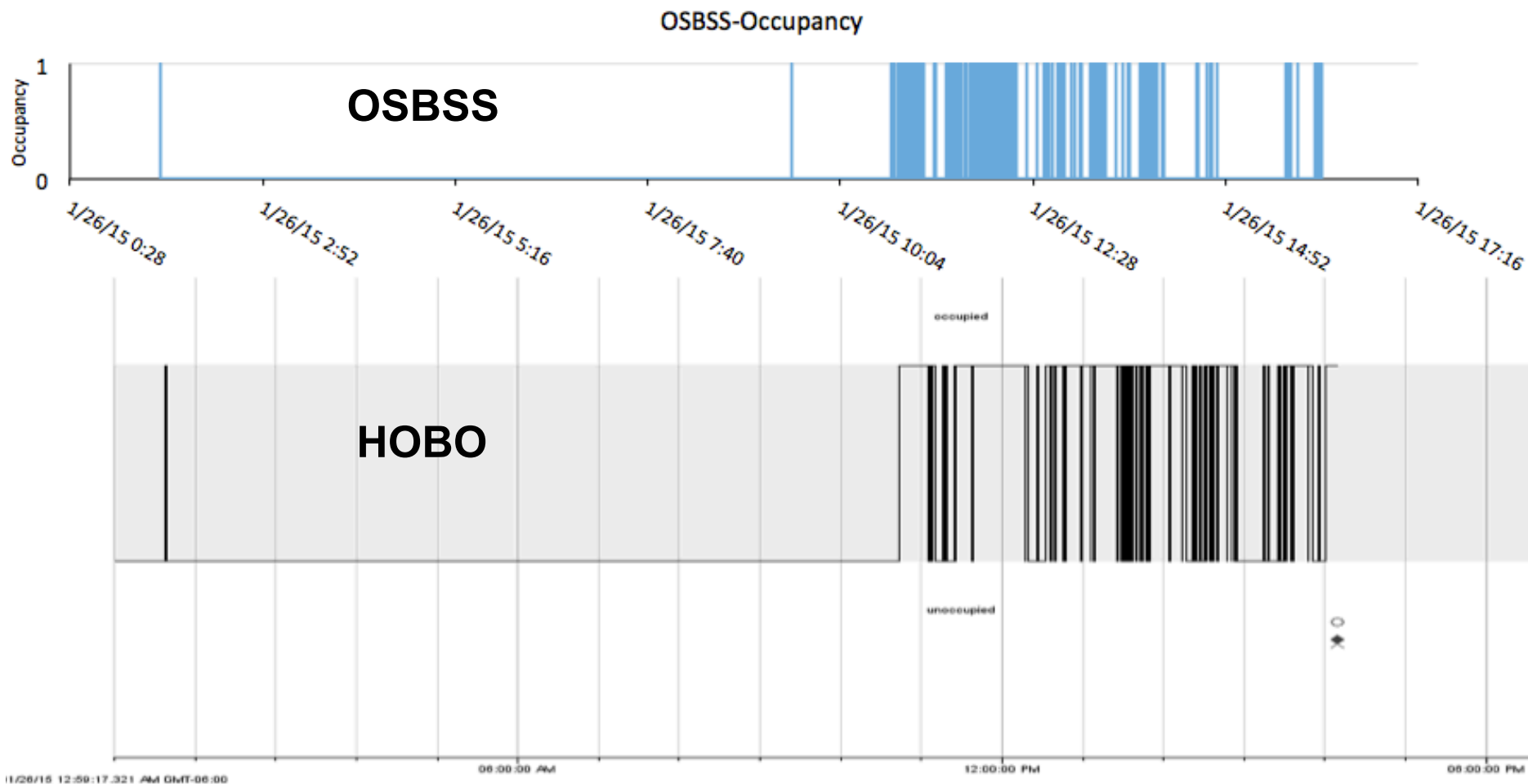
Proximity (IR)



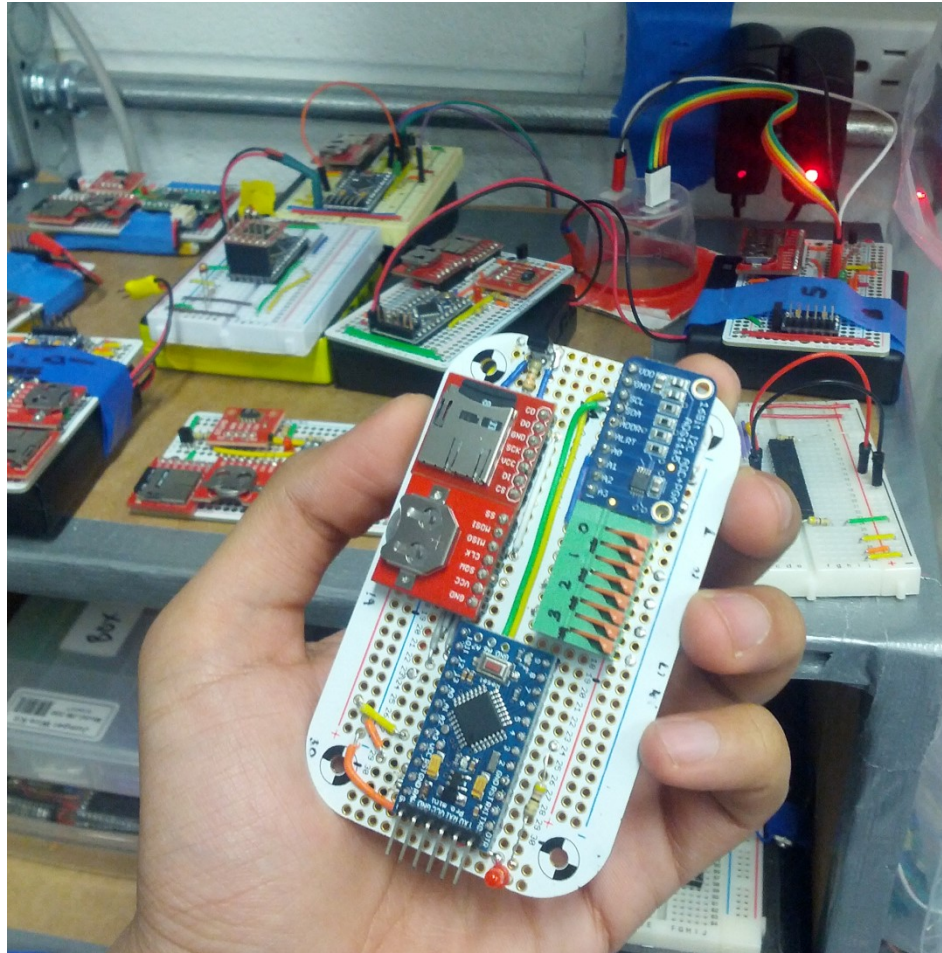
Proximity (IR): OSBSS vs. HOBO



Proximity data: OSBSS vs. HOBO



Generic voltage data logger

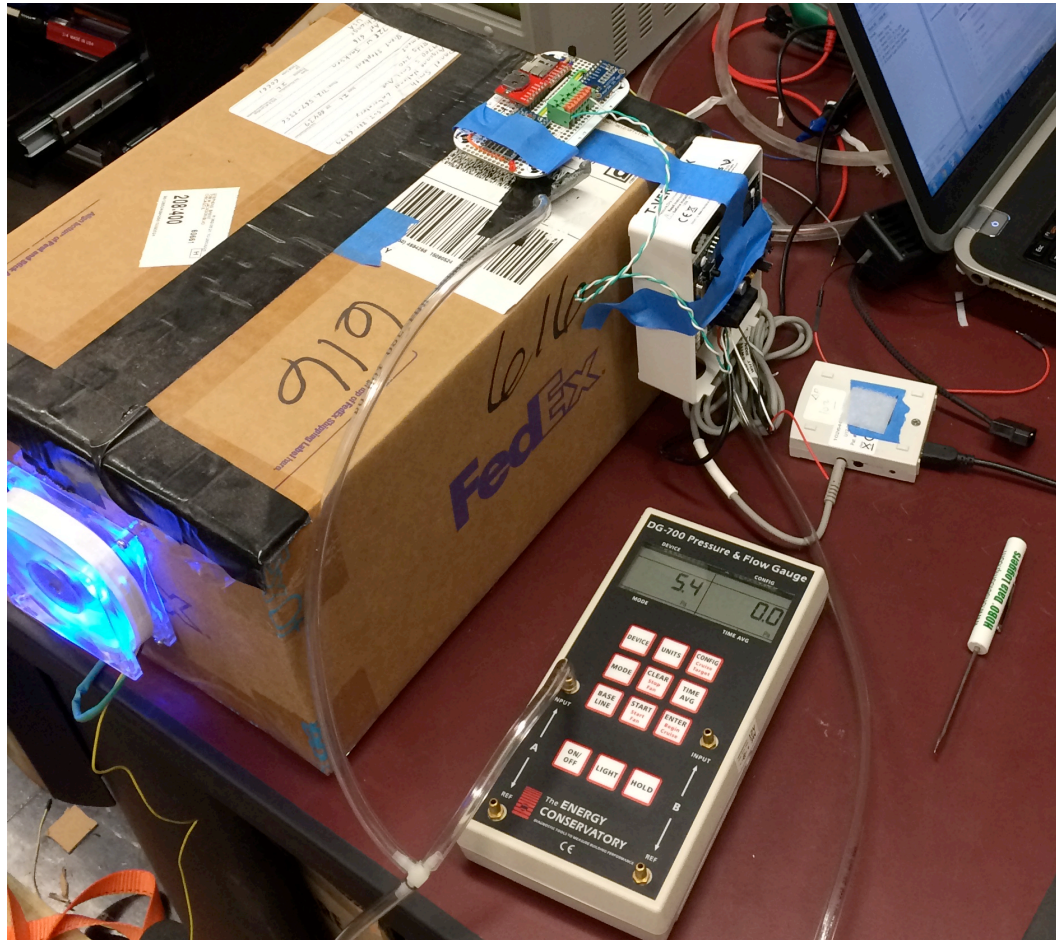


4 terminal blocks
for logging
voltage

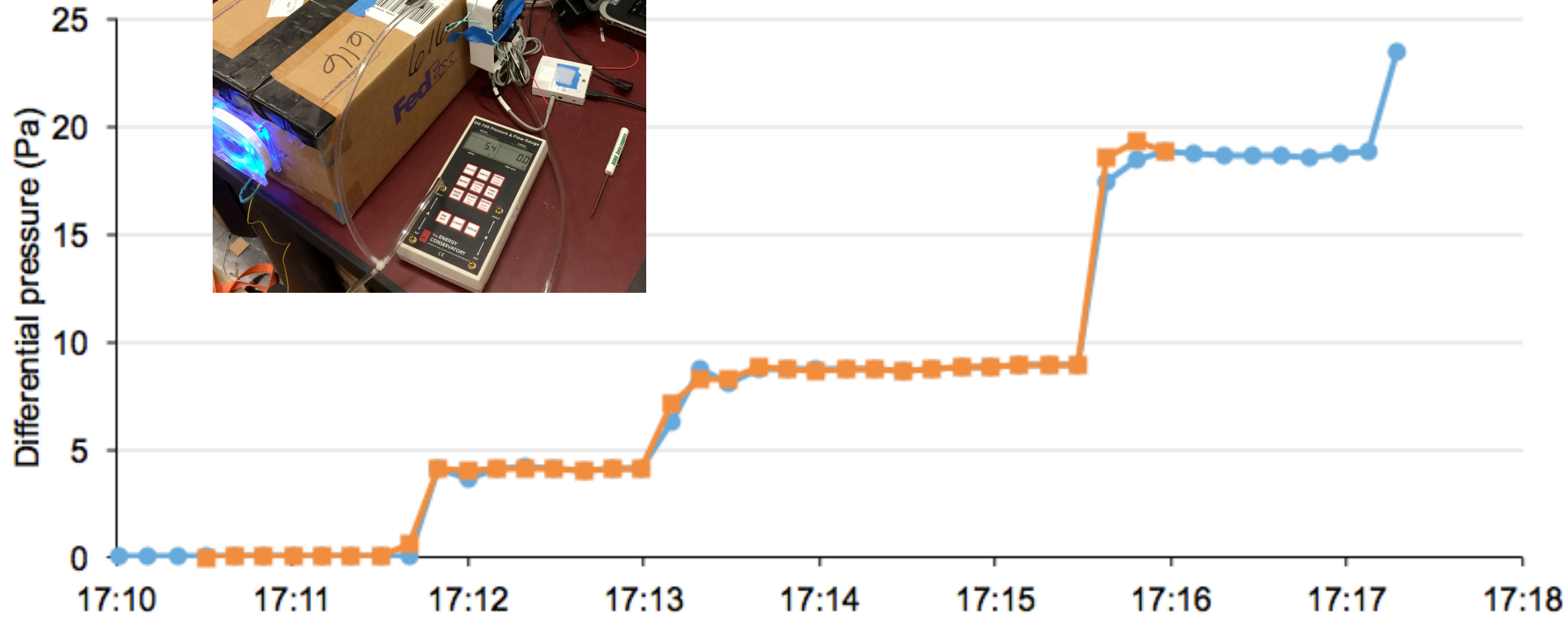
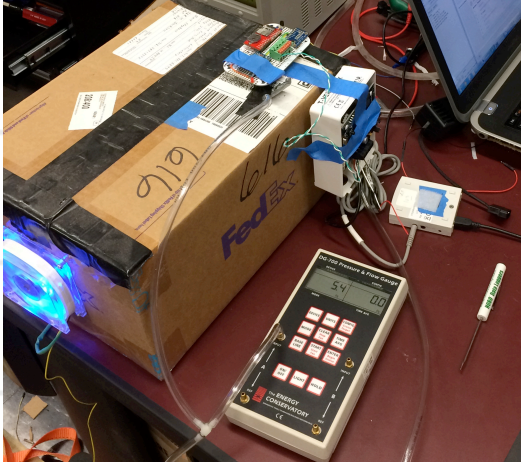
Max. 3.3VDC or
5 VDC



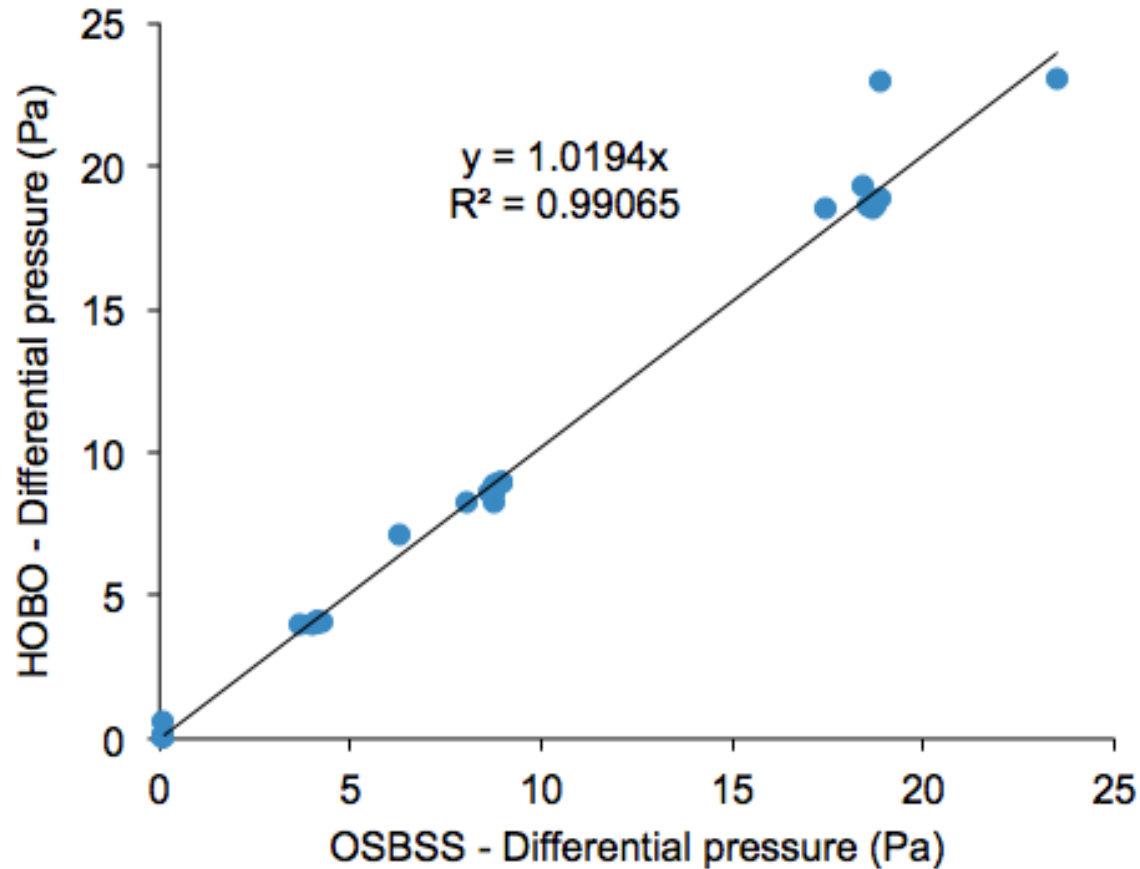
Generic data logger (pressure)



Generic data logger (pressure)



Generic data logger (pressure)



Next steps and other items

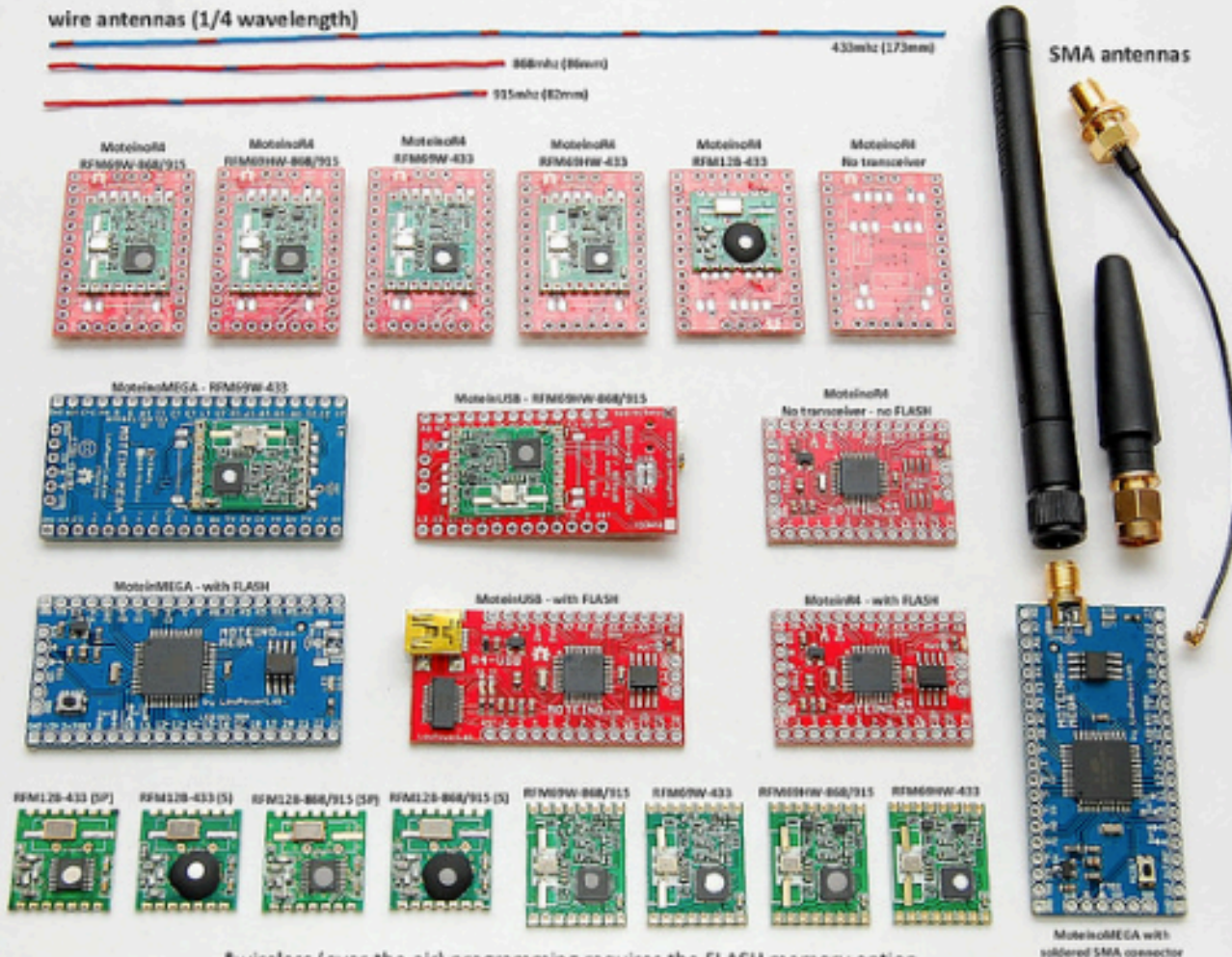
- Advisory board feedback (now and ongoing)
- Wireless
- Stability/accuracy/drift testing
- Enclosures
- PCBs
- Demonstration of applications
- Additional sensors
- Publications

WIRELESS

Wireless progress

LowPowerLab Moetino: low cost, low power, open source, wireless Arduino clone

Moteino variants & options



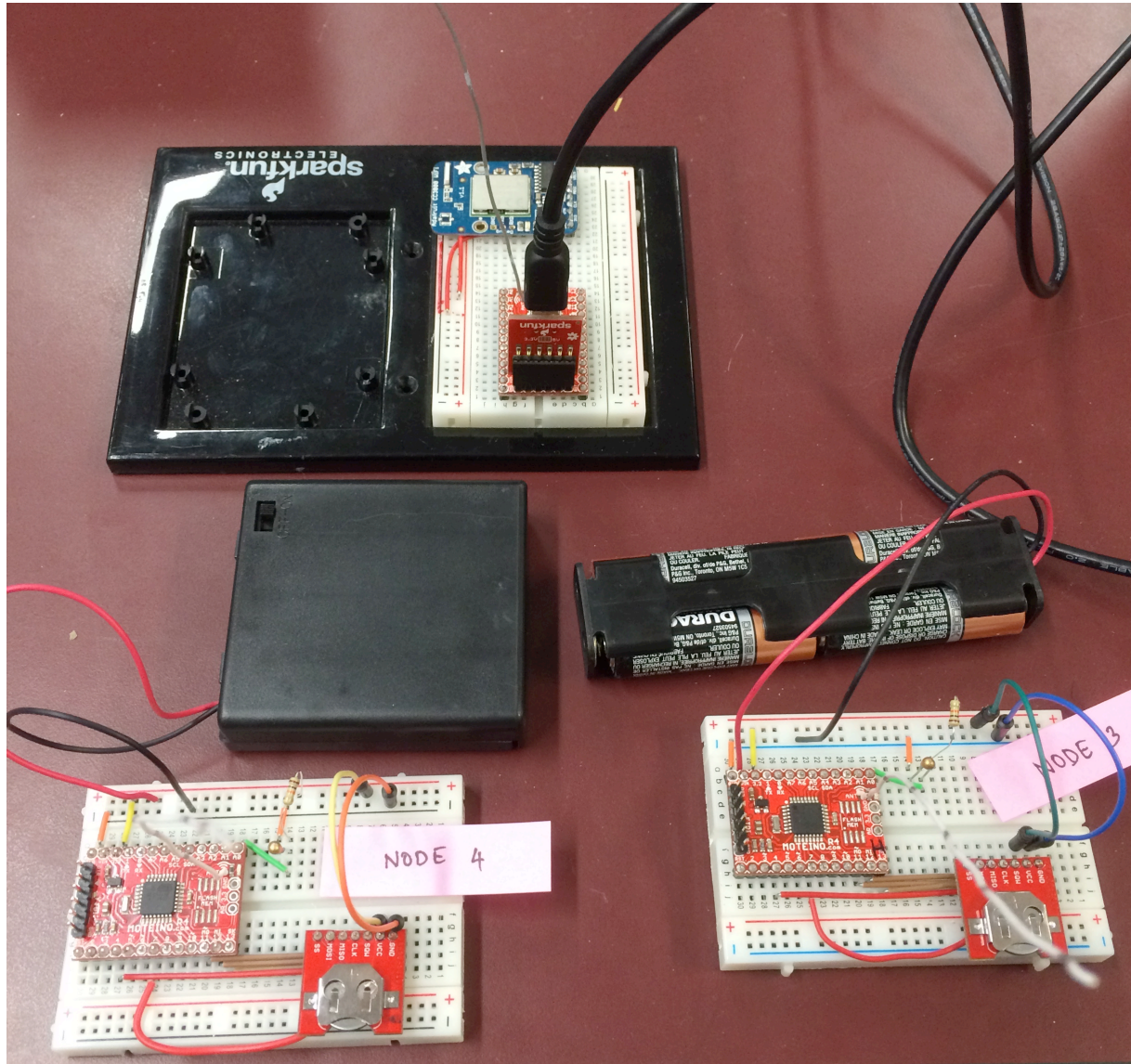
*wireless (over-the-air) programming requires the FLASH memory option



RFM69

Hoperf
RFM69 ISM
Transceiver
Module
433 MHz radio

Wireless temperature demonstration



ENCLOSURES

Custom enclosures

- Un-enclosed (mostly thus far)
- Plastic project boxes (ebay)
- Acrylic (thermal mass issues)
- 3D printed (shapeways)
- Altoids tin

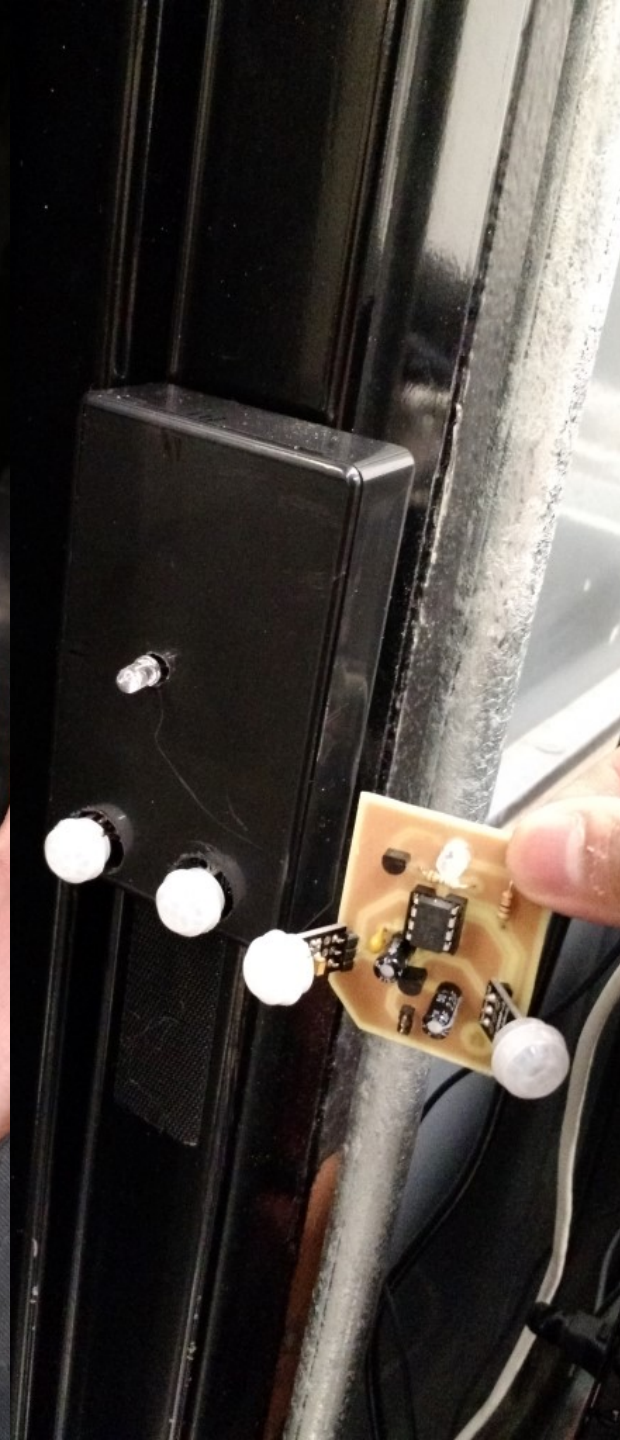
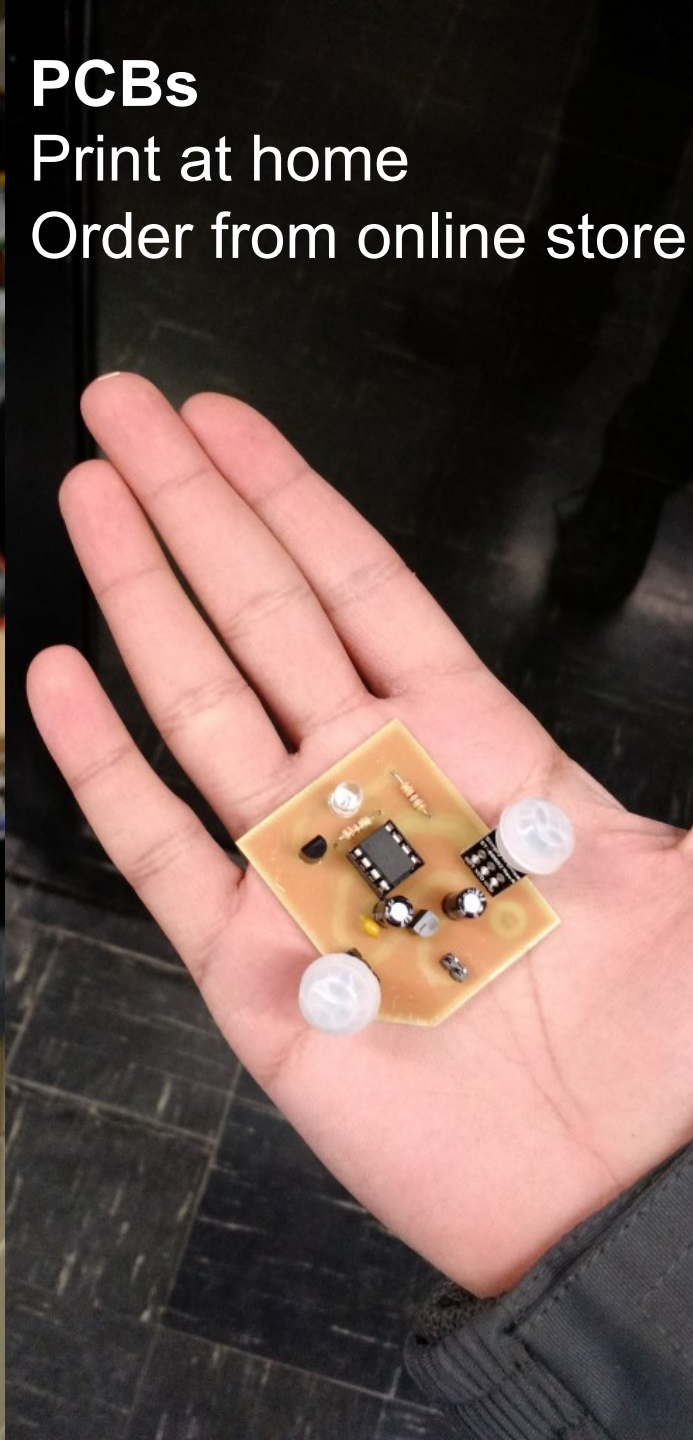
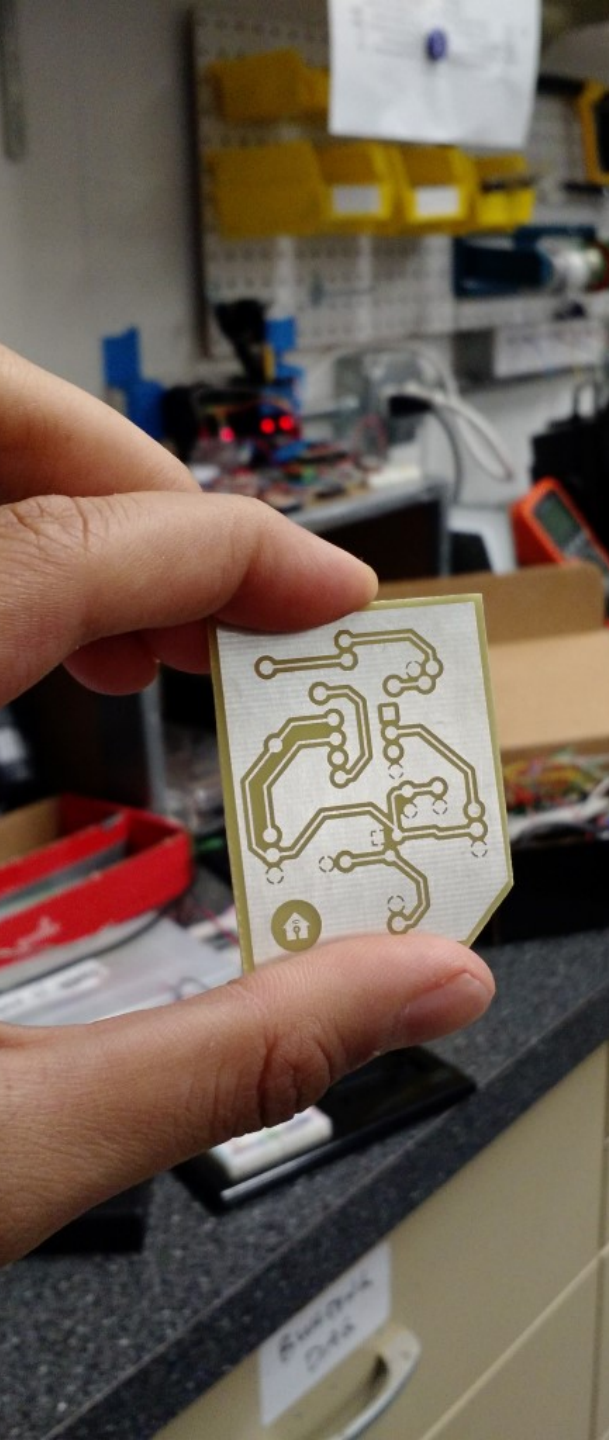


PCB VERSIONS

PCBs

Print at home

Order from online store



DEMONSTRATION OF APPLICATIONS

Demonstration of applications

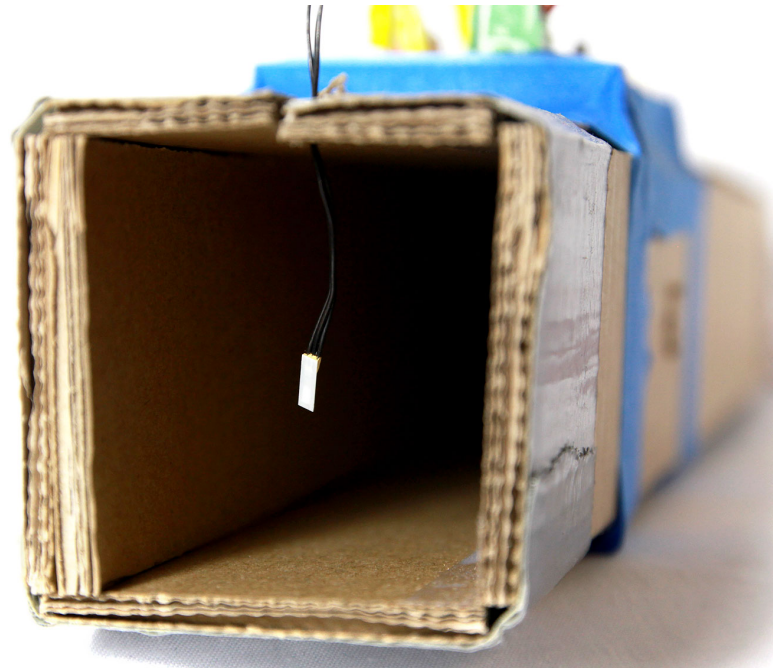
- On campus / in lab (ongoing)
- Integration into our ongoing and future projects
- Classroom
 - e.g., Drexel IAQ class in March 2015 (Waring)
- Integration into other ongoing Sloan projects
 - And others

FUTURE SENSORS

Future sensors

- Air speed
- Window opening
 - Binary
 - Linear
- Illuminance
- Solar radiation
- Power draw/energy logger
- Comfort station
 - MRT + velocity + T/RH + occupancy
- IAQ
 - PM via “dust” sensor
 - TVOC
 - Other electrochemical or metal oxide gas detectors

Air velocity (mass)



Publication plan

- Aiming for 1 publication on OSBSS development and verification
 - Targets: *Sensors*, *PLoS ONE*, *Building and Environment*
- Code on github: <http://github.com/osbss>

Ongoing issues and needs

- Some SD card failures
 - We think this is largely static discharge issues in handling

Back to questions for the board

1. How is this helpful to your respective communities?
2. Do you have suggestions for improvements?
 - Types of measurements
 - Usability of the platform
3. What would you imagine the next phase(s) of this project to look like?
4. Is the example tutorial missing any important information or steps?
 - What kind of tutorial would you be most likely to use?
 - e.g., PDF/HTML