THE IMPACTS OF HUMAN ACTIVITIES ON INDOOR AIR QUALITY IN PASSIVE HOUSES

University of Colorado Boulder
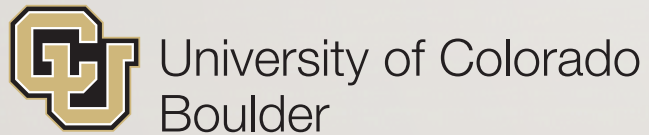
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PERSONAL BACKGROUND

Ryan Militello-Hourigan, PE (CA)

- Graduate Researcher
- Previously, HVAC Design Engineer

- Working toward M.S. at CU Boulder
  - Focusing on Indoor Air Quality
  - Miller Air Quality Research Group

OVERVIEW

- Why we're interested in Passive Houses

- What we're studying

- Preliminary Results

- Potential Implications

- Lessons Learned

MOTIVATIONS

- Homes should be safe and healthy

- Passive Houses are unique

  - Virtually zero infiltration at normal pressures

  - Continuous ventilation

- Limited existing research showing mixed results

- Passive Houses may influence other efficient designs

EXISTING RESEARCH

"Scottish Passive House" (Foster, et al. 2016)

- Five passive houses showed issues with overheating and some w/ high CO_2

"IAQ in Passive and Conventional New Houses in Sweden" (Langer, et al. 2015)

- Swedish passive houses had lower NO_2, and formaldehyde, but higher TVOC than conventional homes

"IAQ in 24 CA Residences Designed as High-Perf. Homes" (Less et al. 2015)

- Study homes (Avg. ACH_{50} = 1.1) in CA showed that good IAQ is possible, but greatly dependent on design
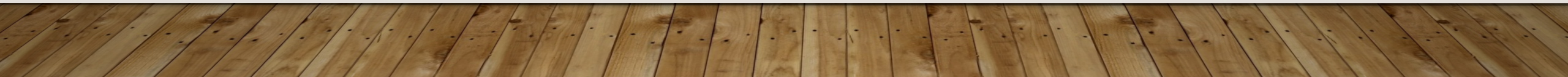
CURRENT STUDY

- Characterize Passive House IAQ performance
  - In-home measurements
  - Repeatable prescribed activities

- Compare to existing air quality standards
  - NAAQS, ASHRAE 62.1/62.2, USGBC/LEED

- Repeat for 10+ passive houses

ACTIVITIES

Cooking: Frying an egg

One egg in 1 tbsp. of canola oil for 6 minutes

Walking: Brisk walking for 10 minutes

Had low emissions, so removed for future

Sleeping: Normal sleeping…

MEASURED POLLUTANTS

Total Volatile Organic Compounds (TVOC)

Gray Wolf TVOC Monitor (PID)

Particulate Matter < 2.5 microns (PM$_{2.5}$)

Dylos - DC1700 Optical Particle Counter

Carbon dioxide (CO$_2$)

TSI Q-Trak (NDIR)

Telaire 7001-CO2 (Not Shown)

Formaldehyde*

Radon*

*To be included in future home tests

PASSIVE HOUSE #1

- Located near Ft. Collins, CO

- PHI Certified

- Area = 1260 ft^2 | Vol. = 18,500 ft^3

- Balanced HRV
  - Standard: 50 cfm (0.16 ACH)
    - ASHRAE 62.2: 53 cfm
  - Boost: 150 cfm (0.48 ACH)
  - Bedroom: 9 cfm @ std. flow (0.25 ACH)
  - No kitchen hood

- Large open layout with partial 2nd story

PASSIVE HOUSE #2

- Located in Ft. Collins, CO
- Not yet certified; ACH_{50} = 0.34
- Area = 2200 ft^2 | Volume = 18,400 ft^3
- Balanced ERV
  - Standard: 56 or 80 cfm? (I'll explain)
    - ASHRAE 62.2: 81-96 cfm
  - Boost: 112 cfm ?
  - No vented hood (recirculating)
- Two-story, 3 Bed / 3 Bath

STANDARD HOUSE #1

- Located in Boulder, CO

- Area = 500 ft^2 | Volume = 4500 ft^3

- Ventilation
  - Drafty Windows
  - Intermittent Bathroom Fan

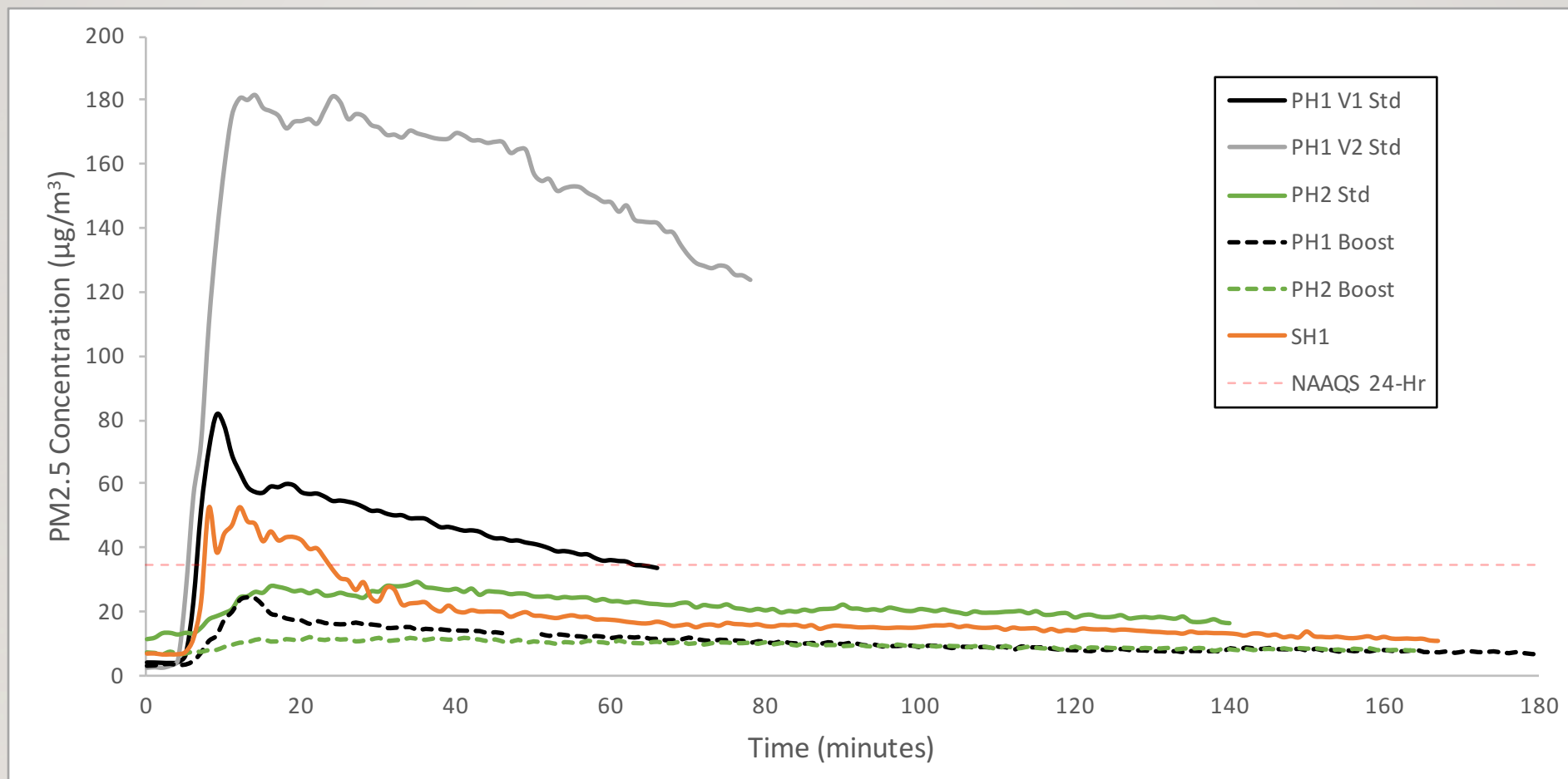- Old Victorian home converted into four 1 BR units
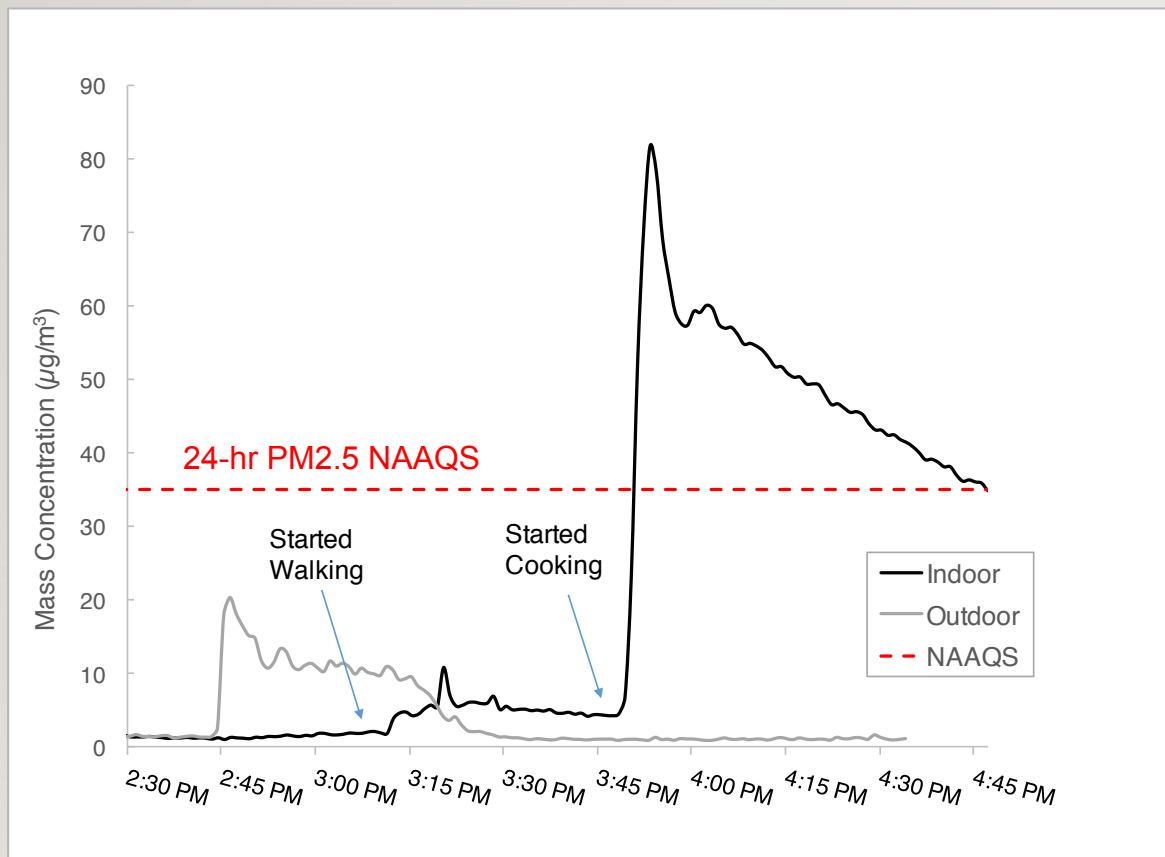
RESULTS: PARTICULATE MATTER
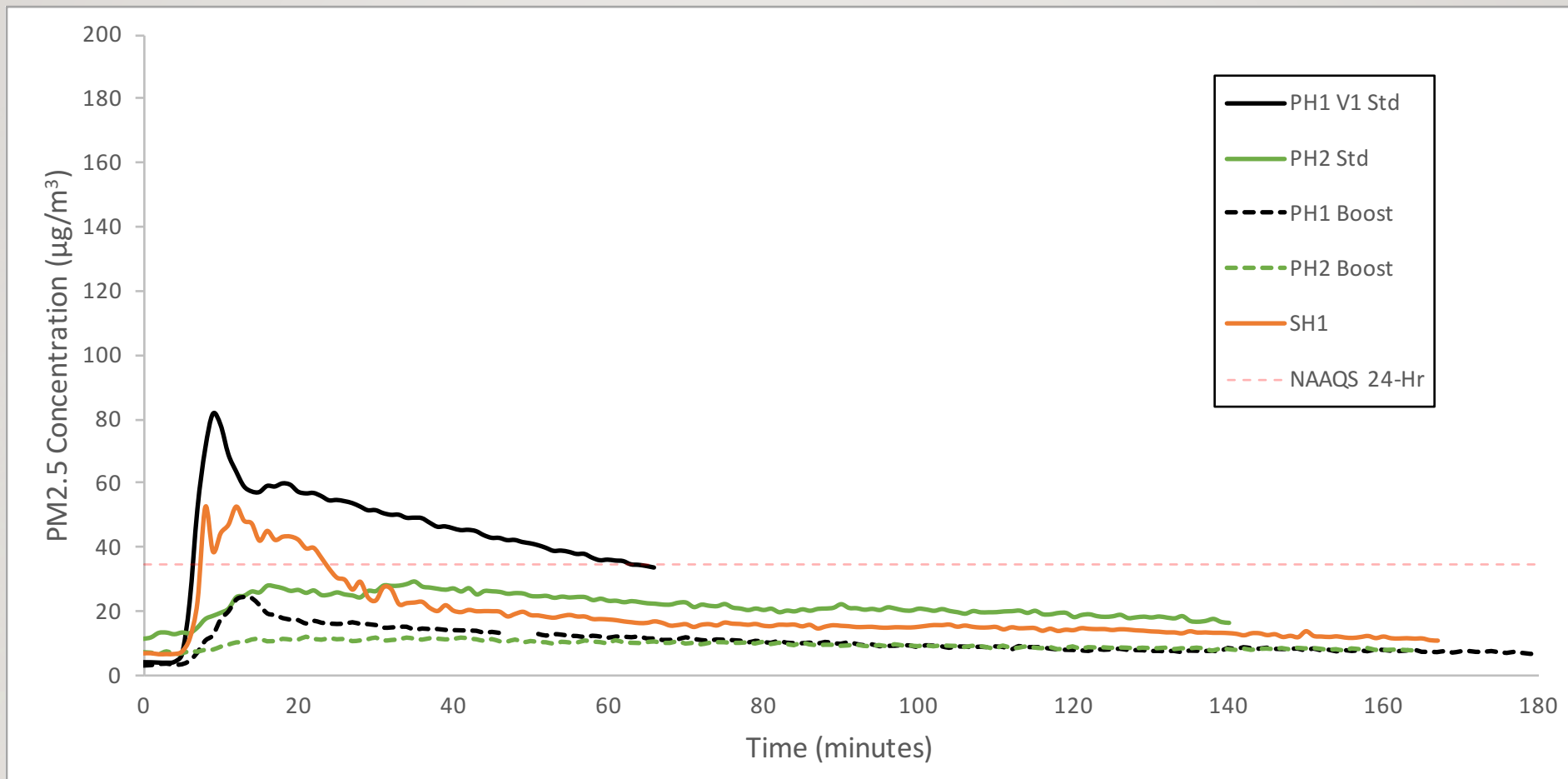
Comparison of particulate responses from cooking activity for all homes and visits.
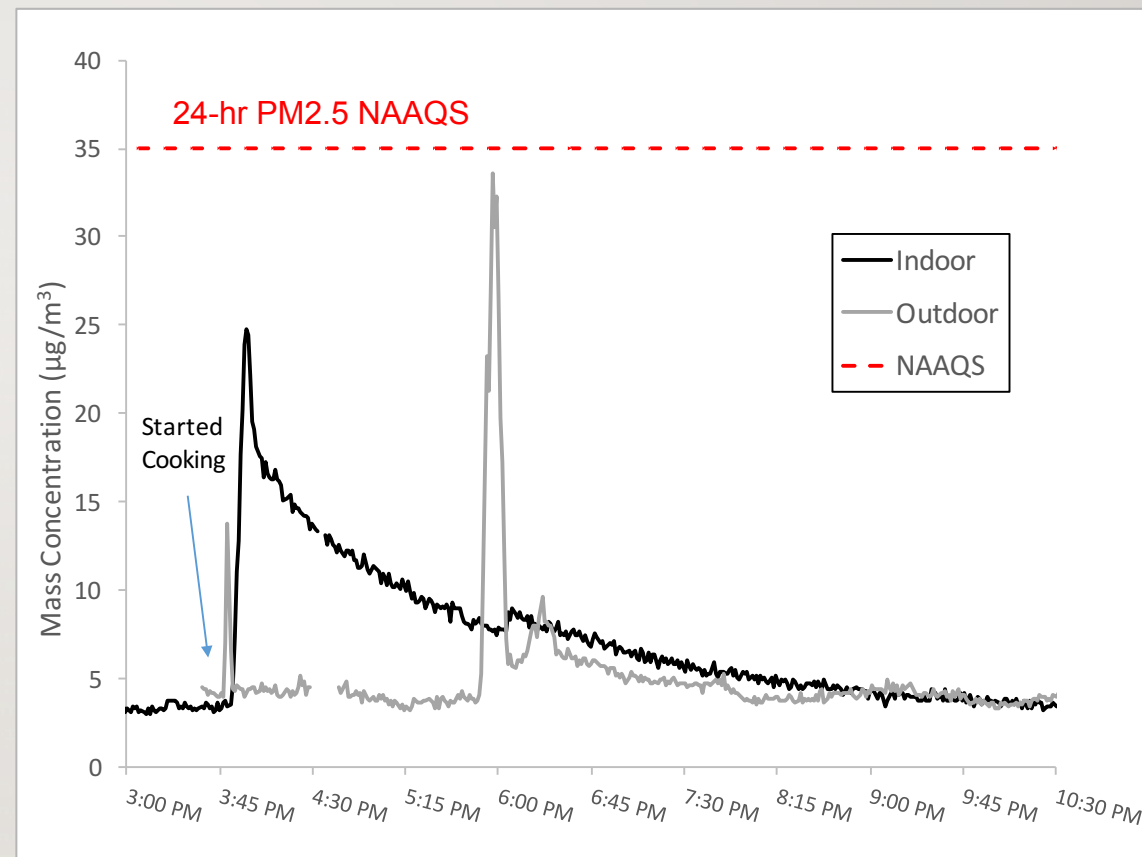
RESULTS: PARTICULATE MATTER

Comparison of particulate responses from cooking activity for all homes and visits.
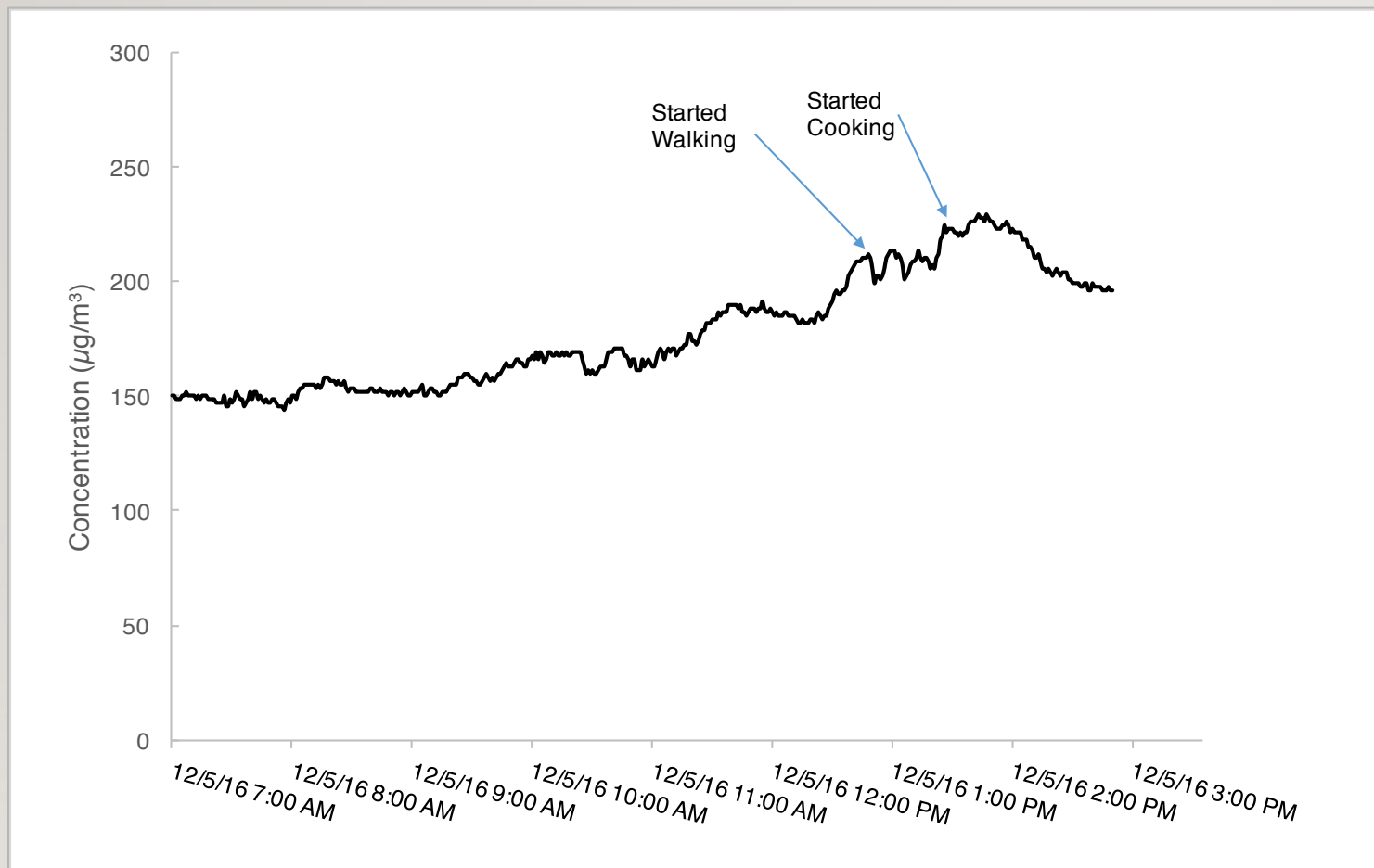
RESULTS: PARTICULATE MATTER

PH#1 - Visit 2: Standard Ventilation
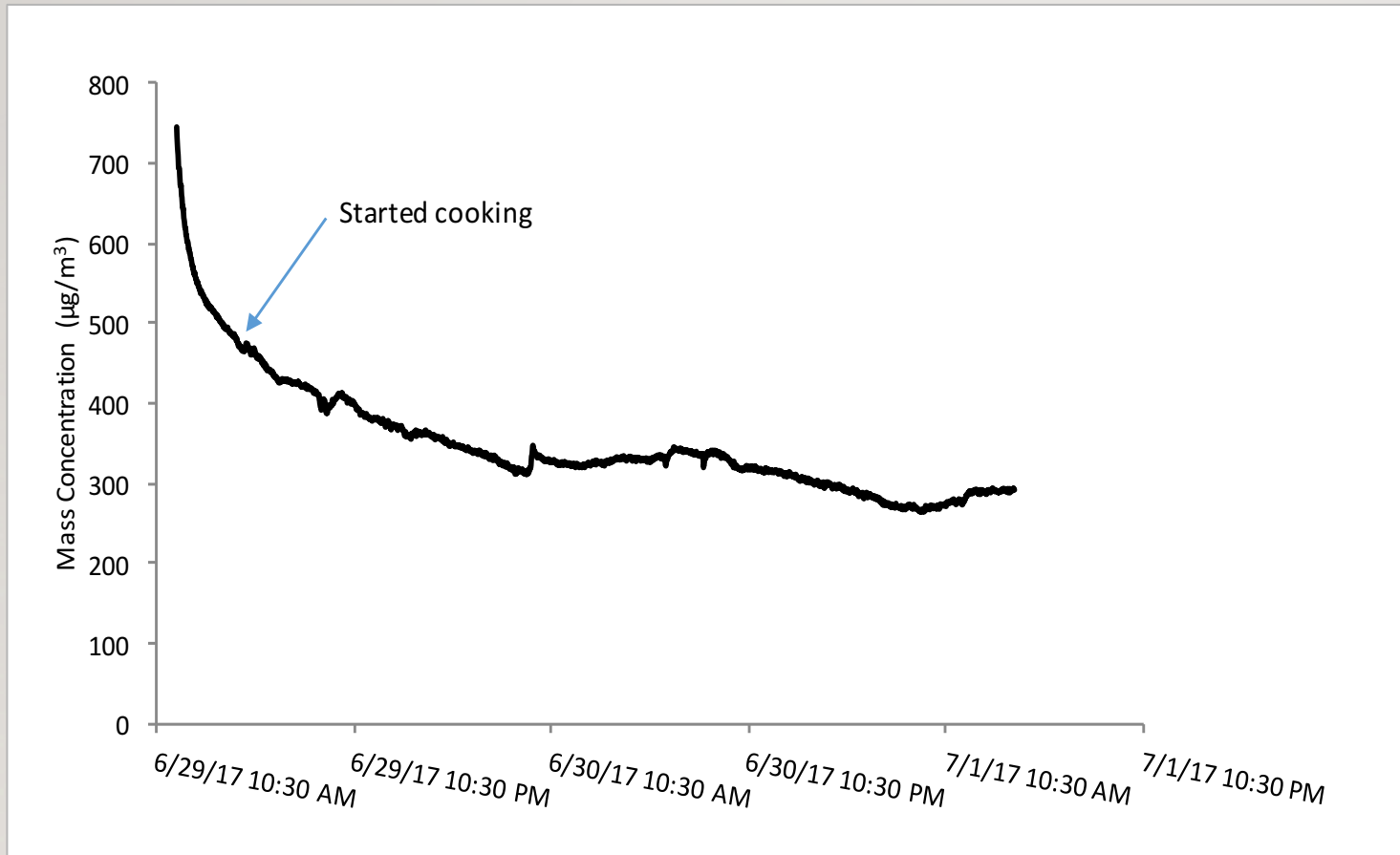
PH#1 - Visit 3: Boost Ventilation (30 min.)

RESULTS: TVOCS

TVOC levels in Passive House #1 – Visit #2

- TVOCs appear to be less impacted by cooking event

- Levels trend up over course of day

- USGBC/LEED maximum limit is 500 µg/m³

RESULTS: TVOCS

Started cooking

800

700

600

500

400

300

200

100

0

Mass Concentration ($\mu g/m^3$)

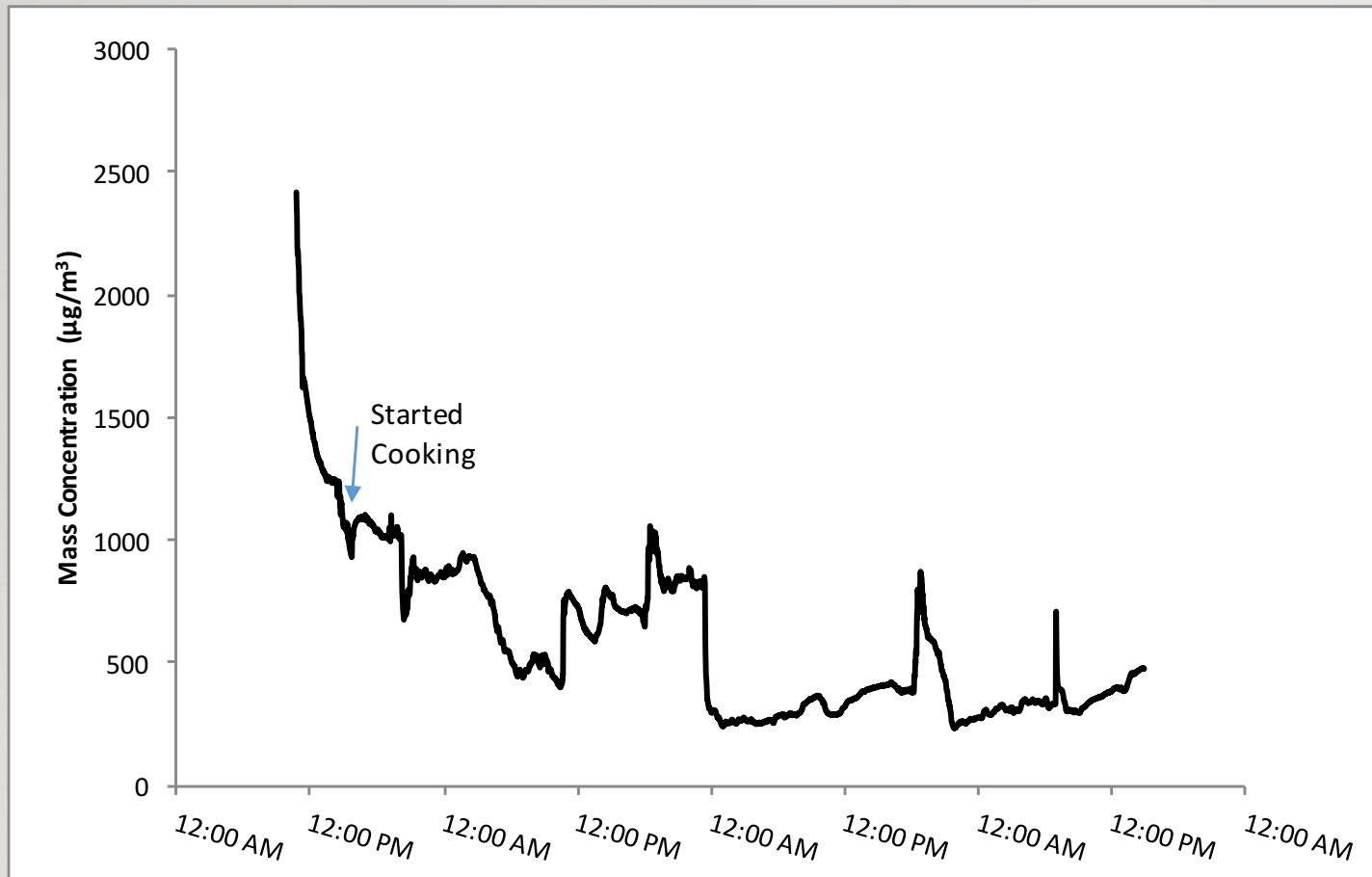6/29/17 10:30 AM   6/29/17 10:30 PM   6/30/17 10:30 AM   6/30/17 10:30 PM   7/1/17 10:30 AM   7/1/17 10:30 PM

- On Visit #3, levels started high after setup but then slowly decayed

- Starts above 500 $\mu g/m^3$, but likely due to human presence

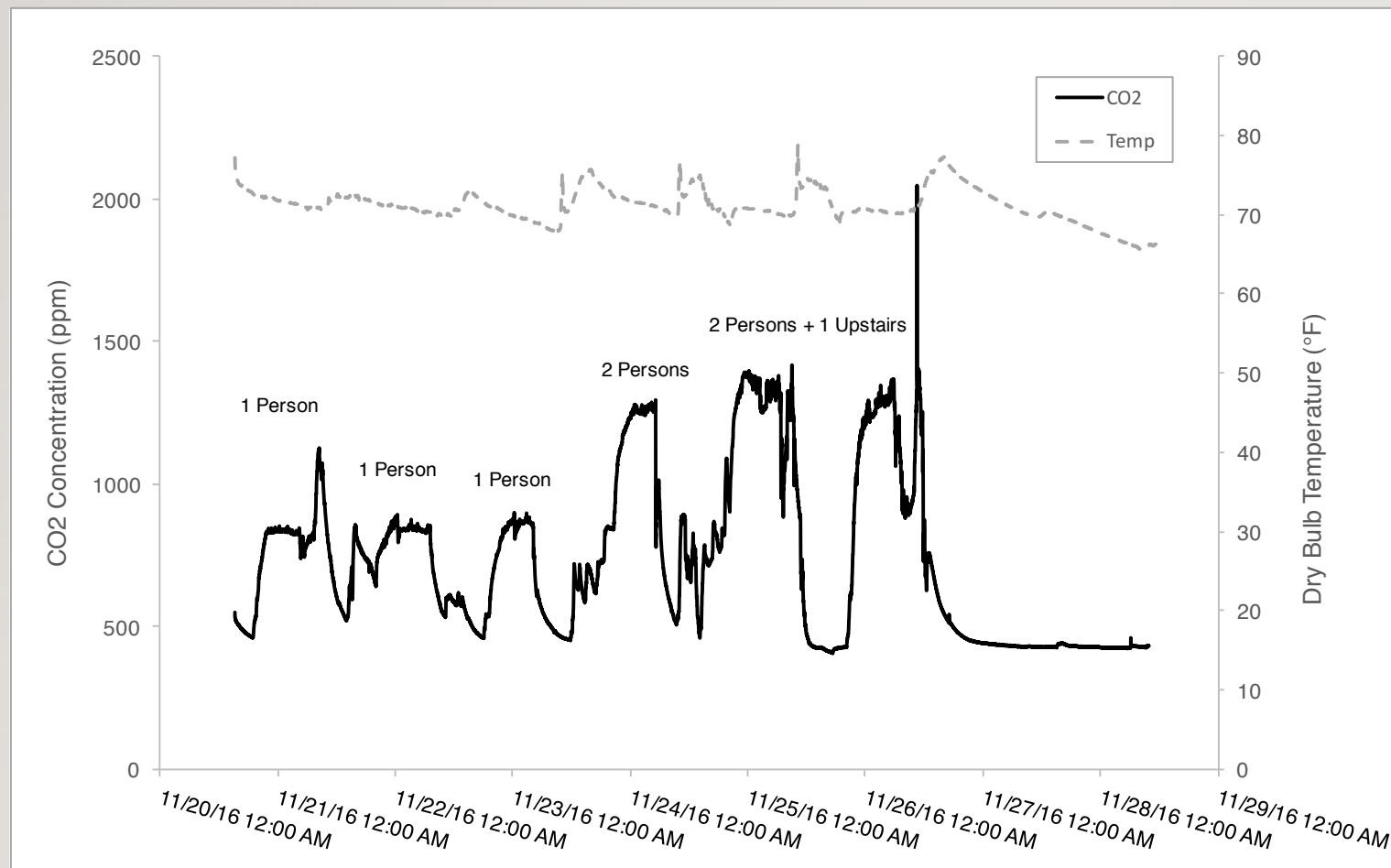TVOC levels in Passive House #1 – Visit 3

RESULTS: TVOCS

TVOC levels in Passive House #2

- House #2 showed similar trends, but with more variance
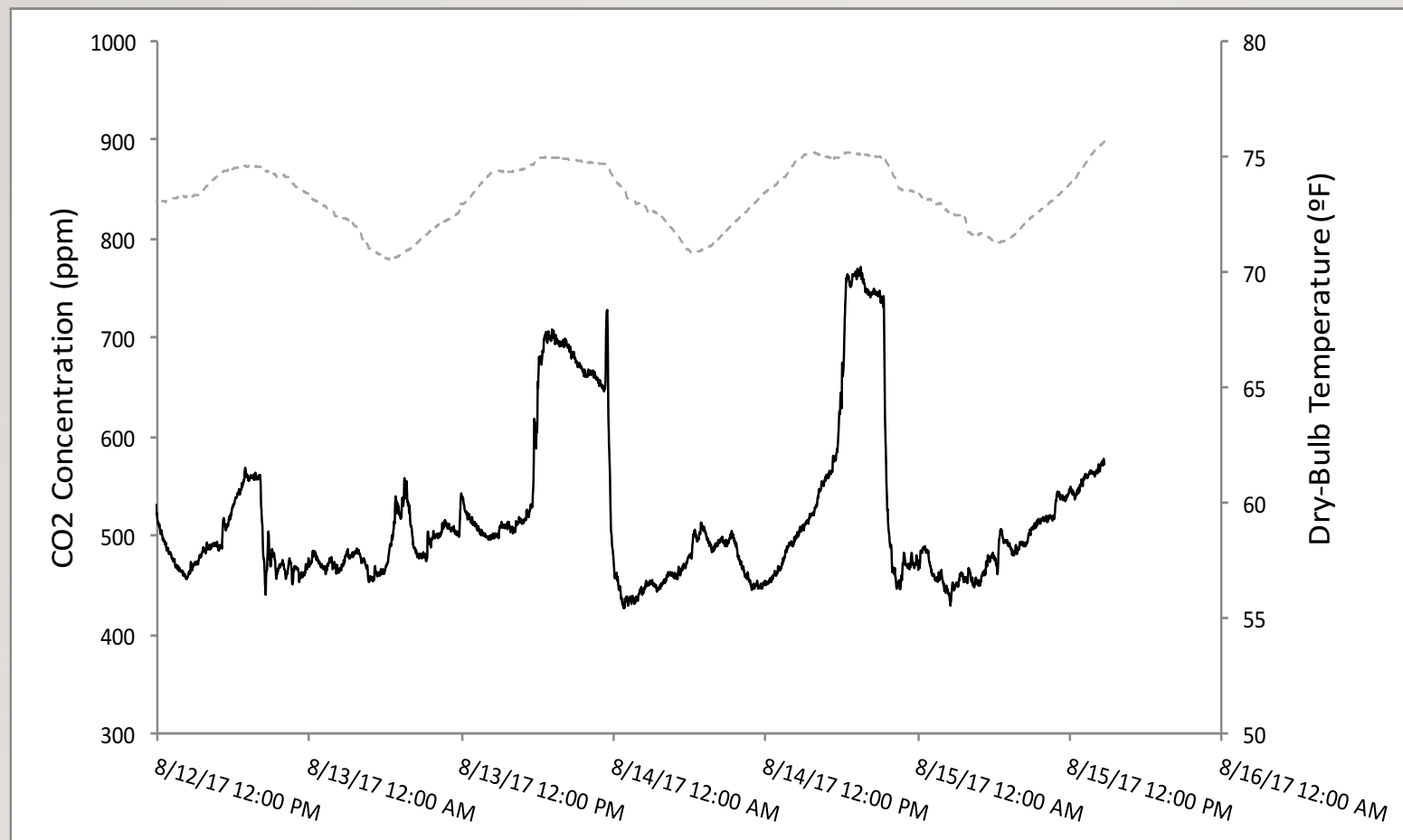
- Looks like it depends on what you cook!

RESULTS: CARBON DIOXIDE

CO$_2$ levels in downstairs bedroom in Passive House #1 – Standard Ventilation

- Cooking had relatively small impact on CO$_2$ levels
- Sleeping was more interesting

RESULTS: CARBON DIOXIDE

- Windows opened right before bed, but after spending time in bedroom

- Sharp drop in concentration before midnight

CO_2 levels in upstairs bedroom in Passive House #2 – Standard Ventilation; windows opened before sleep

OBSERVATIONS

- For Passive House #1, measured overall ACH was slightly lower than designed
  - 0.14 vs. 0.16 ACH
  - Ventilation efficiency not 100%

- Boost mode appears to act as a source control

- TVOCs can be a good measure of IAQ, but trends vary and are hard to correlate with specific activities

IMPLICATIONS

Too early for anything conclusive, but…

- Standard ventilation may not be enough for severe events

- Boost mode highly recommended for cooking
  - Increased boost time could have an energy impact
  - Real-time feedback would prevent "over-boosting"

- Though CO_2 levels did not exceed 1500 ppm at night, they were above 1000 ppm with multiple people
  - Consider increasing ventilation for additional guests

LESSONS FROM THESE FIRST TESTS

- Baseline levels take longer to reach than anticipated

  - Adding air cleaners to speed up process

- Stove burners are inconsistent

  - Switching to hot plate

- Humans are a variable

  - Need to request specific behaviors if required

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- ASHRAE. 2013. *ANSI/ASHRAE Standard 62.2-2013,* Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings. Atlanta: ASHRAE

- Dacunto, P. J., Neil E. et al. 2015. "Determining PM2.5 Calibration Curves for a Low-Cost Particle Monitor: Common Indoor Residential Aerosols" 17 (11): 1959–66. doi:10.1039/C5EM00365B.

- J. Foster, T. Sharpe, A. Poston, C. Morgan, and F. Musau, "Scottish Passive House: Insights into Environmental Conditions in Monitored Passive Houses," *Sustainability*, vol. 8, no. 5, p. 412, Apr. 2016.

- S. Langer, G. Bekö, E. Bloom, A. Widheden, and L. Ekberg, "Indoor air quality in passive and conventional new houses in Sweden," *Building and Environment*, vol. 93, Part 1, pp. 92–100, Nov. 2015.

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THANK YOU

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