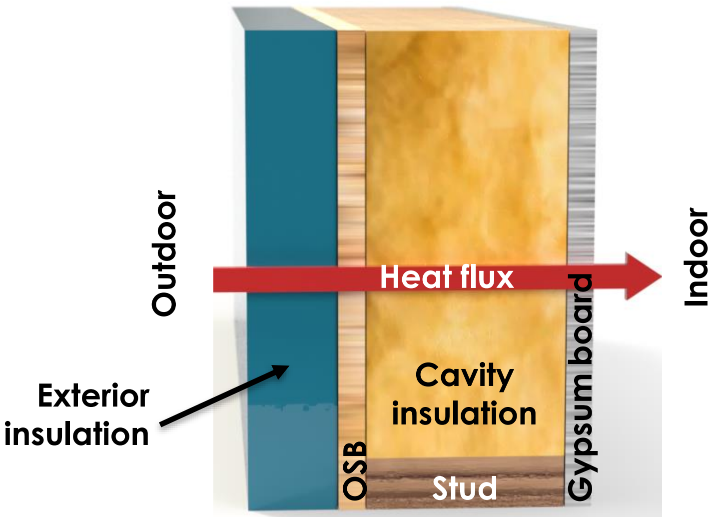
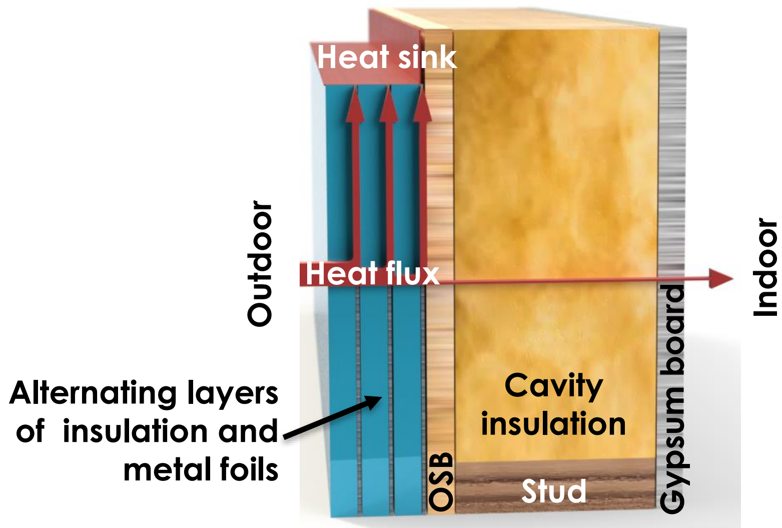
Anisotropic Thermal Management for Building Envelopes



Conventional envelope systems



Envelope systems with anisotropic thermal management

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Project Summary

Timeline:

Start date: 10/1/2018

Planned end date: 9/30/2021

Key Milestones

- Demonstrate reduction in unwanted heat flux by ≥ 25% using lab experiments, Sep 2019
- Conduct field evaluation of technology optimized for reduction in heating/cooling load, reduction in peak demand, maximized energy harvesting, Mar 2021
- Predict savings potential at various weather conditions, Sep 2021

Key Partners: N/A

Budget:

Total Project $ to Date:

- DOE: $483K
- Cost share: $0

Total Project $:

- DOE: $1,452K
- Cost share: $0

Project Outcome:

Optimized design for anisotropic thermal management system for existing and new building envelopes to significantly reduce heating and cooling loads and peak demand

Team

Kaushik Biswas, PhD

Som Shrestha, PhD

Amit Rai, PhD

Kaushik Biswas, PhD

Som Shrestha, PhD

Simon Pallin, PhD

Diana Hun, PhD

Jerry Atchley

Tristan Alexander

Diana Hun, PhD

Team expertise

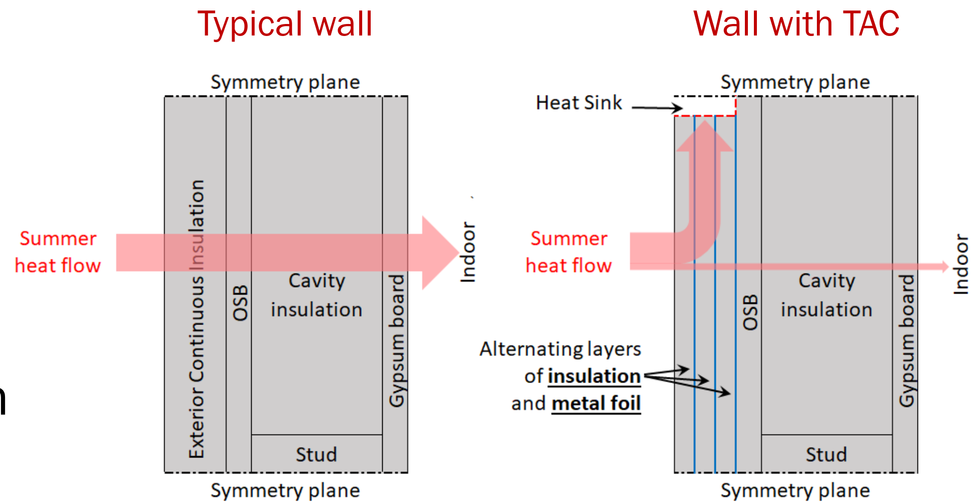
- Design, development, evaluation, and integration of new building envelope technologies
- Experimental and numerical evaluations
- Heat and moisture transport analysis
- Whole-building energy simulations

Thermally Anisotropic Composites (TACs)

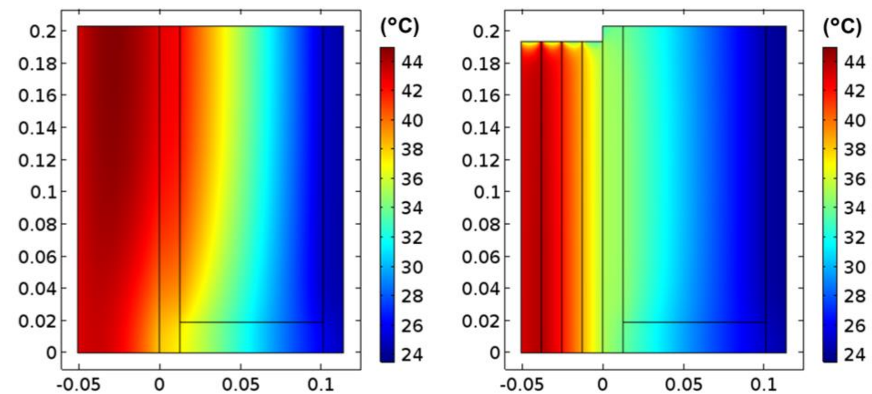
- Conceptual design

$$\frac{Thermal\ conductivity_{metal}}{Thermal\ conductivity_{insulation}} > 1{,}000$$

Metal layers connected to heat sinks/sources (HSSs) are the path of least resistance to heat flow



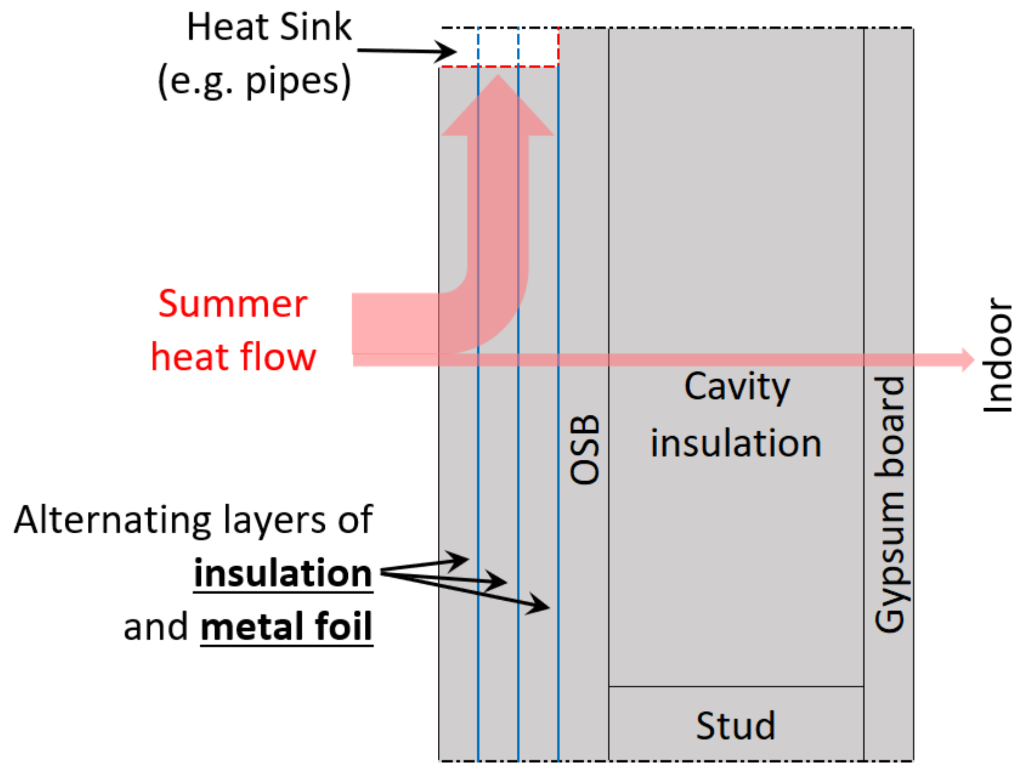
- TACs redirect and significantly reduce unwanted heat flows through building envelopes that decrease heating and cooling energy use and peak electric demand



Proof of concept through COMSOL simulations

Design Variables

- Metal foil
  - Thickness
  - Perforation
  - Number and location of metal foils
- Insulation
  - Thickness
  - Location
- HSS
  - Water and air
  - Temperature
  - Fin dimensions
  - Natural vs. forced convection
- Dynamic control of HSS
- Pipe materials
  - Copper, aluminum, and PEX
  - Two different diameters
- Thermal contact between pipe and foil
  - Aluminum and copper tape
  - Thermal paste



Wall with TAC

Challenge

- Heat transfer through building envelopes ≈ 5.75 quads of primary energy consumption in 2010.*
  And a significant fraction of peak electric demand
- Conventional insulation
  - Needs more space
  - *Does not allow dynamic control of heating and cooling loads*
- Technologies that dynamically control building envelopes can significantly reduce energy use and peak electric demand; however, to our knowledge, such technologies are not available

* DOE BTO Windows and Building Envelope R&D: Roadmap for Emerging Technologies, Feb 2014

Approach and Resources

Conceptual and experimental design

↓

Bench-scale prototype tests | Large-scale prototype tests

↓

Component model calibration → whole-building modeling → systems design

↓

Field evaluation and active control system optimization

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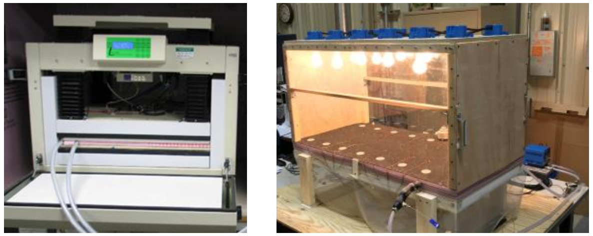
Technical potential* evaluation, identify risks and mitigation plan

*Energy savings, peak load reduction, and thermal energy harvesting potential under various weather conditions using field data and simulations.



Heat flow meter apparatus and custom-built setup for proof-of-concept and bench-scale tests

Large-scale climate simulator for prototype tests

Natural exposure test (NET) facility at Charleston, SC, for field evaluation

Impact

- Support the BTO's goal of reducing building energy use
  - Technical potential for R12/in. insulation is 1.1 quads in 2030*
  - Technical potential of TAC is expected to be higher than that of R12/in. insulation
- Support BTO's grid-interactive efficient building (GEB) initiative by reducing the peak electricity demand
- Proposed technology can potentially reduce peak electric demand attributable to heat flow through building envelopes by ≥ 25%
- Low-grade thermal energy harvesting for misc. applications

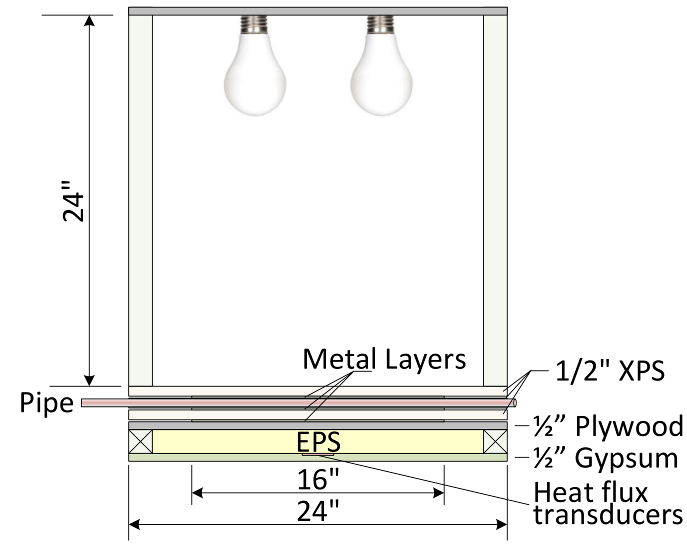
*DOE BTO Windows and Building Envelope R&D: Roadmap for Emerging Technologies, Feb 2014
Assuming addition of 2-in insulation.

Bench-Scale Test

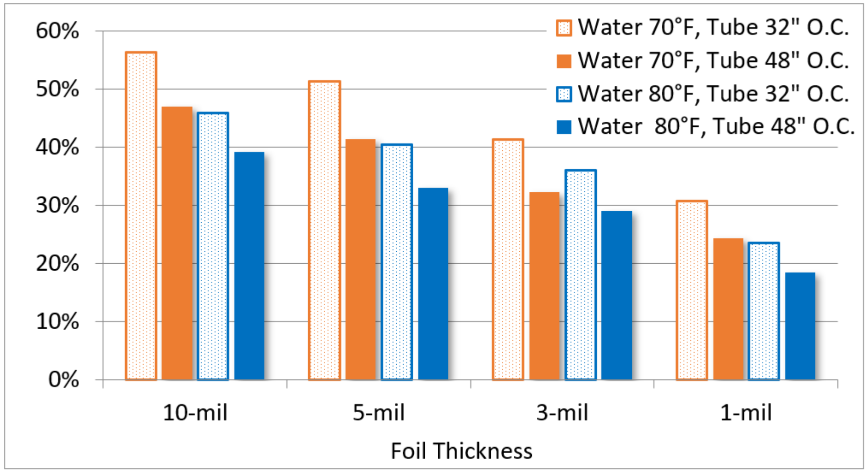
Goal: faster evaluation of relative performance of various design parameters

- Metal foil
  - Thickness: 1, 3, 5, and 10 mil
  - Perforation*
  - Number and location of metal foils
- Insulation
  - Thickness*
  - Location
- Heat sink
  - Water and air*
  - Temperature
  - Fin dimensions
  - Natural vs. forced convection
- Pipe materials
  - Copper, aluminum, and PEX*
  - Two different diameters*
- Thermal contact btn pipe and foil
  - Al and copper tape*
  - Thermal paste*

*Yet to evaluate.



Bench-scale experimental setup

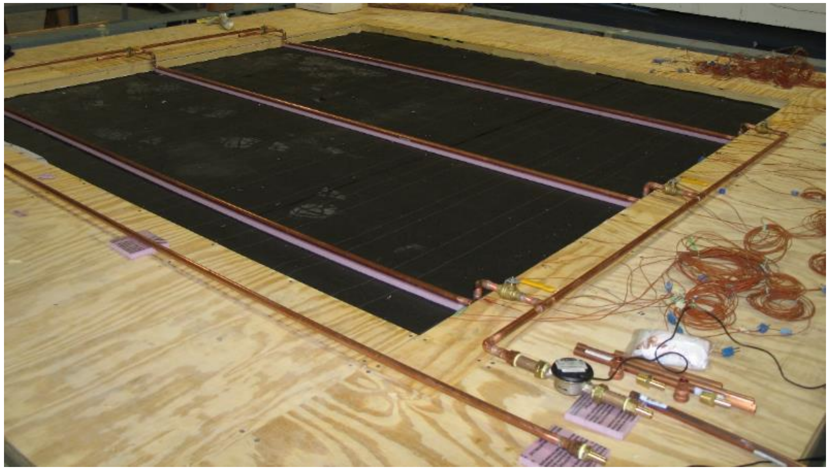


Reduction in heat flux
3 alternating layers of aluminum foil and ½-in XPS
Indoor T 72°F, irradiance 80%

Large-Scale Chamber Test Setup

- Three tests conducted under simulated diurnal weather conditions
  - Baseline wall with R13 cavity insulation
  - Baseline + 1.5” XPS exterior insulation
  - Baseline + TAC (3 alternating layers of 0.5 in. XPS and 0.005 in. aluminum foil) connected to water tubes
- Climate chamber air temperature and irradiance were controlled to simulate summer and winter conditions on a south-facing wall
  - Summer condition for Phoenix, AZ
  - Winter condition for Baltimore, MD

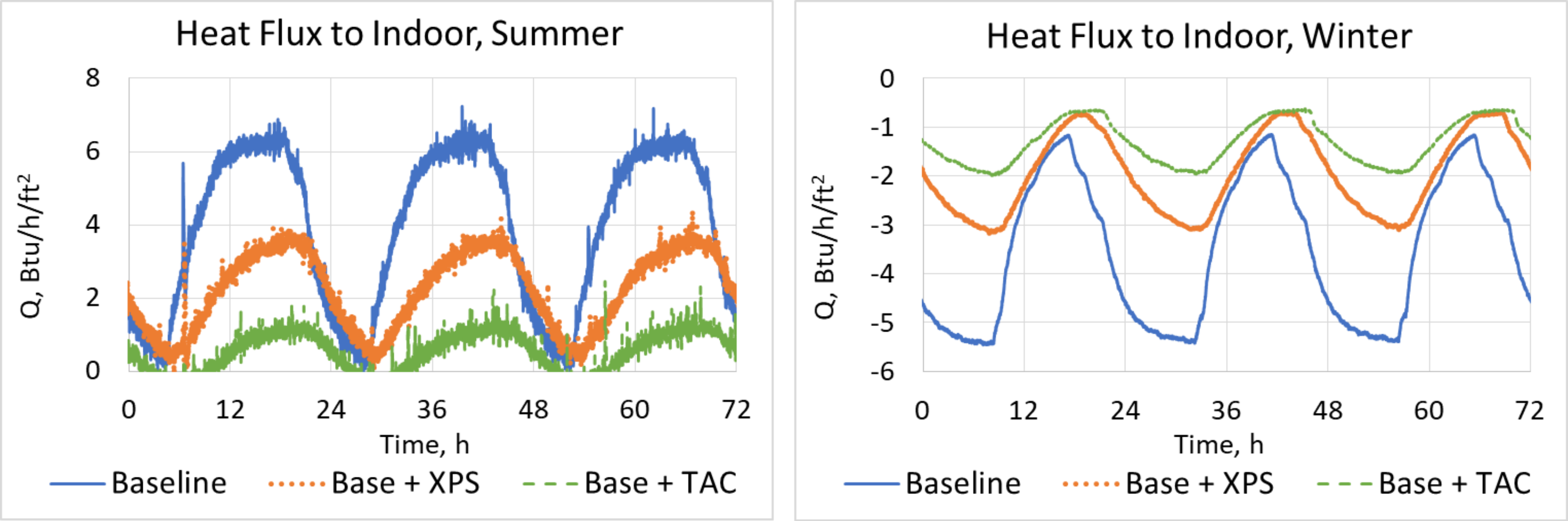
Circulating water	Summer		Winter	
	Supply	Return	Supply	Return
Temperature, °F	81.8	82.0	69.1	68.6
Flow Rate, GPM	2.7		2.6	



Prototype TAC wall being built for large-scale test

Large-Scale Chamber Test Results

- Proof-of-concept Test
- Nonoptimized design w/o dynamic controls
- Significant reductions in summer heat gains and winter heat losses



	Summer heat gain reduction	Winter heat loss reduction
Base + XPS	43%	45%
BASE + TAC	86%	63%

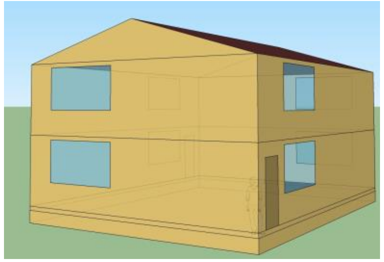
Peak Loads Reduction

- Based on the large-scale climate simulator test (8’ x 8’ metering area)
- Nonoptimized design w/o dynamic controls

Setup	Summer peak heat gain reduction	Winter peak heat loss reduction
Base + XPS	39%	42%
BASE + TAC	66%	63%

- Calibrated COMSOL model using chamber test results and calculated hourly heat flow through walls for DOE residential prototype building using Phoenix and Baltimore weather data

Location	Setup	Summer peak heat gain reduction	Winter peak heat loss reduction
Phoenix	Base + XPS	33%	44%
	BASE + TAC	56%	64%
Baltimore	Base + XPS	41%	36%
	BASE + TAC	59%	66%



Rendering of DOE residential prototype building model

Stakeholder Engagement

- This is an early-stage R&D project
- Introduced TACs to the New York State Energy Research and Development Authority (NYSERDA) and the California Energy Commission.
- Introduced TACs to Katerra, which is a manufacturer of panelized systems. Katerra indicated interest in tracking evolution of TACs given that this technology is ideal for panelized systems.
- Gave a presentation at the Buildings XIV Conference in December 2019

Remaining Project Work: FY 19

TACs and HSS design optimization for field evaluation

- Complete evaluating impact of design variables through bench-scale tests and identify promising designs to run large-scale tests
- Evaluate promising designs in large-scale chamber
- Optimize the TAC designs for field evaluation through simulations of models that are calibrated using large-scale chamber data
- Design dynamic control system and algorithm for heat sink and source for field evaluation

Remaining Project Work: FY 20–21

Field evaluation of the technology to refine the HSS control strategy to maximize savings potential and increase the credibility of the outcome

- Evaluate performance of at least three prototypes, optimized for each of three distinct objectives, and a baseline at a NET facility
- Refine the dynamic control algorithm for heat sink and source for field evaluation
  - Control algorithm will be based on the HVAC operation mode and temperature gradient in building envelope

Remaining Project Work: FY 20–21

Evaluate options to maintain HSS temperature without requiring vapor compression system or thermal energy

- Use harvested heat from TAC in summer for other applications (e.g., domestic water use, water heater, heat-pump dryer)
- Heat transfer to ambient air
- Evaporative cooling
- Ground source using a ground loop (if already existing)

Remaining Project Work: FY 21

Evaluate technical potential and mitigate risks to attract industry collaboration and commercialization of TACs

- Evaluate energy savings, demand reduction, and thermal energy harvesting potential of TACs for various applications and weather conditions through whole-building energy modeling
- Evaluate moisture damage risk of TACs and mitigation plans through hygrothermal simulations
- Explore manufacturing options (preferably prefabricated panel)

Thank You

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REFERENCE SLIDES

Project Budget

Project Budget: $483K
Variances: None
Cost to Date: ~ $127K
Additional Funding: None

Budget History					
FY 2017 – FY 2018 (past)		FY 2019 (current)		FY 2020 – FY 2021 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$447K	0	$36K	0	$969K	0

Project Plan and Schedule

Deliverable/Milestone	FY 2019				FY 2020				FY 2021			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Task 1: Conduct lab tests on various bench-scale and large-scale prototypes												
Designed bench-scale and large-scale prototype TACs for experimental evaluations	Completed											
Completed lab tests on various bench-scale and large-scale specimens using steady-state and diurnal conditions to evaluate the impacts of design variables		Regular	Regular									
Large-scale lab test results demonstrated that TACs reduce unwanted heat flux by ≥ 25% compared to baseline without TACs				Go/No Go								
Task 2: Evaluate and optimize performance of the technology												
Fabricate, install, and instrument TAC panels at natural exposure test facilities					Regular							
Review and analyze the initial data from field experiments						Regular						
Setup detailed 2-D finite element analysis (FEA) models of baseline and various TAC walls and roofs along with the mechanisms for HSS							Regular					
Run FEA simulations using boundary conditions as measured in field and compare the simulation predictions against the measured heat flux. The targeted max. discrepancy is 15%.								Regular				
Optimize HSS and its control algorithm by varying on/off schedule and temperature of the HSS								Regular	Regular			
Complete field evaluation of TAC walls and roofs and calculate reduction in heating and cooling loads compared to the baselines. Assure that the data show at least 25% reduction in heat transfer through test specimens.										Go/No Go		
Task 3: Design the prototype TACs walls and roofs for field evaluations												
Evaluate the performance of TAC walls and roofs with different HSSs under various weather conditions using whole building models. Determine technical potential of TACs walls and roofs in US climate zones 1 to 4											Regular	
Study manufacturing options, materials, performance, and cost of the TACs. Explore ways to overcome any gaps and technical barriers											Regular	
Final report will include experimental results (both the lab and field test results), component level simulation results, and whole-house simulation results. The report will also include the manufacturing options, materials, performance, and cost of the TACs, and some suggestions to overcome the gaps and technical barriers												Regular

Completed Regular Go/No Go