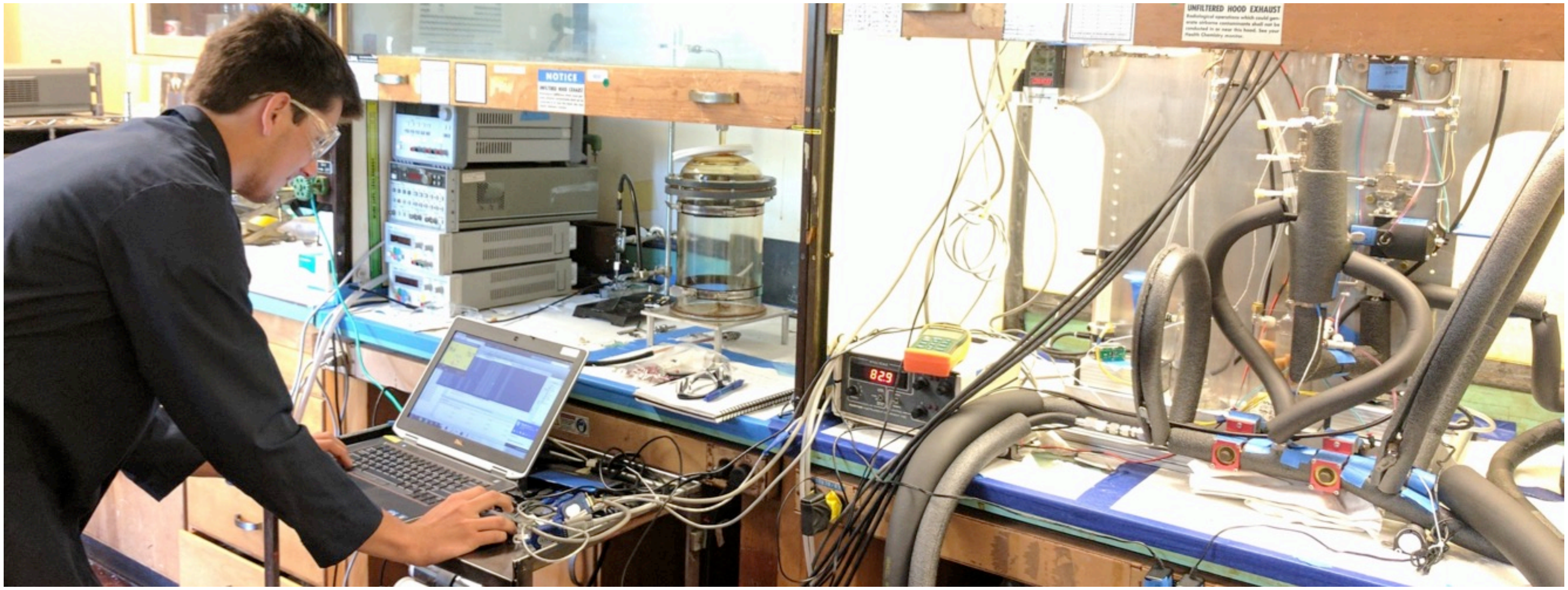
HVAC Energy Savings and IAQ: Integrating Air Cleaning with Smart Ventilation



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This project is part of the US-China Clean Energy Research Center – Building Energy Efficiency program

Project Summary

Timeline:

Start date: 4/1/2016

Planned end date: 3/31/2021

Key Milestones

1. Demonstrate sorbent for VOC, formaldehyde & >40 mg CO_2/g capacity at room scale; Q4 of Y3
2. Submit Pre-Manufacture Notice to EPA for BASF Sorb300; Q4 of Y3
3. Air cleaning tool added to development version of Energy Plus, Q4 of Y4

Key Partners:

US Partners	China Partners
BASF USA	Tsinghua University
United Technologies	Shenzhen IBR
Johnson Controls (Y1)	Inst. of Bldg Envt & Energy Eff.
eLichens (Pending)	Merchants Property Develop Corp.

Budget:

Total Project $ to Date:

- DOE: $600K Y1–Y2 (Mar-18);
  $300K for Y3 (to Mar-19)
- Cost Share: $1380K projected through Y3

Total Project $:

- DOE: $1500–1550K
- Cost Share: $2300K

Project Outcomes:

Vision is for smart ventilation with integrated air cleaning and IAQ sensor feedback to be common in new buildings and HVAC retrofits, helping achieve BTO goal of 30% energy savings by 2030.

The project aims to develop and demonstrate air cleaning materials, air quality sensor applications, and building simulation tools that reduce energy and peak loads and improve indoor air quality.

Team

US TEAM

RESEARCH:
LBNL

BERKELEY LAB

Brett Singer
(Lead)

Hugo Destaillats
(Co-lead)

Xiaochen Tang

Spencer Dutton

Xiwang Li

INDUSTRY:

BASF
We create chemistry

Ying Wu (Lead),
Rachel (Rui) Dong,
Mark T. Buelow

United Technologies

Catherine Thibaud
Ellen Sun
Zhipeng Zhong

Johnson Controls

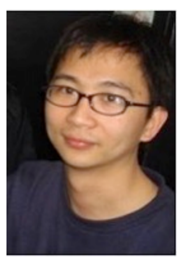
(Year 1)
Clay Nesler

elichens

(Pending)
Marc Attia

CHINA TEAM

RESEARCH:
Tsinghua Universitiy



Jinhan Mo
(Lead)

Xin Feng,
Air Cleaning
Tech Center,
CABR
(Co-lead)

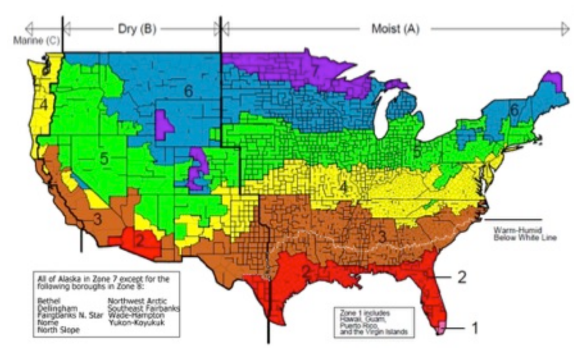
Institute of
Building
Environment
& Energy
Efficiency
(CABR)

INDUSTRY:
Shenzhen Institute of
Building Research
Co, Ltd

Merchants Property
Development Co, Ltd.

Challenge

Commercial buildings use outdoor air to dilute bioeffluents & indoor pollutants, creating large thermal conditioning loads that are unresponsive to system-wide demand signals



This approach is ineffective when outdoor air is polluted, either routinely or during events like wildfires.

Beijing seasonal air pollution
guardian.com Jan 16, 2017

San Francisco during Sonoma wildfires
mercurynews.com Oct 15, 2017

Solution: Smart ventilation with air cleaning enables HVAC energy savings, demand response, climate resilience, and improved IAQ with health and productivity benefits

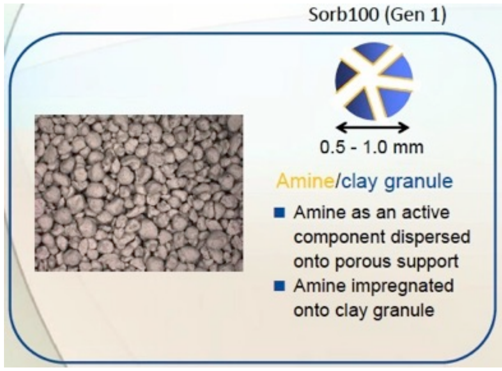
Approach – Four Key Elements

- Efficient **air cleaning technologies** for CO_2, formaldehyde, VOCs and particulate matter (PM)
- Reliable, real-time data from **air quality sensor** networks
- **Simulation tools** for system design and controls
- **Demonstrations** of sensor-informed ventilation with integrated air cleaning

Approach – Four Key Elements

Advanced Air Cleaning Technologies

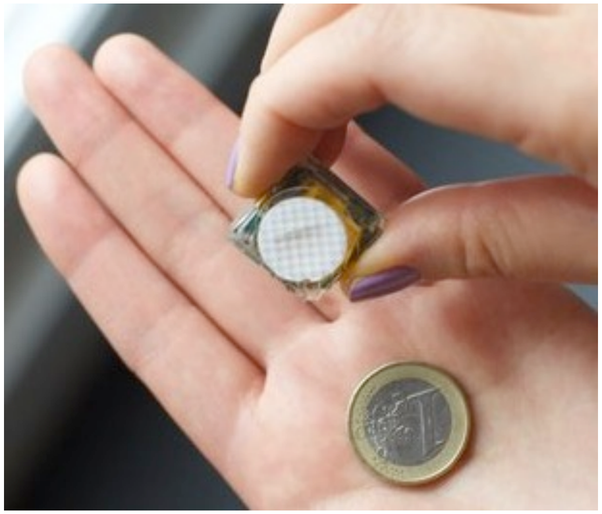
- Develop sorbents with high capacity for CO_2; some formaldehyde removal
- Pair with VOC removal and efficient particle filtration
- Detailed performance evaluations in lab, chambers, and buildings



BASF developed better CO_2 sorbent

IAQ Sensor Performance

- Evaluate consumer products (residential)
- Evaluate novel sensors
- Evaluate networked systems for commercial buildings
- Develop and demonstrate controls



Approach – Four Key Elements

Simulation Tools

- Inform design and sizing
- Estimate savings, demand response potential
- Python model of air cleaning system using parameters from lab performance evaluation
- Formally integrate into Energy Plus
- Adapt to industry tools, e.g. HAP

Demonstrations

- Prototype system for CO_2 and formaldehyde removal with regeneration (Y3)
- Residential formaldehyde removal system with Chinese team
- Demonstrations in buildings, Y4-Y5

Impact

Vision: The project will advance the use of air cleaning technologies to reduce ventilation-related energy and add demand response in commercial buildings

Products and Outputs

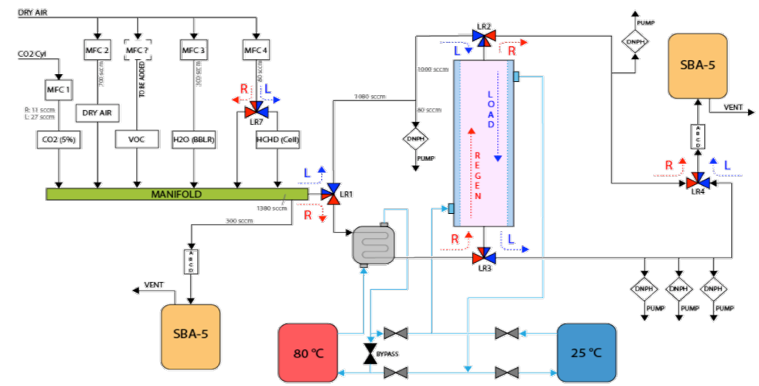
- Air cleaning materials that cost-effectively remove CO_2, formaldehyde and bioeffluents
- Simulation tools to guide system design and sizing and to maximize benefits
- Demonstrations of integrated air cleaning and ventilation driven by air quality and other sensor input

Target Impacts

- By 2030, 25% penetration of smart ventilation with air cleaning in commercial bldgs
- Potential HVAC energy savings of 10% to >50% by climate zone
- Annual savings of 56 TWh and 22 MMT CO_2 in US, 105 TWh and 44 MMT CO_2 in China

Progress – Air Cleaning Materials

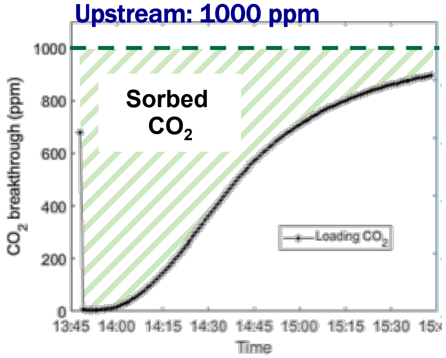
Designed, constructed, & commissioned automated apparatus to repeat CO_2 and formaldehyde loading and regeneration though 30-50 cycles.

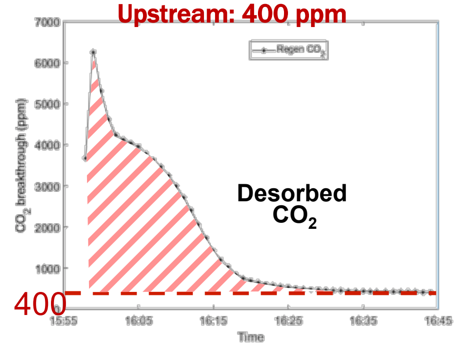


Evaluated loading and regeneration of BASF Sorb300 at varying T and RH.

CO_2 capture not sensitive to humidity

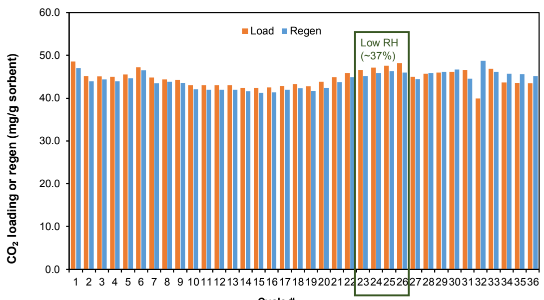
Incomplete formaldehyde release during quick regeneration





Verified consistent performance for CO_2 through 36 cycles at 25°C, ~45% RH

CO_2 capacity: 44 ± 2 mg/g sorbent



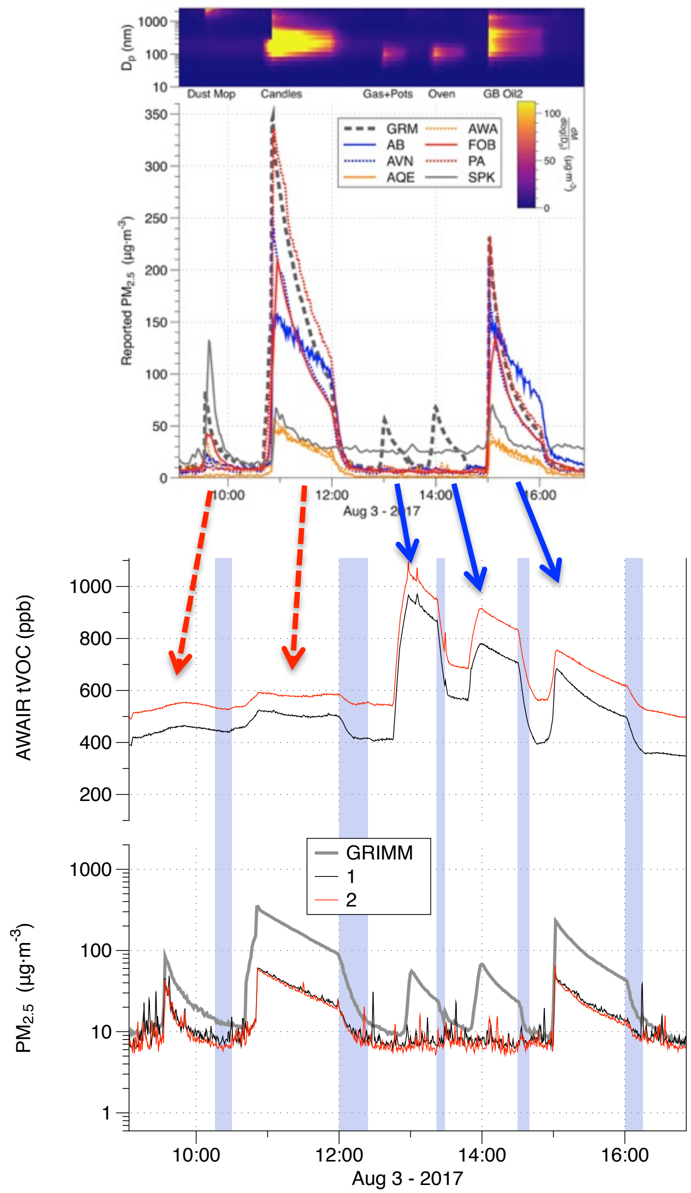
Progress – Air Quality Sensors

Studied performance of consumer monitors that use $PM_{2.5}$ sensors

- Funded mostly by Building America project
- Focus on residential sources but relevant to some commercial building applications

Demonstrated potential to use for control

- Response factors varied by source
- None of the low-cost sensors saw ultrafine particles; but…
- VOC sensor detected some of the sources that emitted ultrafine particles
- Combining VOC, CO_2 and particle sensors may enable more robust control



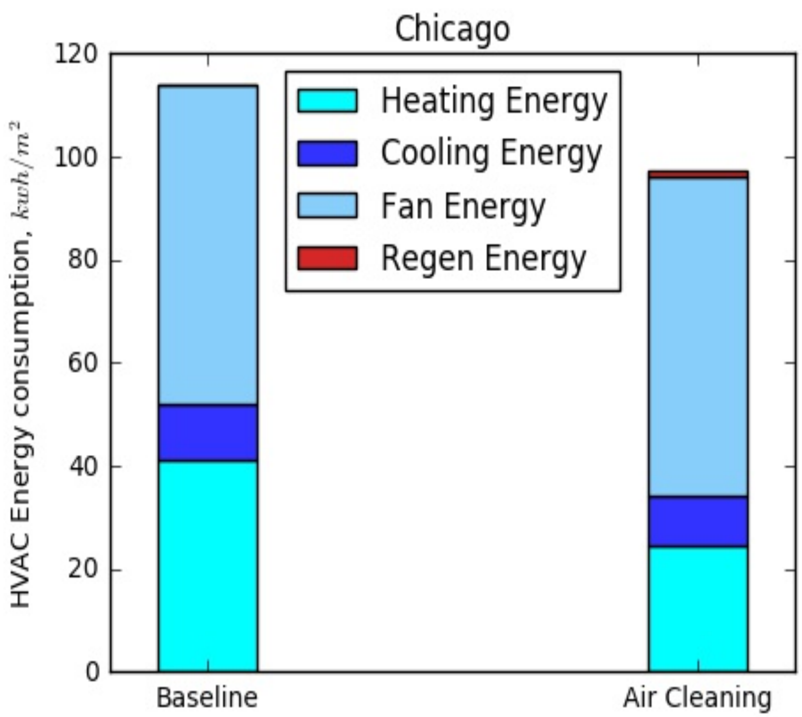
Progress – Simulation Tools

Built single-zone simulation tool to evaluate air cleaning benefits

- Energy Plus calculates energy savings from reduced ventilation
- Efficient, Python mass balance model tracks contaminant concentrations
- Tracks loading and regeneration vs. sorbent capacity

Industry consultations guiding simulation tool development

- Focus on adding air cleaning module to Energy Plus
- Create easy adoption pathway for industry design tools (e.g. Carrier's HAP tool)



Example analysis of annual energy savings smart ventilation w/air cleaning

Stakeholder Engagement

- **Air cleaning equipment**
  - Engaging various industry players (EnVerid, Honeywell, St. Gobain)

- **Air quality sensors**
  - Advising Building America team on ASTM test method for IAQ sensors
  - Information sharing with sensor and platform developers

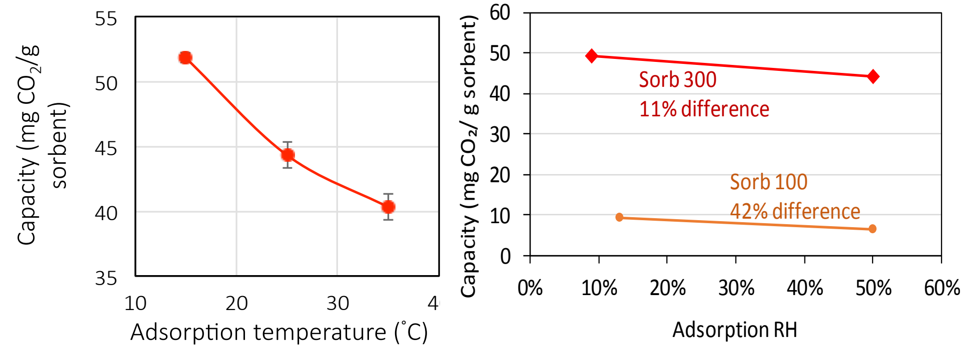
- **Simulation tools**
  - Input from mechanical design engineers
  - Energy Plus development team
  - Carrier HAP team

Remaining Work – Year 3

Advanced Air Cleaning Technologies

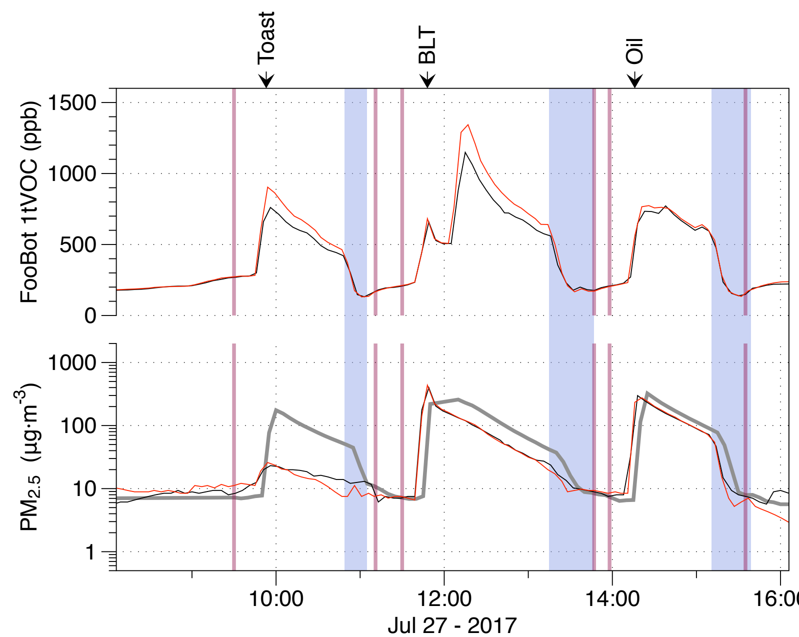
- Evaluate performance through accelerated aging; varied temperatures
- Potential collaboration with Tsinghua Univ. to test in residential system
- BASF will file Pre-Manufacture Notice
- Report performance via conf. and journal

Temperature and humidity effects



IAQ Sensor Performance

- Expand industry team with eLichens
- Investigate source identification using multiple sensors: PM, VOC, CO_2
- Chinese team working on sensors for VOC and formaldehyde



Workshop on Energy and IEQ in Chinese Residential Buildings – Berkeley, July 30-31

Remaining Work – Year 3

Simulation Tools

- Build out mass-balance air cleaning tool using lab-scale performance data
- Apply simulation tools to quantify air cleaning benefits & sizing
- Pre-evaluation tools for Chinese Buildings (Tsinghua) including source emissions database

Demonstrations

- Develop sorbent mix (BASF)
- Design, build commission apparatus
- Test protocol to simulate office day
- Conduct testing, analyze and report
- Identify sites for Y4 building demos

Thank You

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REFERENCE SLIDES

Project Budget

Variances: Y2 funding was $40K less and Y3 is $20K less than proposed; work plan adjusted by extending some subtasks.
Cost to Date: ~81% of Y2 (Work remaining mostly in demonstration task)
Additional Funding: Low-cost sensor / consumer monitor evaluation supported by Building America and EPA IAA.

Budget History					
Apr-2017 to Mar-2018 (past)		Apr-2018 to Mar-2019 (current)		Apr-2019 to Mar-2020 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$280K	$500K	$300K	$465K*	$320K	$565K*

*Assumes $25K per year eLichens and $100K from demonstration partner in Y4.

Project Plan and Schedule

Subtask	Milestone / Deliverable
1.1.1 Evaluate regeneration at lower temperatures.	M1.1: Complete analysis of data to determine regen capacity at T=35–55 °C.
1.1.2 Assess the performance of aged sorbents.	M1.2: Develop sorbent aging procedure. M1.3: Determine regen capacity of aged sorbent.
1.1.3 Document and report new sorbent performance to experts	D1.1: Indoor Air 2018 conference presentation. D1.2: Manuscript submitted to journal.
1.2.1 Sorbent for VOC removal.	M1.4: Suitable VOC sorbent identified.
1.2.2 Prepare and PMN.	M1.5: Experiments to support PMN. M1.6: PMN submitted.
2.1.1 Identify and recruit sensor platform providers	M2.1: Identify 3 potential partners; connect with CERC leaders and IAB as appropriate.
3.1.1 Extend Python-air cleaning tool	M3.1: Model outputs verified by comparison to lab data.
3.2.1 Develop model scenarios	M3.2: List of parametric scenarios to model.
3.2.2 Demonstrate air cleaning system sizing function	M3.3: Complete modeling to determine system capacities.
3.2.3 Conduct simulations to find annual energy, seasonal peak, IAQ	M3.4: Complete set of parametric simulations.
3.2.4 Analyze data and report results	D3.6 Technical report or presentation summarizing results.
4.1.1. Develop sorbent mixtures to be used in room-scale tests	M4.1: BASF provides sufficient quantity of sorbent for room-scale tests at LBNL.
4.1.2 Design and fabricate prototype air cleaning apparatus for testing.	M4.2: Prototype design.; M4.3: Prototype fabricated. M4.4: Prototype installed.
4.2.1 Develop protocol	M4.4: Testing protocol is completed.
4.3.1 Cx prototype system	M4.5: Complete prototype commissioning
4.3.2 Perform tests	M4.6: Complete first room-sale performance tests
4.3.2 Analyze data, report results	D4.1: Presentation summarizing findings of demo

Tasks and Subtasks	Y3 (2018-19)				Y4 (2019-20)				Y5 (2020-21)			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Task 1.1 Chamber testing of air cleaning materials												
1.1.1 Evaluate regeneration at lower temps		M										
1.1.2 Assess the performance of aged sorbents		M	M									
1.1.3 Report new sorbent performance to technical experts		D		D								
Task 1.2 Develop higher performance air cleaning materials												
1.2.1 Select sorbent to add VOC removal		M										
1.2.2 Prepare and submit materials for PMN.			M	M				M				
Task 1.3 Production scale up and commercialization												
1.3.1 Scale up to commercial volumes								M				
1.3.2 Produce sorbents for additional building testing			M			M		D				M
Task 1.4 RD&D on other technologies												
1.4.1 Placeholder tasks for other air cleaning technologies								M				M
Task 2.1 Identify industry partners for IEQ sensing												
2.1.1 Identify and recruit sensor platform providers			M					M				
Task 2.2 RD&D with IEQ sensor industry partners												
2.2.1 Placeholder for work with industry partners								M				D
Task 3.1. Develop mass balance model of air cleaning systems												
3.1.1 Extend Python-based, mass-balance air cleaning tool			M									
Task 3.2 Demonstrate simulation tools to quantify benefits												
3.2.1 Develop parametric model scenarios		M										
3.2.1 Demonstrate air cleaning system sizing function		M										
3.2.3 Simulations of annual energy, seasonal peak, and IAQ impacts			M									
3.2.4 Analyze data and report results				D								
Task 3.3. Connect python air cleaning system tool to Energy Plus												
3.3.1 Submit air cleaning model to EnergyPlus development team						M		D				
3.3.2 Incorporate into local development version of EP								M		D		
3.3.3 Coordinate with Carrier to roadmap addition to HAP tool								M				D
Task 3.4 Expand model capabilities for system optimization												
3.4.1 Use simulation tools to improve air cleaning system controls						M		M		D		
Task 3.5 Add health impacts to tool and assess benefits												
3.5.1 Add health impacts from exposures to model calculator								M			D	
Task 3.6 Apply models to IAQ and energy savings in comm bldgs												
3.6.1 Validate and improve the air cleaning simulation model								M				D
3.6.2 Run parametric simulations to estimate energy and health benefits								M				D

Tasks and Subtasks	Y3 (2018-19)				Y4 (2019-20)				Y5 (2020-21)			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Task 4.1 Design prototype air cleaner for room-scale testing												
4.1.1 Develop sorbent mixtures to be used in room-scale tests		M										
4.1.2 Design and fabricate prototype apparatus for room-scale testing.		M	M	M								
Task 4.2 Develop test protocol for room-scale chamber												
4.2.1 Develop protocol to evaluate sorbent performance			M									
Task 4.3 Demo in room-scale chamber at LBNL												
4.3.1 Commission prototype system			M					M				
4.3.2 Perform tests				M				M				
4.2.3 Analyze data and report results				D				D				
Task 4.4 Demos/Evaluations at other sites (TBD)												
Task 5.1 Reporting												
5.1.1 Quarterly Reporting	D	D	D	D	D	D	D	D	D	D	D	D
5.1.2 Peer review, work scope update, final report				D				D				D
Task 5.2 Workshop on Energy & IEQ in Chinese homes			D									