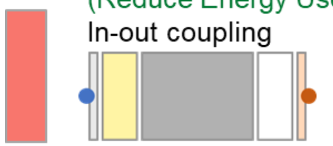
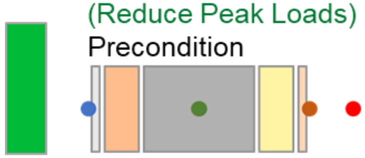
Active Insulation Systems

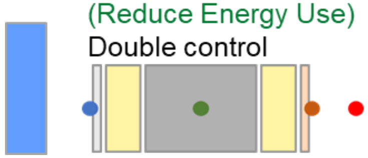
Scenario 2
(Reduce Energy Use)
In-out coupling

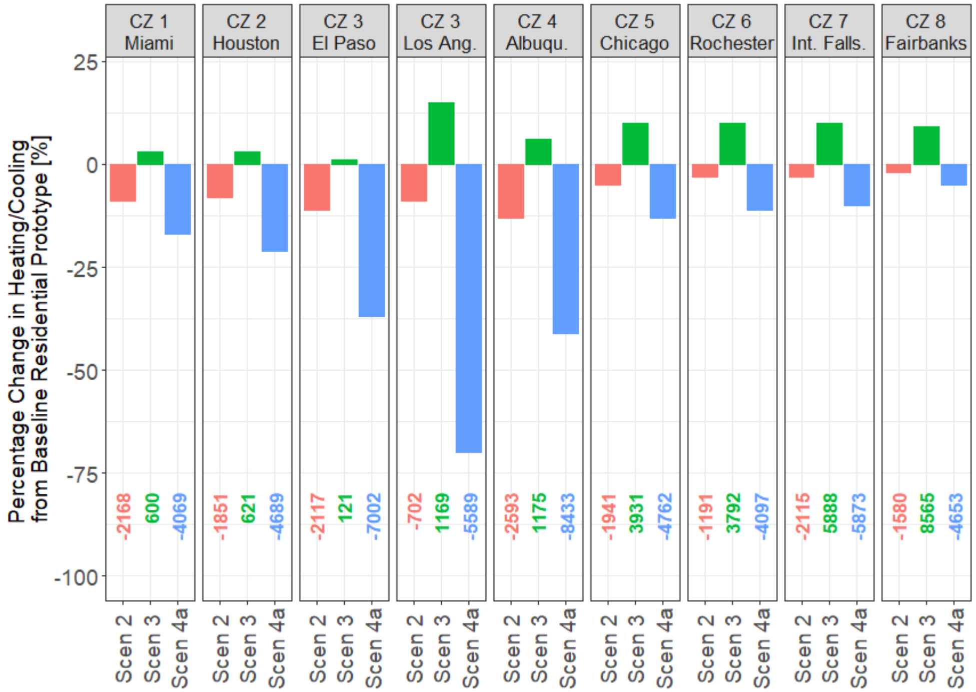


Scenario 3
(Reduce Peak Loads)
Precondition



Scenario 4a
(Reduce Energy Use)
Double control





Oak Ridge National Laboratory
Florian Antretter
+1 865 241 9151, antretterf@ornl.gov

Project Summary

Timeline:

Start date: October 1, 2018

Planned end date: September 30, 2019

Key Milestones:

1. Determined simulation procedure, December 31
2. Summarized simulation results, June 30
3. Developed schematic designs for two active insulation systems (AISs), September 30

Budget:

Total Project $ to Date:

- DOE: $240K
- Cost share: $0K

Total Project $:

- DOE: $350K
- Cost share: $0K

Key Partners:

The project is an initial scoping study.

After confirmation that active insulation achieves significant energy savings, potential partners for the highest impact solutions will be identified in a targeted manner.

Project Outcome:

Simulation results will indicate whether AISs are a technology that should be pursued to make building envelopes dynamic based on:

- Potential energy savings
- Potential reductions in peak demand

Challenge

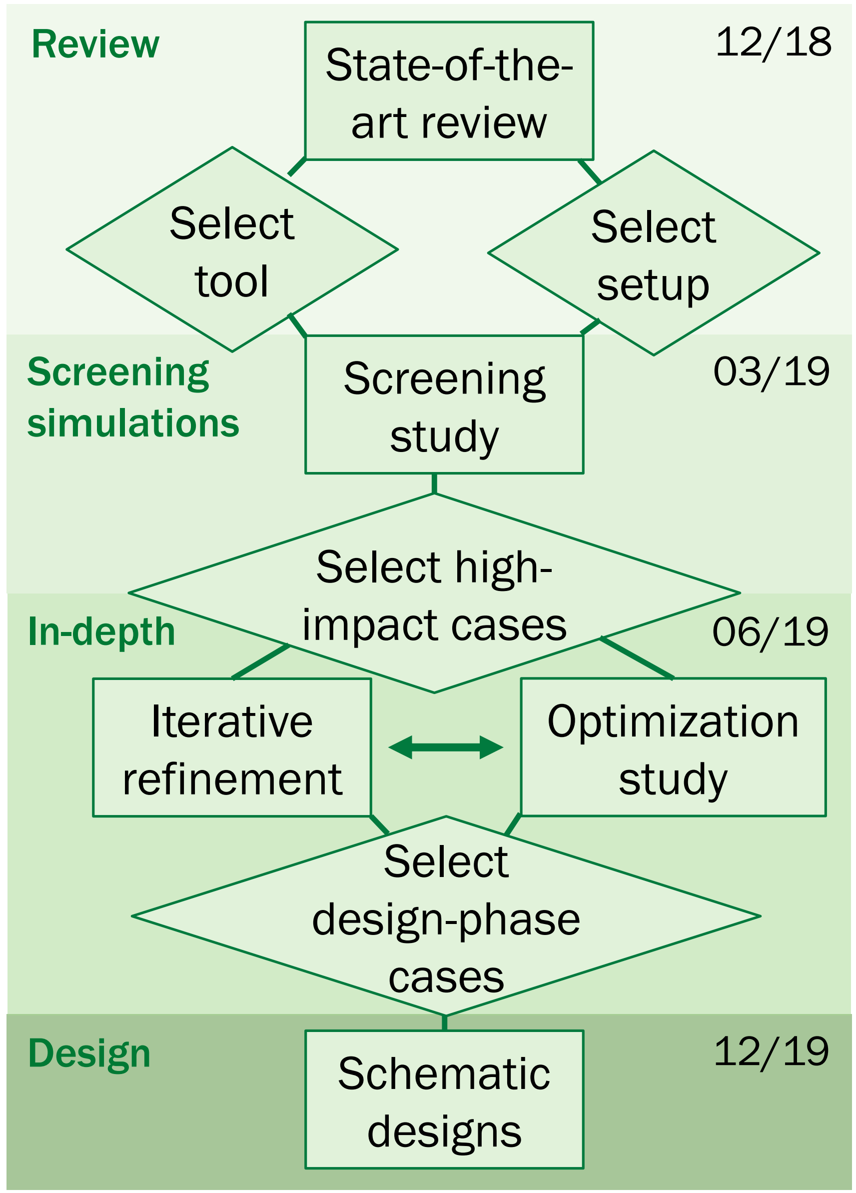
- **Current opaque envelopes are static systems in dynamic environments that cannot do the following:**
  – Use beneficial outdoor conditions
  – Use dynamic controls
  – Control and optimize heat storage
    - Preconditioning
    - Integrate renewable sources

- **Building envelope storage capacity is being underused**
  – Single family wood-frame building storage capacity ~11 kWh/K
  (Diurnal use ~30 kWh, Mass Walls ~25 kWh/K, Powerwall II: 13.5 kWh)
  – Single family water heater storage capacity ~0.22 kWh/K

- **AISs**
  – Can they save energy and provide grid services?

Approach and Team

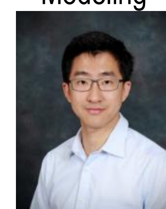
AIS: Material/system that changes thermal conductivity based on external control



Philip Boudreaux
Envelope Systems, Modeling

Som Shrestha, PhD
EnergyPlus Modeling

Florian Antretter
Dynamic Building Performance



Borui Cui, PhD
Optimization Algorithms

Diana Hun, PhD
Envelope Systems New Materials

Mikael Salonvaara
Grid Impact

Systems and Technologies

Mechanism	Description	Reference	Conductivity		Speed of change
			Min	Max	
Gas Pressure	Variable conductance insulation	Benson (1994)	0.025	0.200	-
	Hydrogen adsorption/desorption	Horn (2003)	0.003	0.140	-
	Variable pressure aerogel blanket	Berge (2015)	0.011	0.017	Minutes
	Variable pressure fumed silica VIP	Berge (2015)	0.007	0.019	Minutes
Convection (liquid)	Fluid tanks with different conductivity	Al-Nimr (2009)	0.018	0.640	-
Convection (air)	Permeodynamic wall (breathing wall)	Imbabi (2006)	0.002	0.039	Minutes
	Parietodynamic wall (dynamic void space)	Imbabi (2012)	0.036	0.130	Minutes
	Translucent element with insulation panel between two air gaps	Pflug (2015, 2012)	0.046	0.170	Minutes
	Porous wall with cross airflow	Ascione (2015)			Minutes
	Forced airflow through insulation layer	Elsarrag (2006, 2009, 2012)	0.014	0.090	Minutes
Multi-layer	Collapsing number of air layers	Kimber (2014)	0.026	0.800	Minutes
	Transparent exterior with movable multilayers	Pflug (2017)	0.013	0.262	Seconds
Thermodiode	Direction of nanotube	Wu (2014)	0.400	1.200	-
	Bidirectional thermodiode	Varga (2002)	0.061	0.360	Minutes

Most promising technologies provide controllable thermal conductivity in a broad range with fast switching

Modeling and Control

Tool	Approach	Reference(s)
RC model	Simplified model, limited applicability to reality	Park (2015), Menyhart & Krarti (2017), Shekar & Krarti (2017)
ESP-r	Source code modifications	Loonen et al. (2014)
TRNSYS	No detailed description about implementation	Pflug et al. (2015)
TES	Air channels to short circuit insulation	Elsarrag et al. (2012)
Energy Plus	Two built-in approaches: • "Surface Control: Movable Insulation" • Energy Management System	Pflug et al. (2017), Favoino et al. (2017), Jin et al. (2017), Homem et al. (2017)

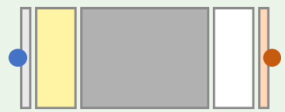
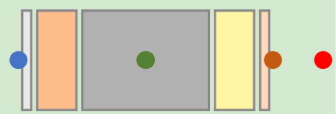
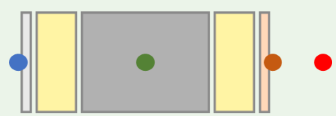
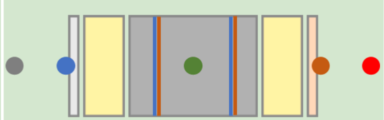
Loonen et al. (2014):

"Despite the limitations in existing software tools, researchers and engineers have developed numerous customized simulation strategies for predicting the performance of responsive building elements in whole-building performance simulation programs… So far, most of these attempts have used workarounds, which tend to rely on approximations or simplifications."

Research Gaps

- Proposed technologies
  - Only tested at lab level or with bench-scale prototypes
  - Most have high energy demand to change thermal conductivity
  - Focus on exterior walls
  - Do not address building integration
- Control strategies are very simple or too complex
- No coupling with dedicated heat charging/discharging system
  - Hydronic system
  - Direct electric heat
- No reproducible and easy-to-implement simulation methods

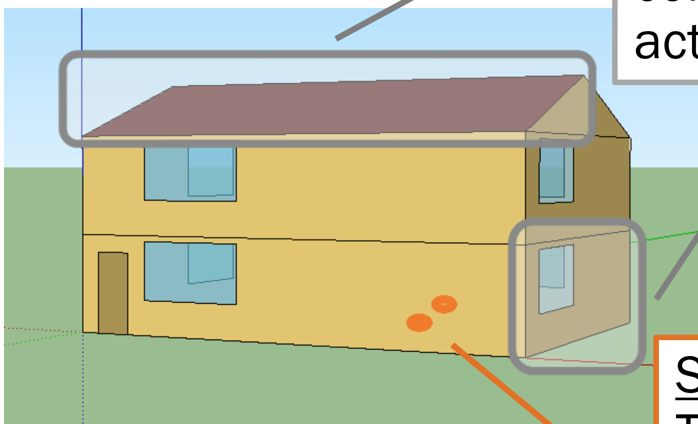
Application Scenarios

Sce- nario	Envelope assembly	Assembly and monitors	Control Comments
1	AIS_{ext} + low thermal mass		Control: Difference in surface temperature Lightweight indoor-outdoor coupling
2	AIS_{ext} + high thermal mass		Control: Difference in surface temperature Mass indoor-outdoor coupling
3	Exterior static insulation + high thermal mass + AIS_{int}		Control: Difference in surface to zone temperature, time of day Pre-conditioning with HVAC (Peak Reduction)
4 (a) (b)	AIS_{ext} + high thermal mass + AIS_{int}		Control: Difference surfaces to thermal mass temperature, difference surface to zone (a) free energy, (b) additional pre-conditioning
5	AIS_{ext} + high thermal mass + dedicated heating/cooling + AIS_{int}		Control: Difference surfaces to thermal mass temperature, time of day energy price Total control over charging and discharging time with highest localized comfort control

● Energy Price ● Exterior surface ● Thermal mass ● Interior surface ● Zone operative temperatures

Active Insulation · Static Insulation · No Insulation · Cladding · Drywall · Low Mass · High Mass

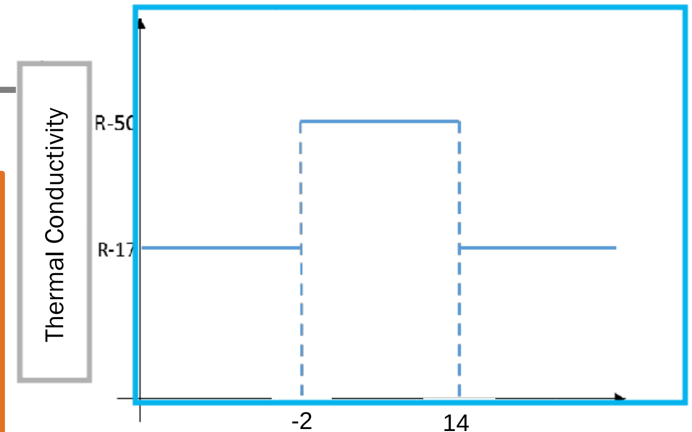
Modeling in Energy Plus



__Actuators__:
Building components with active insulation

Energy Plus
Energy Management System

__Control__:
User-defined, rule-based control algorithm



Temperature Difference in-out [°C]

DOE Prototype Buildings:
- Residential
- Medium office
- Stand-alone retail

__Sensors__:
Triggering parameters:
- Temperatures
  - Surfaces
  - Mass
  - Operative
- Surface heat fluxes
- Energy price

Simulation Study Outline

Screening Simulation Matrix

		Base light	Base mass	Scen 1	Scen 2	Scen 3	Scen 4a	Scen 4b	Scen 5
Residential	CZ 1								
	CZ 2								
	CZ 3								
	CZ 4								
	CZ 5								
	CZ 6								
	CZ 7								
	CZ 8								
Medium Office	CZ 1								
	CZ 2								
	CZ 3								
	CZ 4								
	CZ 5								
	CZ 6								
	CZ 7								
	CZ 8								
Stand-alone Retail	CZ 1								
	CZ 2								
	CZ 3								
	CZ 4								
	CZ 5								
	CZ 6								
	CZ 7								
	CZ 8								

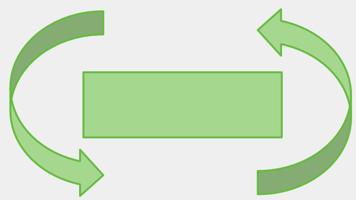
Matrix with

- 48 Baseline variants
- 144 Scenario variants

Iterative Refinement

Identify options with potential based on

- Energy demand
- Peak load



Improve iteratively

Identify ~4 ideal combinations

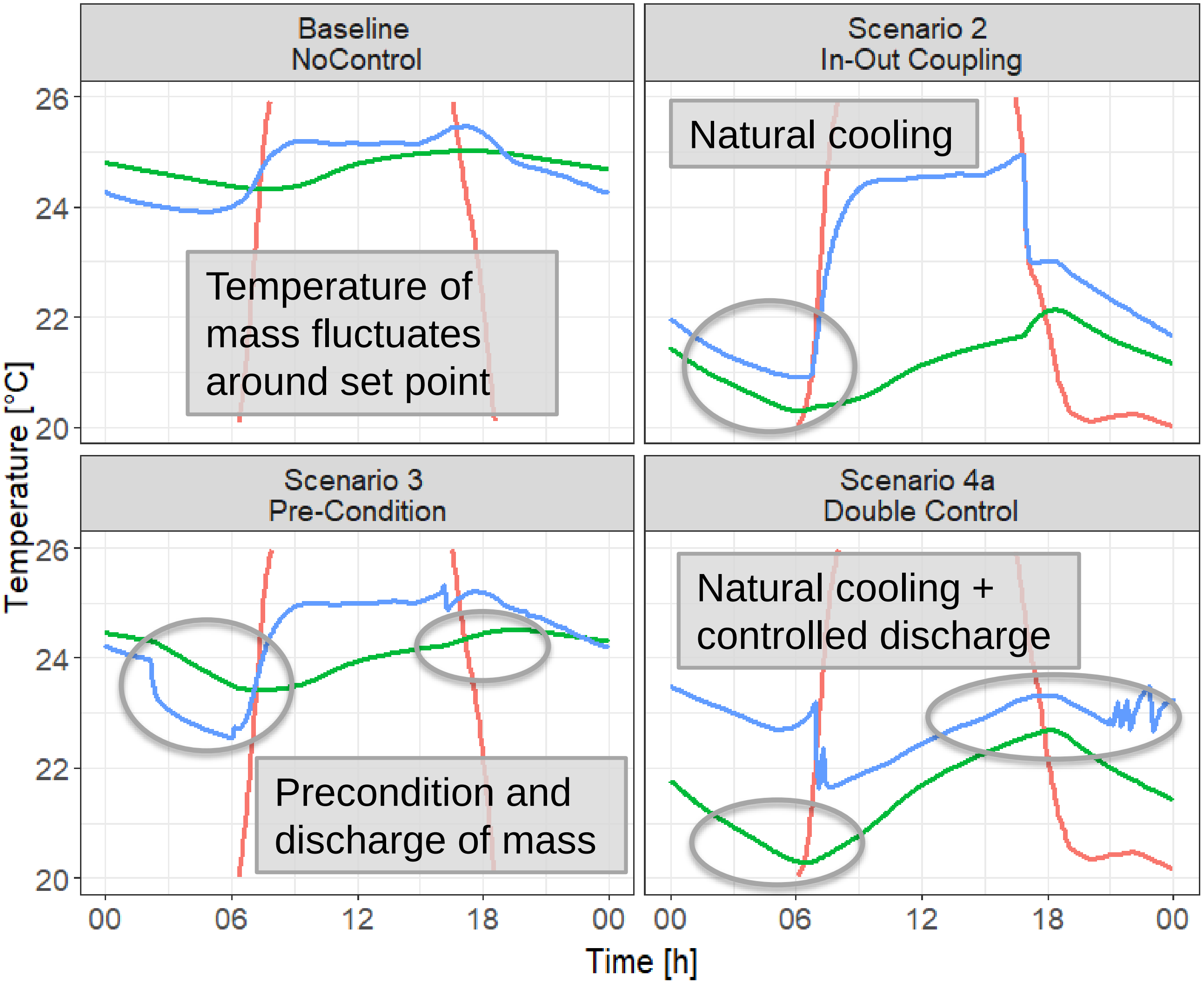
Optimization Simulation

$$f = \min \sum_{t=0}^{t=24} Energy_{cooling+heating}$$

$$f = \min(\sum_{t=start}^{t=end} PeakLoad_{cooling} + \sum_{t=start}^{t=end} PeakLoad_{heating})$$

Apply evolutionary algorithm in conjunction with multi-objective optimization functions

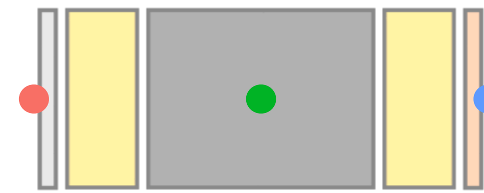
Example Results: Residential Summer



Los Angeles
Residential Prototype

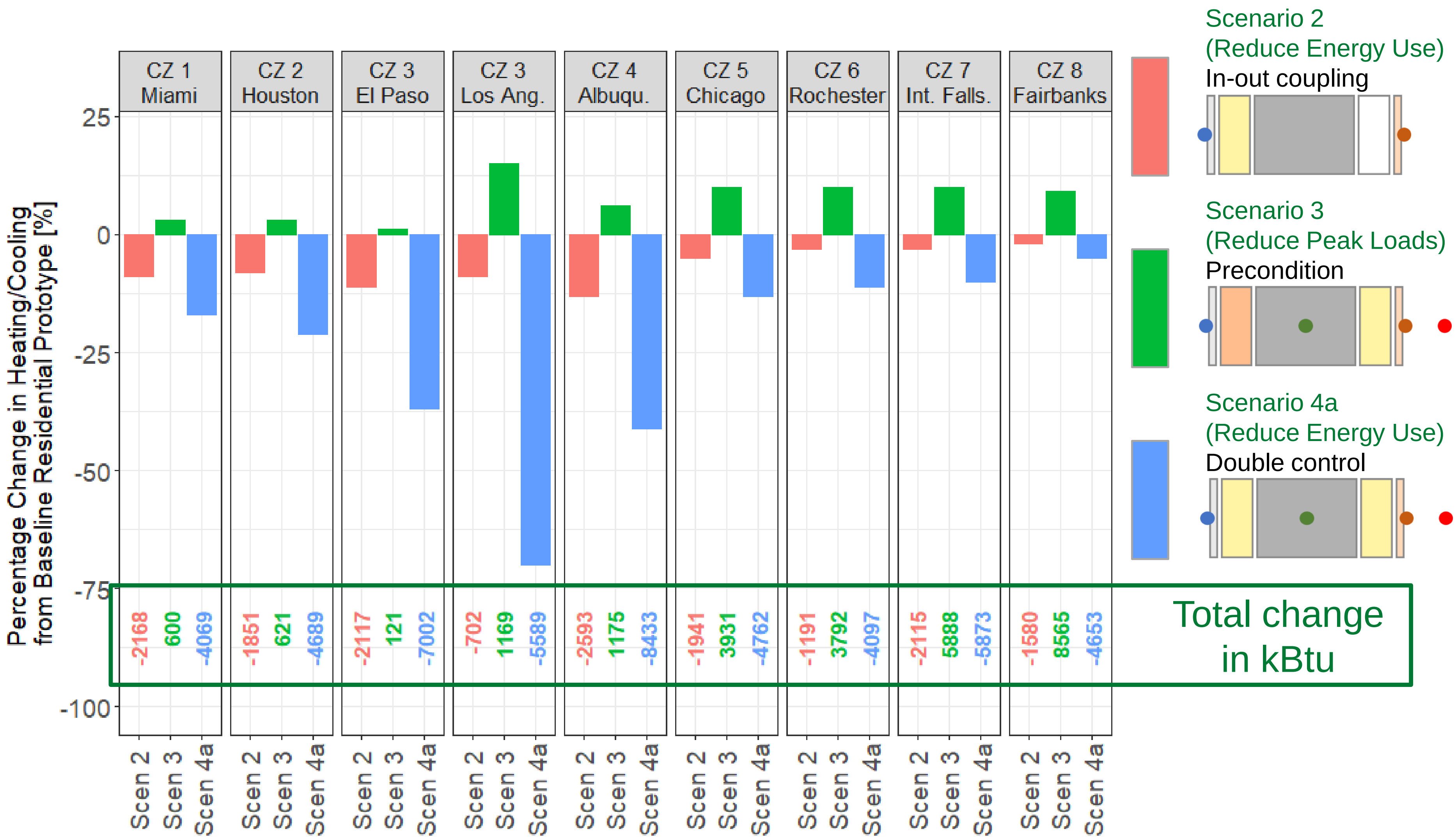
South Wall - August 4

- Exterior Surface Temperature
- Enclosed Thermal Mass Temperature
- Interior Surface Temperature



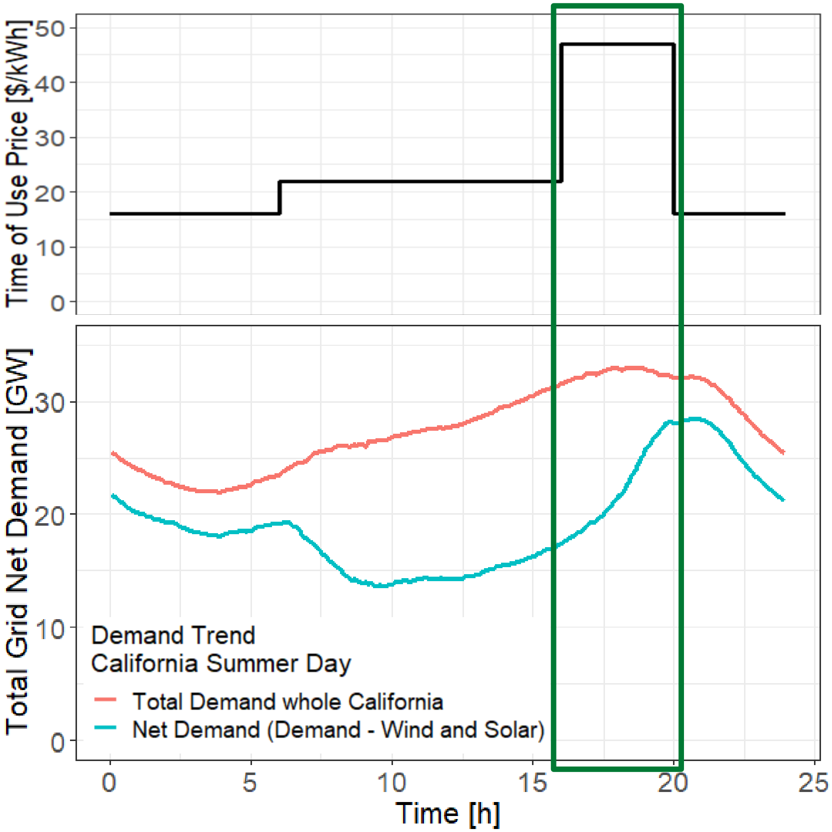
- Wall as naturally driven cooling element (Scenario 2, 4a)
- Coast through peak hours (Scenario 3)

Impact - Energy Savings

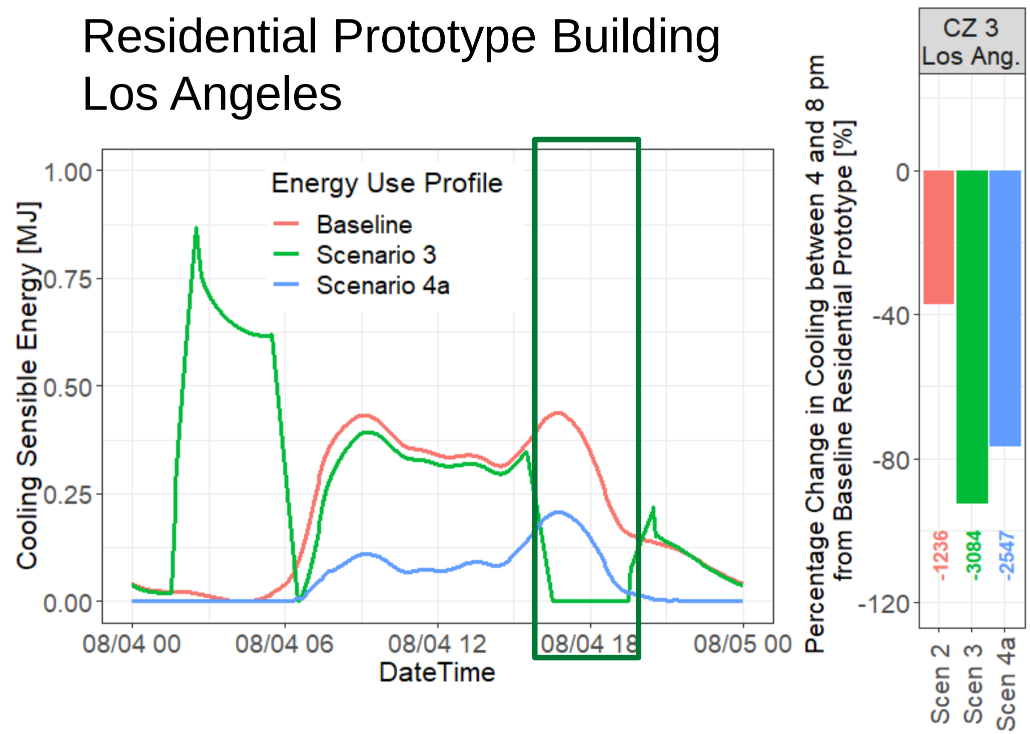


Impact - Grid Services (Los Angeles Example)

Grid Challenge: Afternoon Ramp



Building contribution to address grid challenges: Increase efficiency and shed/shift load



- Shift cooling demand away from “ramp” using active loading
- Lower consumer cost due to Time Of Use price

Stakeholder Engagement

- Presentation at the ASHRAE 2019 Buildings XIV International Conference
- Ongoing discussions with other national labs on ongoing simulation efforts on thermal storage

FY20 and Beyond (DOE funds approved only for FY19):

Based on impact and requirements:

- Involve industry to develop materials and systems
- Involve industry to include controllable building envelopes in building energy management systems
- Discussions with utilities on load shedding, shifting, and modulation requirements

Remaining Work and Outlook

Remaining FY19 Work:

- Simulation Study
  - Complete screening simulations
  - Pick and optimize high-potential options
  - Optimize control with evolutionary algorithms
- AISs schematic designs that integrate simulation results

Building envelope systems with AIS can significantly

- **reduce energy for heating and cooling (up to 70% from free energy sources in first iteration of screening study)**
- **provide grid services (shed, shift, and even modulate loads)**

in all climate zones to make the building envelope an efficient active component

Future Work (Funds Approved Only for FY19)

Benefit

Technologies
- Identification
- Specification

Impact
- Energy
- Grid
- Comfort

System Design
- Properties
- Speed
- Climate

Material/System

Material
- Conductivity
- Speed
- Cost

System
- Sizing
- Loading/unloading
- Cost

Integration
- Airtightness
- Durability
- Connections

Sensor/Control

Sensors
- Integration
- Lifetime

Building Energy Management Sys.
- Integration
- Priority

Advanced Control
- AI integration
- Utility communication

Thank You

Oak Ridge National Laboratory
Florian Antretter
antretterf@ornl.gov
+1 865 241 9151

REFERENCE SLIDES

Project Budget

Project Budget: $350K
Cost to Date: ~$136K

Budget History					
FY 2018		FY 2019 (current)		FY 2020 – FY 2021 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$130K	$0	$220K	$0	TBD	$0

Project Plan and Schedule

		10/18	11/18	12/18	01/19	02/19	03/19	04/19	05/19	06/19	07/19	08/19	09/19
Task 1: Assessment of the State-of-the-Art													
Literature review													
	Technologies and systems												
	Simulation methods, tools, controls												
	Optimization control												
	Identification of research gaps			D1									
Establish simulation procedure													
	Simulation tool												
	Building models												
	System modeling												
	Application scenarios												
	Scoping study set-up												
	Report			D2									
Task 2: Feasibility Analysis													
General preparation													
	Simulation model set-up												
	Logic implementation for control						D3						
Full-scale parametric study													
	Set-up full-scale parametric simulations												
	Run and assess full-scale parametric simulations												
	Identify options with potential												
In-depty simulation study													
	Iterative control improvement												
	Summarize full-scale and in-depth parametric simulation study									G1			
	Identify ideal scenarios									D4			
Task 3: Initial Development of Active Insulation Systems													
Combine information													
	Identify conductivity range, applications												
	Identify large scale manufacturing requirements												
	Identify cost effectiveness												
Schematic designs													
	Describe schematic designs												D5

Deliverables and Milestones

Deliverables/Milestones	Due date	Type
Submitted a summary of the literature to guide the research	12/31/18	Regular
Established a simulation procedure for a 6-month scoping study	12/31/18	Regular
Integrated logic, thermal, and optimization control models for selected residential and/or commercial prototype buildings into simulation environment	3/30/19	Regular
Identified example implementation scenarios for active insulation systems	6/30/19	Regular
Completed summary of simulation results on potential energy savings estimates and benefits to the grid. Decide on: Energy consumption and peak loads can be decreased by at least 20%	6/30/19	Go/No Go
Submitted schematic designs for two AISs based on info gathered in Tasks 1 and 2	9/30/19	Regular