THE UNIVERSITY OF UTAH

SPAN
Sensing and Processing Across Networks

Smart Home Air Filtering System: A Randomized Controlled Trial for Performance Evaluation

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Colleges of Engineering, Nursing, and Medicine

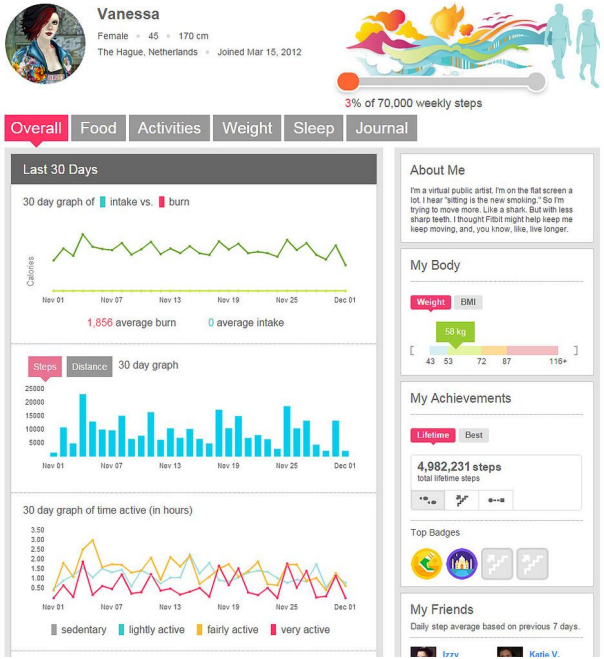
Humans are Natural Scientists

We collect lots of data and build a model of ourselves in the world

https://en.wikipedia.org/wiki/Experiment

E.g. Personal Fitness, Sleep Sensors

Fitbits, tracking apps demonstrate a want to self-observe



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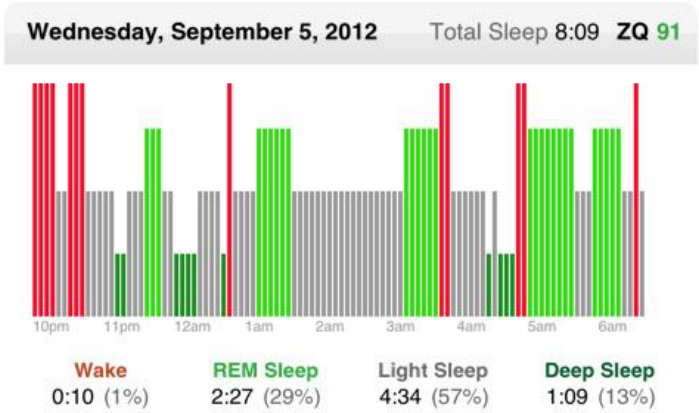
"How do we know whether these systems are better?"

-- Wendy Nilsen

(But what should we do with all this data?)



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Goal: Answer questions about how to live

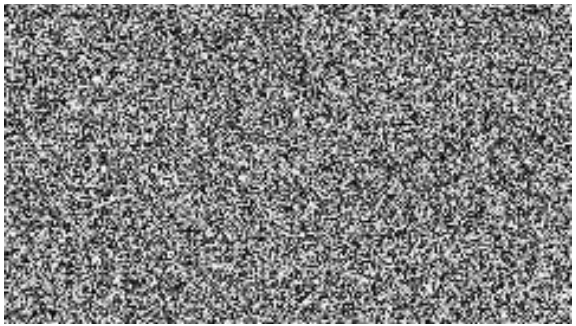
Does waking to smart lighting improve my morning mood?

https://www2.meethue.com/en-us/light-your-home-smarter/early-bird-light

sensor: survey, mood sensors

actuator: smart lighting algorithm

Does white noise help me fall asleep faster?

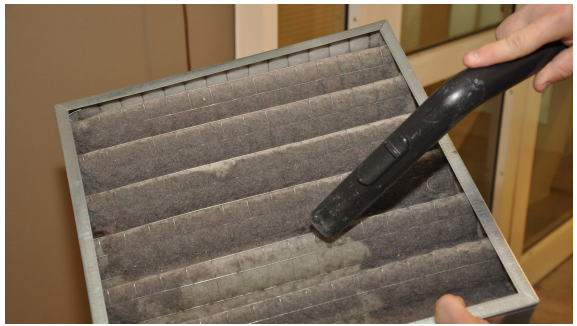


https://en.wikipedia.org/wiki/White_noise

sensor: sleep sensor data

actuator: smart speaker track, volume

How well does smart air filtering system reduce my indoor air pollution?

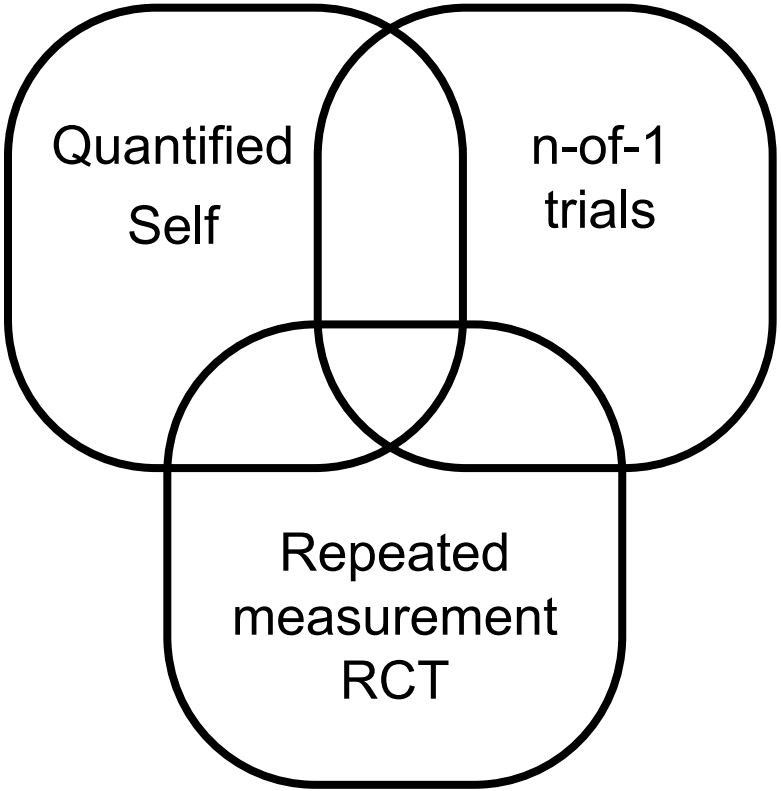


https://upload.wikimedia.org/wikipedia/commons/2/28/Stacken_0c149d_1755.jpg

sensor: air quality

actuator: smart air filtering algorithm

Related Work



Outline

TESS: Tool to enable self-science with IoT devices

SmartAir: Results for smart air filtering system

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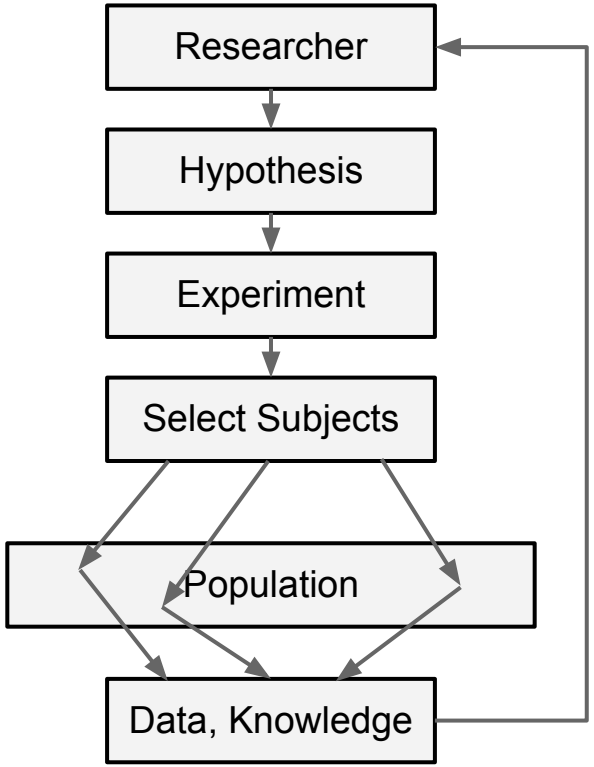
TESS: Tool to enable self-science with IoT devices

SmartAir: Results for smart air filtering system

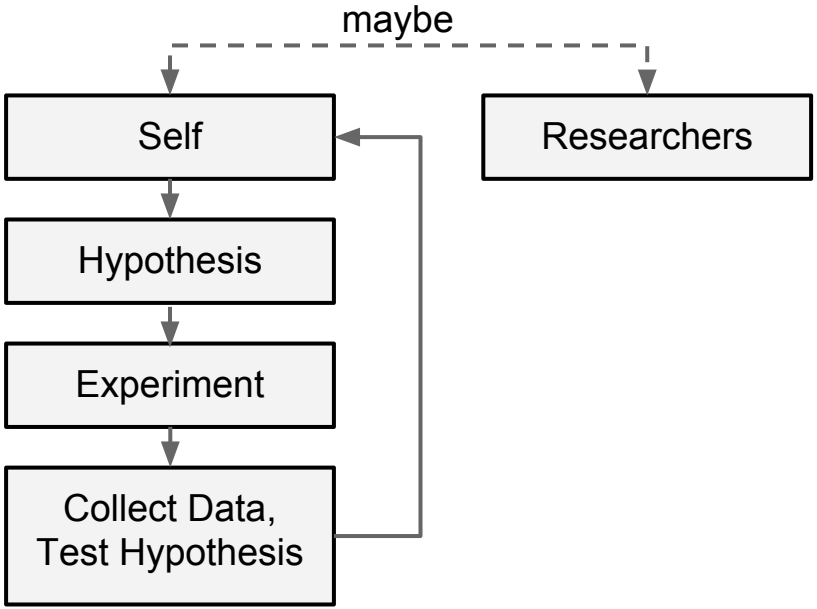
How to do Science (today)

Research:
a top-down
process



How to do Self-Science

Answer a question we have about our self



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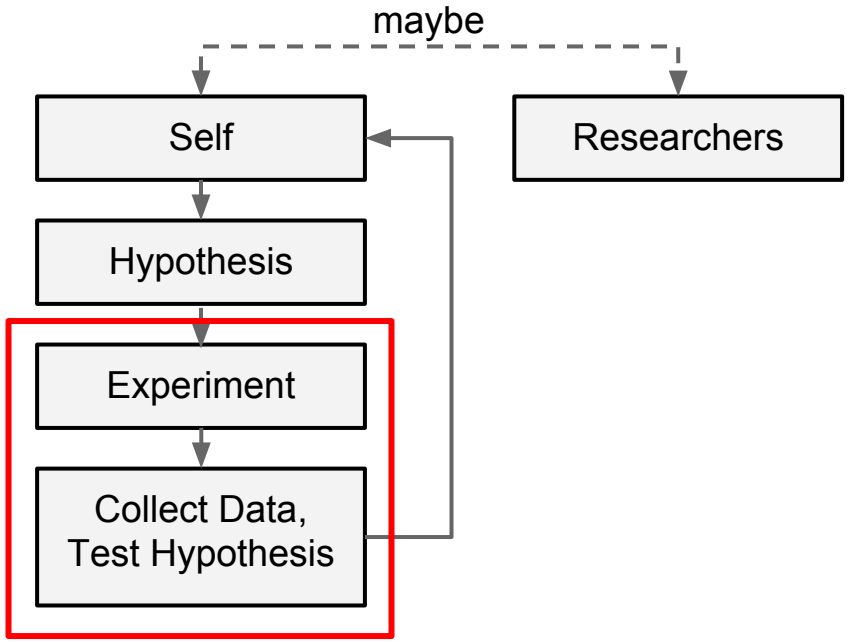
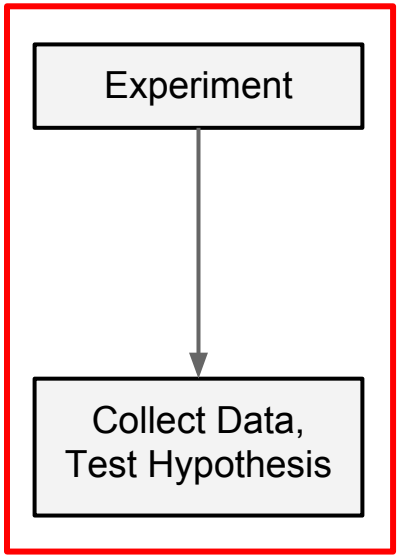
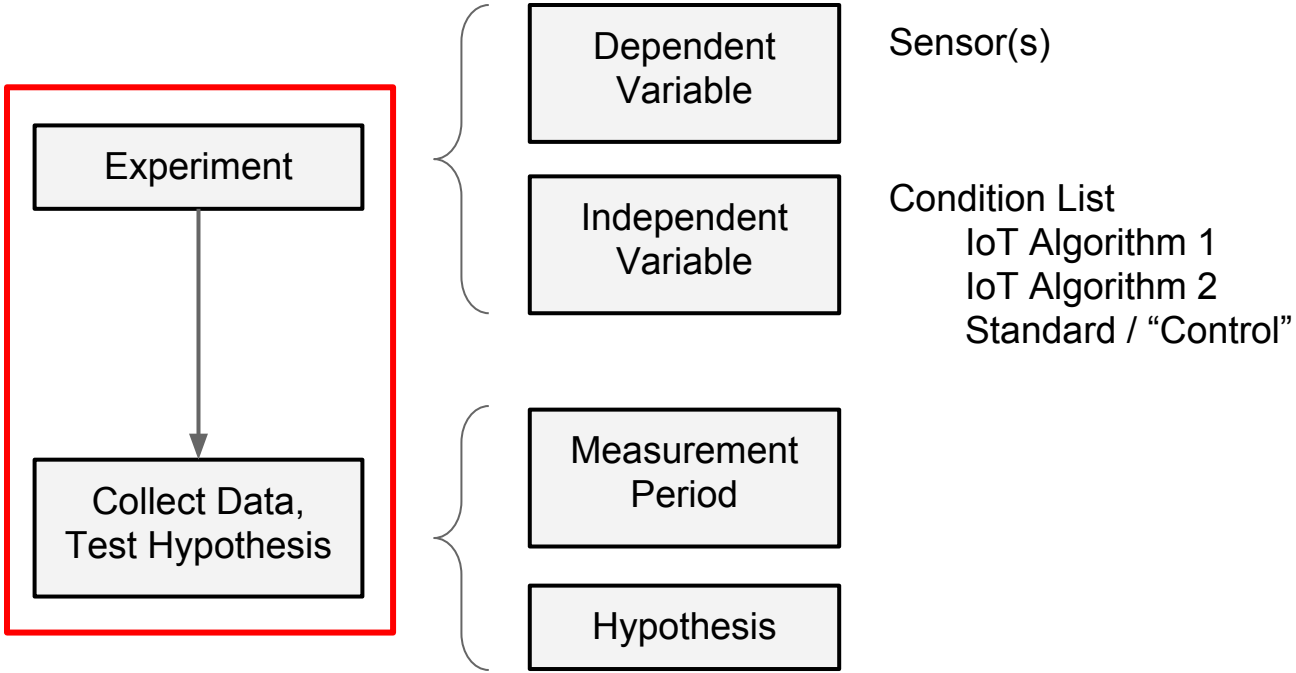


Thing-Enabled Self-Science



What is needed to run an self-science experiment?

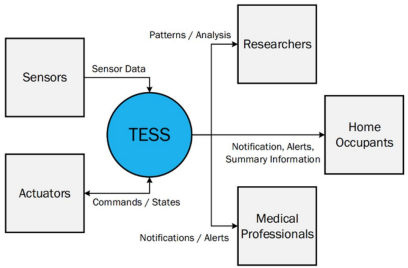
Thing-Enabled Self-Science (TESS)



What is needed to run an self-science experiment?

TESS: open & adaptable by design

TESS is open source & available:
https://github.com/VDL-PRISM/TESS



TESS is built on Home Assistant

https://www.home-assistant.io/

1155 open source components

Python 3 / Raspberry Pi

Outline

TESS: Tool to enable self-science with IoT devices

SmartAir: Results for smart air filtering system

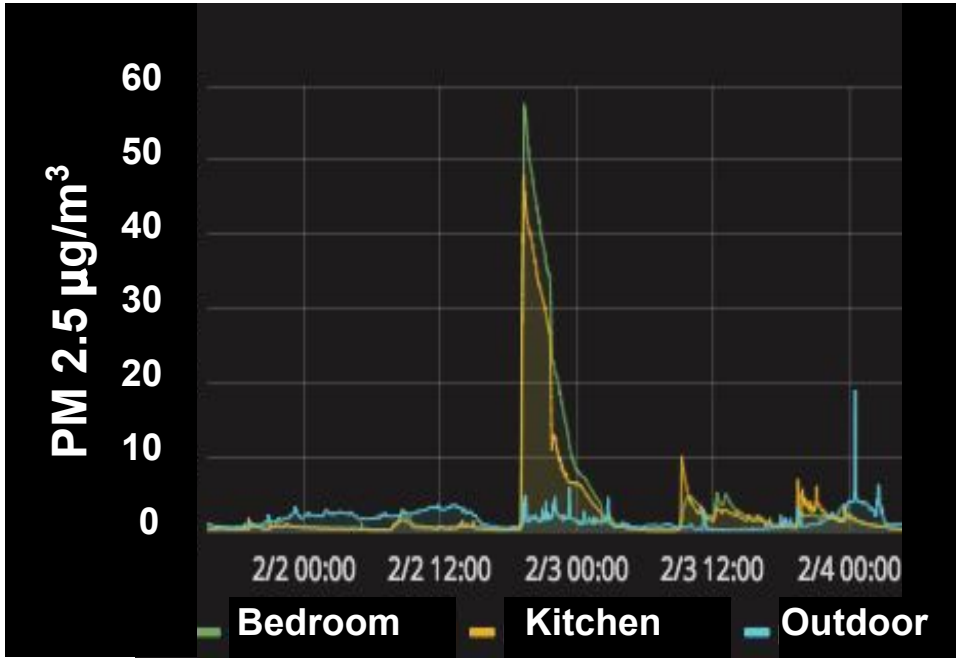
Air pollution kills, exacerbates conditions

- Airborne particulate matter is associated with disease
- PM 2.5 (particles d < 2.5 μm)
- Increase outdoor PM2.5 by 10 μg/m^3 → Shorten avg lifetime by 1.5 years
- Most of our day is indoors

University of Utah Webcam

Indoor air is no less of a problem...

- Certain activities make indoor air 10x+ worse than the EPA limit
- Cooking, burning candles or incense, smoking, cleaning
- PM is spiky
- Worse when we're home



Deployment A data, SLC, 2-4 Feb 2018

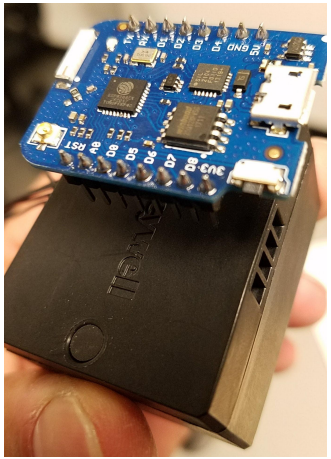
Grant focus: pediatric asthma

- NIH Pediatric Research using Integrated Sensor Monitoring Systems (PRISMS) Program
- Grant #1U54EB021973-01
- Air pollution is a major cause of asthma exacerbation

The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

Wireless PM sensing

We've deployed many wireless PM sensors in many homes



Utah-Modified Dylos Sensor: Dylos + WiFi + Temp/Humidity
https://github.com/VDL-PRISM/prisms-wifi-sensor

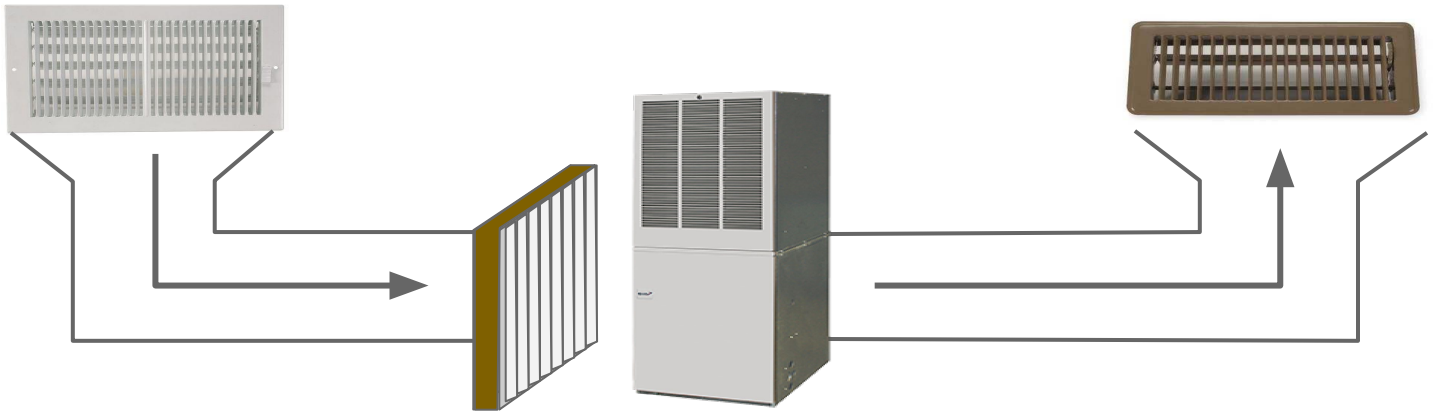
Next gen: Honeywell + ESP8266

SmartAir: Proposed IoT System

Running HVAC fan → pulls air through a filter → reduces PM2.5, increases $$$

- **Normal**: Fan on when heat/AC is on
- **On**: Fan always circulates air

Fan on continuously uses
300 kWh ($30-40) per month



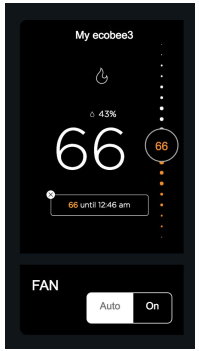
SmartAir: Proposed IoT System

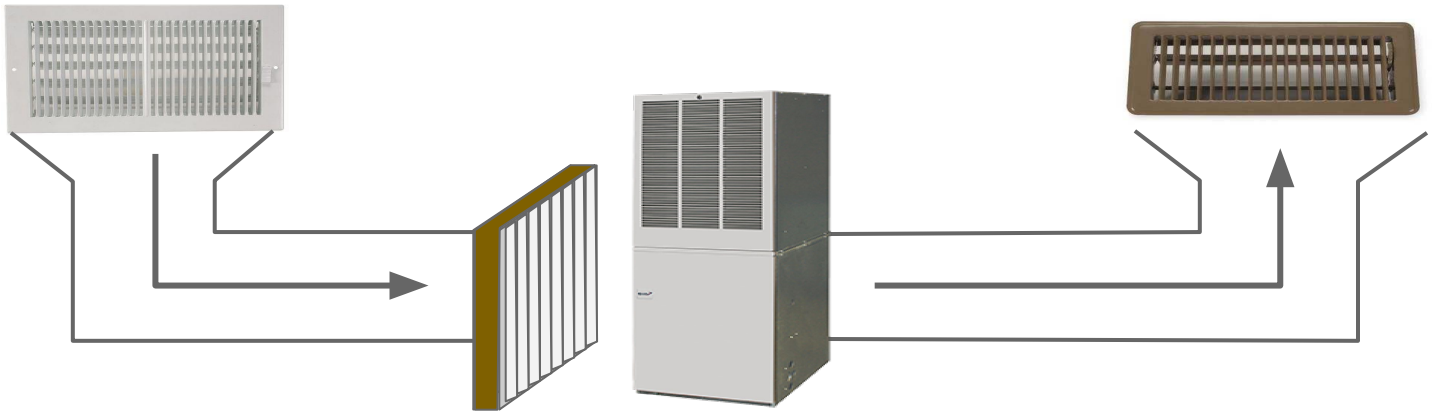
Running HVAC fan → pulls air through a filter → reduces PM2.5, increases $$$

- **Normal**: Fan on when heat/AC is on
- **On**: Fan always circulates air
- **SmartAir**: Run fan whenever PM2.5 is high

Sensor:
Utah modified Dylos

Actuator:
Ecobee smart thermostat





SmartAir: How to Judge Performance

Run in three different homes at one time

Pros: Simultaneous

Cons: Different Residents, house construction will complicate results

Run in one home for three periods of time

Pros: House, residents are same

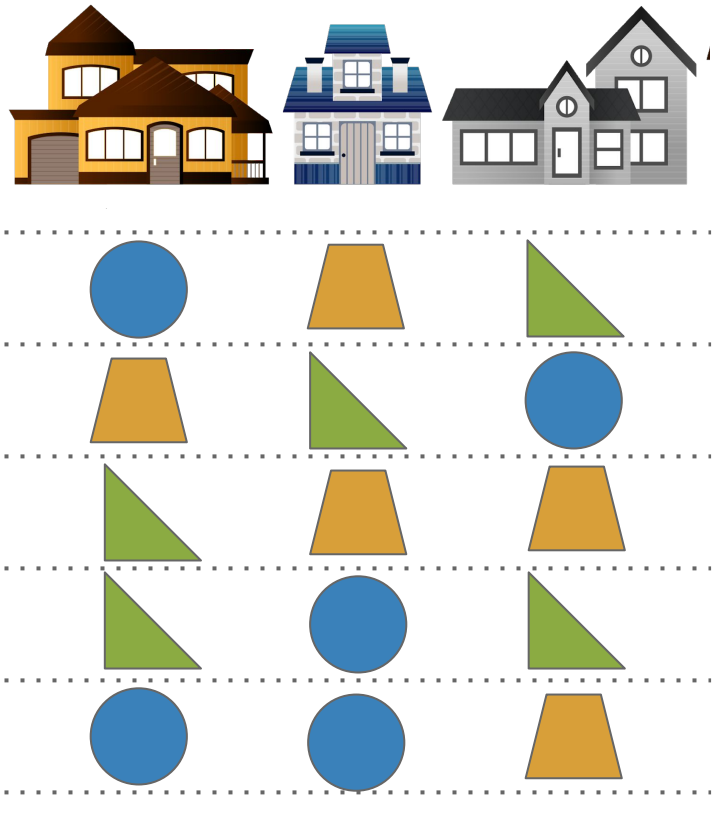
Cons: Different weather will complicate results

Run in simulation

Pros: Easy, same settings in each run

Cons: Simplified model, inaccurate compared to the real-world

SmartAir: How to Judge Performance

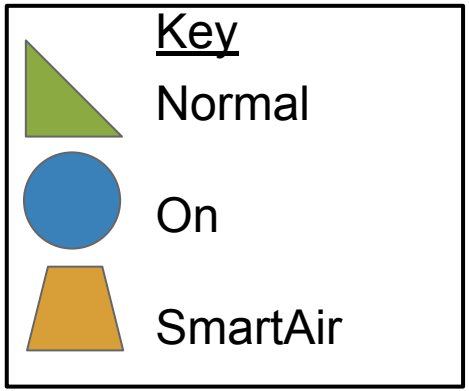


Run random condition each measurement period, in each home

Period = 1 day

TESS randomly sets condition @ midnight

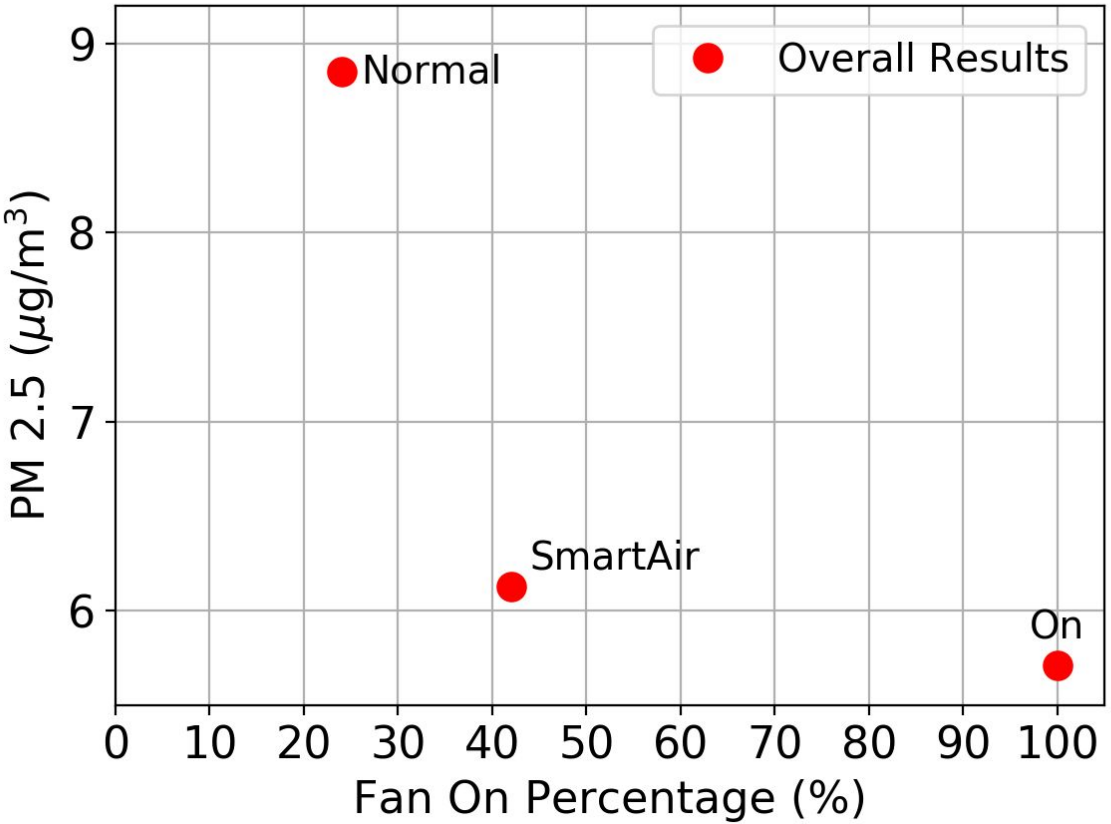
Counters selection bias



SmartAir: Experimental Conditions

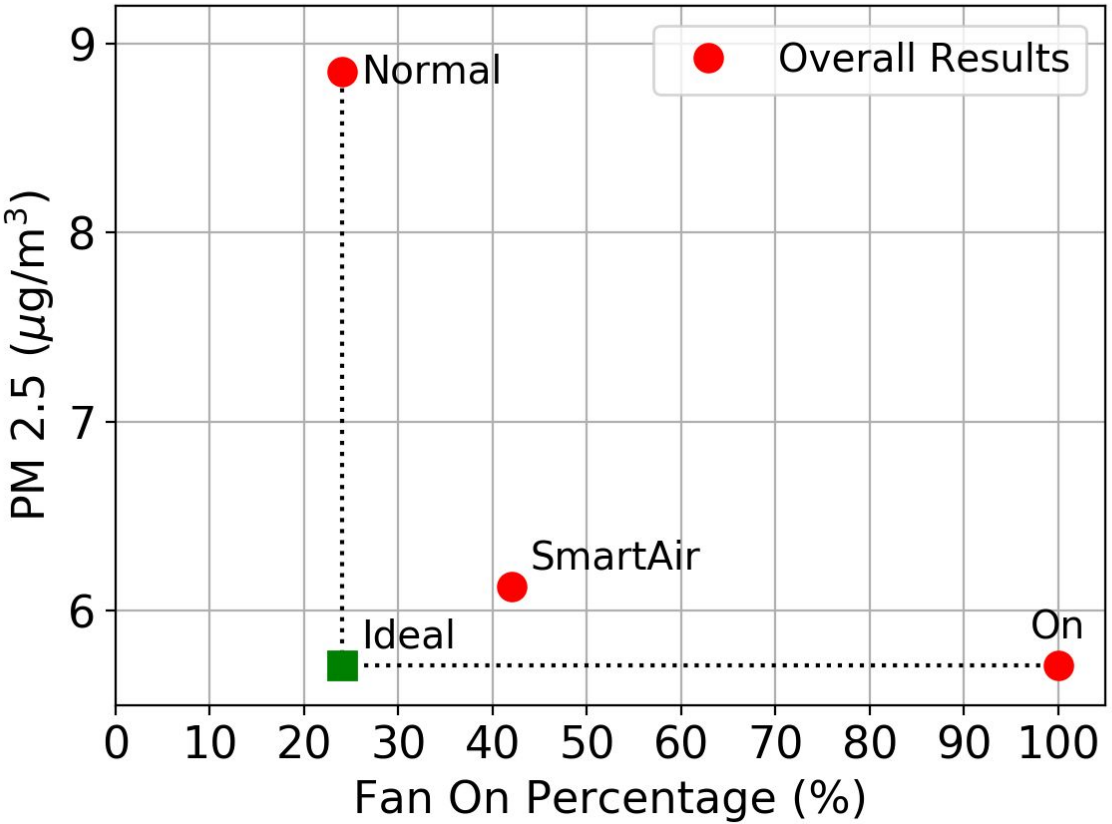
- Four single-family houses in Salt Lake City, Utah
- Three families with asthma, one without
- Four months from start to finish, Spring and Summer
- 350 days total (across all houses)

Overall Results



Under three conditions, all data

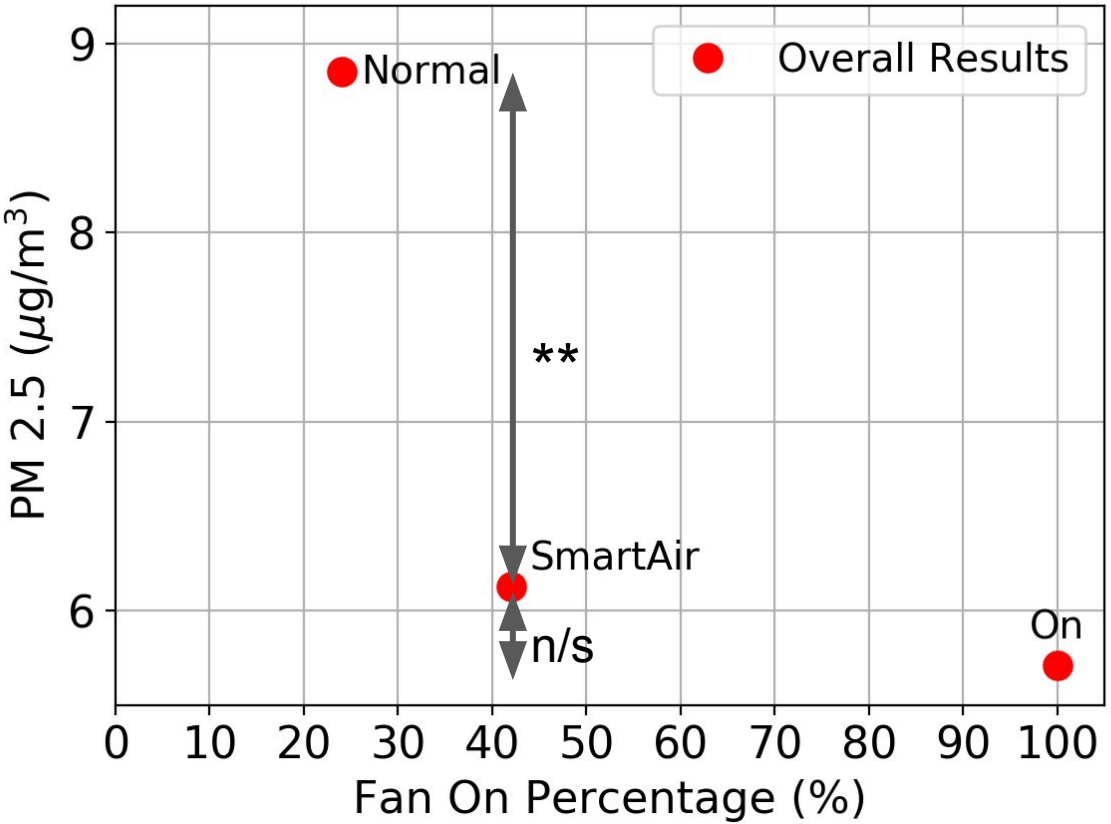
Overall Results



Under three conditions, all data

Ideal would be PM as low as when fan is always on, AND fan on as little as Normal

Overall Results



Under three conditions, all data

Ideal would be PM as low as when fan is always on, AND fan on as little as Normal

** p-value < 0.01

n/s not statistically significant

Results Summary

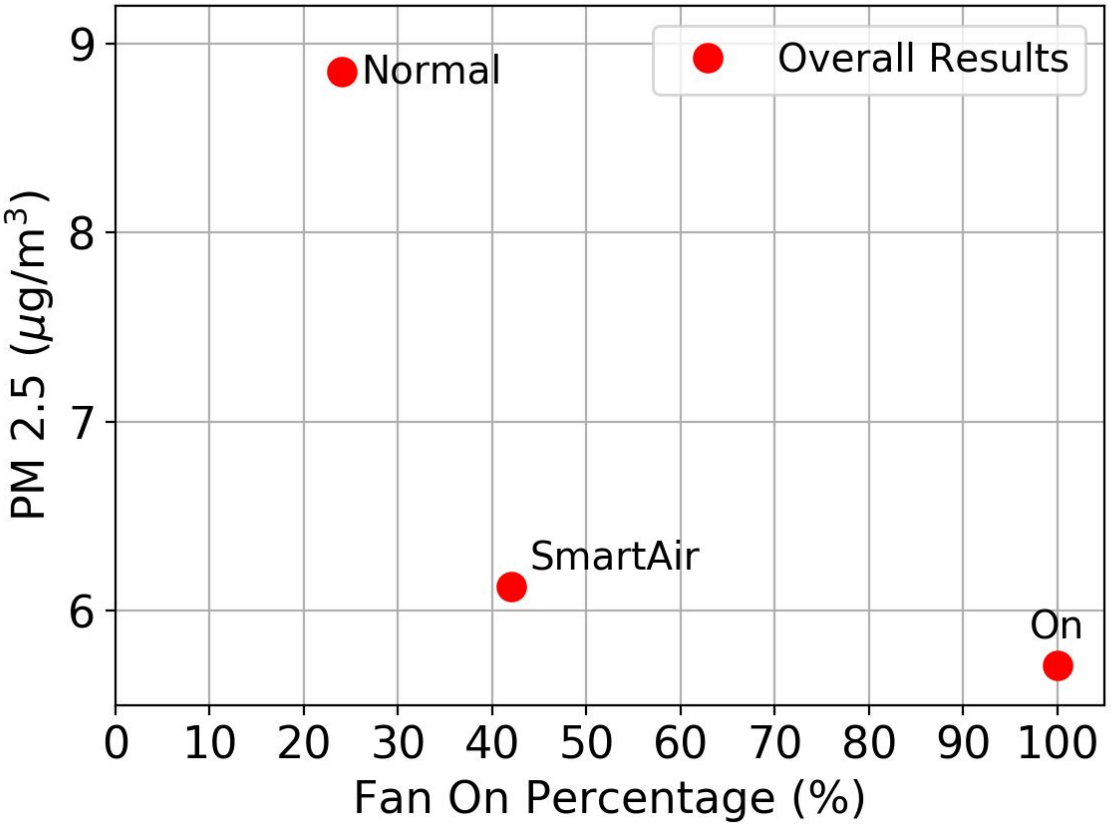
SmartAir vs. Normal

- reduces PM2.5 (6.13 vs. 8.85 $\mu g/m^3$)
- increase in fan use (42% vs. 24%)

SmartAir vs. On

- reduces fan use (42% vs. 100%)
- marginal increase in PM2.5

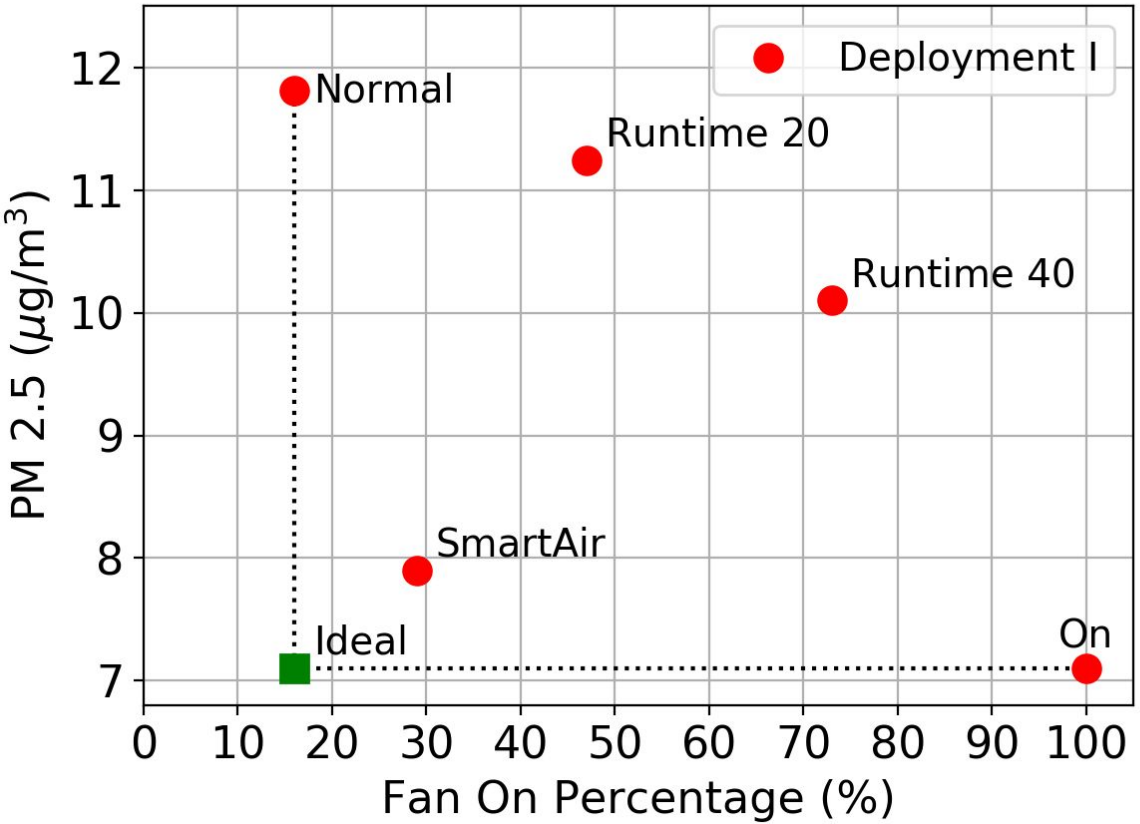
Results Question



Would any increase in fan use result in this performance?

Or is a PM sensor required?

Improvement not from more fan use alone



For Deployment I, we added two conditions:

- Runtime 20
- Runtime 40

These are Ecobee settings which ensure the fan is on at least 20 minutes (or 40 minutes) each hour

Future Work

Thing-enabled self-science

- Recruit participants to design-their-own experiments from IoT sensors & actuators

Improving indoor air quality

- SmartAir is only one algorithm. Test others.
- Compare to human-in-the-loop systems

Conclusion

- IoT offers ability to control repeated measurement RCTs, automatically test hypotheses and improve individual outcomes
- SmartAir significantly improves air quality but without the high energy cost of HVAC fan always on