Field demonstration of an attic retrofit strategy using cellulose insulation and phase change material

Kaushik Biswas, PhD, Som Shrestha, PhD,
Andre Desjarlais
(Oak Ridge National Laboratory)

Nicholas Josefik, Andrew Nelson, Larry Stephenson, PhD,
Jeffrey Lattimore
(Construction Engineering Research Laboratory)

Robert DeVries
(Nu-Wool Co., Inc.)

Buildings XIII Conference

December 5, 2016

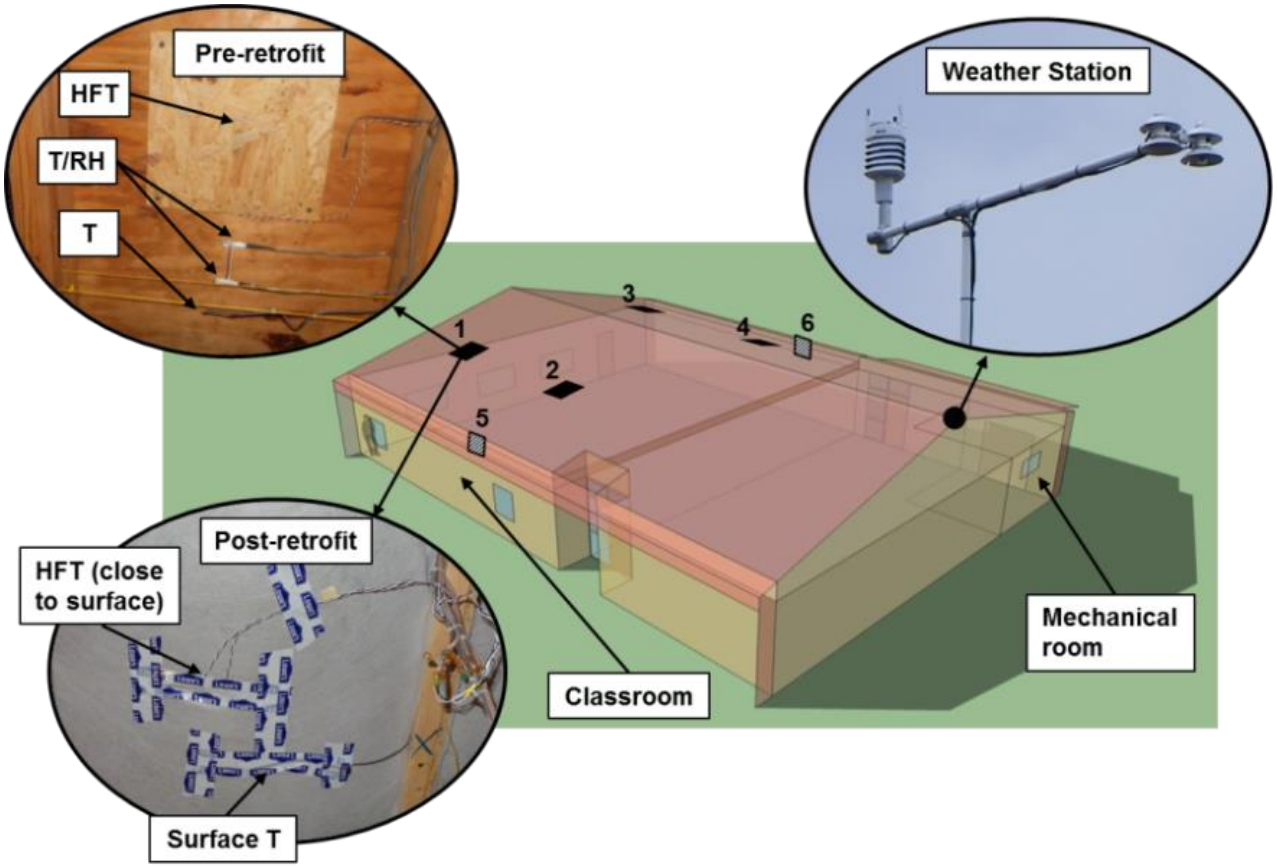
Background

- Energy losses through envelopes cost the DOD more than $200M/year
- DOD is introducing state-of-the-art designs and technologies into its new building design and building upgrade programs
- Insulating the roof and sealing the attic can result in significant energy savings
  - Especially if HVAC equipment and/or ducts are present in the attic
- Present study investigates energy benefits of insulating the roof decks and gables of a classroom building in Ft. Bragg, NC
  - Stage 1: Add cellulose insulation
  - Stage 2: Cellulose insulation + phase change material (PCM)

Classroom building at Ft. Bragg, NC

- Located in ASHRAE climate zone 3 (mild winters and hot summers)
- Vented attic with ducts and R19 ceiling insulation

Instrumentation



- Arrays of temperature (T), RH and heat flux sensors at 4 locations on the roof deck
- T and RH sensors in the classroom.

Research phases

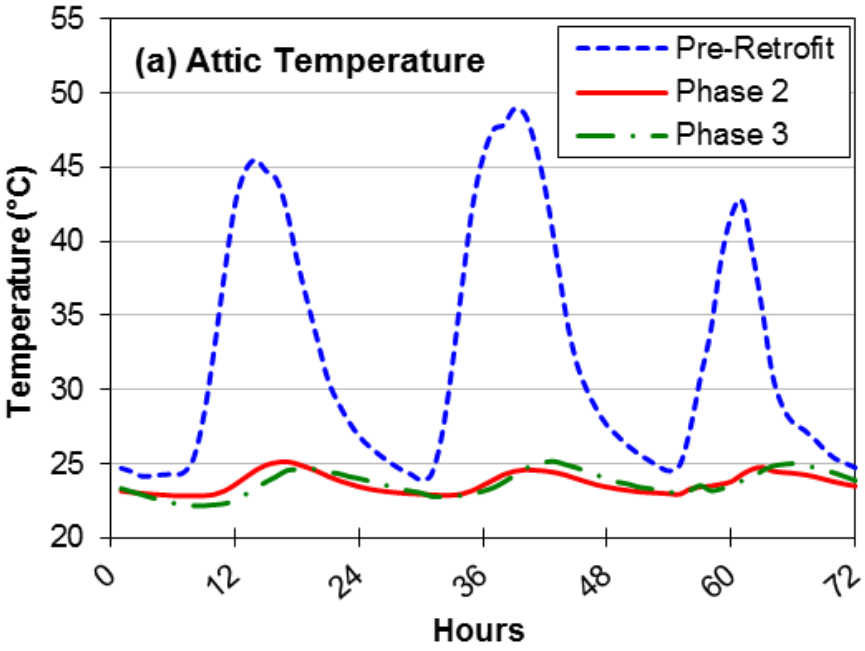
- Phase 1: Existing condition (Feb 2012 – Jul 2013)
- Phase 2: Attic sealed; R29 cellulose insulation added to roof decks and gables; ceiling insulation removed (Jul 2014 – Jun 2015)
  - R16.5 cellulose batt + R12.5 dense-packed cellulose
- Phase 3: PCM added to roof decks and gables, in addition to the existing cellulose insulation (Jul 2015 – Jun 2016)
  - PCM: fatty acid/ester blend; nominal melting/freezing point – 25/22°C; phase change enthalpy – 200 kJ/kg

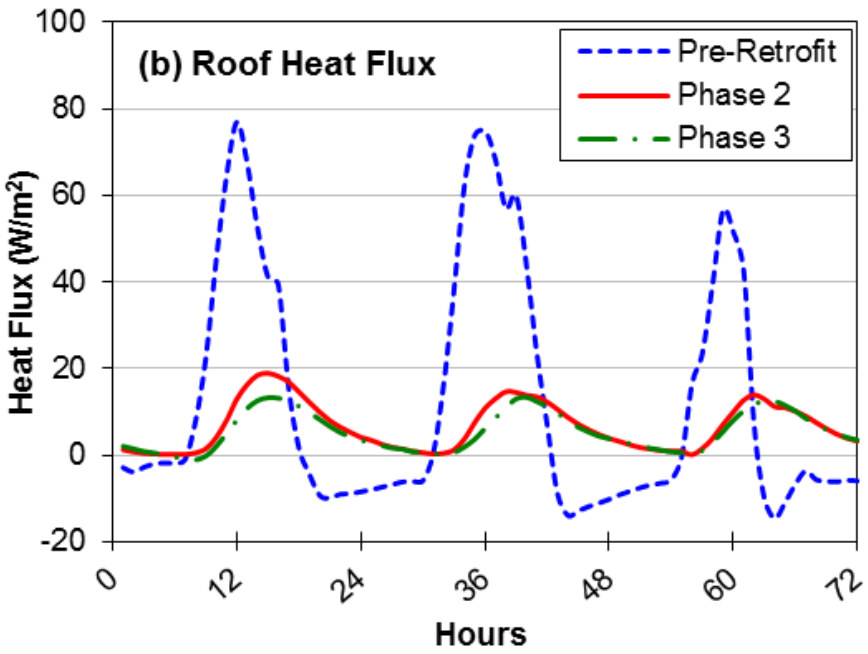


Structural changes in the attic

- Changes needed to add sufficient R-value at the roof decks and gables
- (a) original ‘2x6’ rafters, (b) extended rafters with ‘2x4’ studs added, (c) original framing at gable ends, and (d) extended framing at gable ends

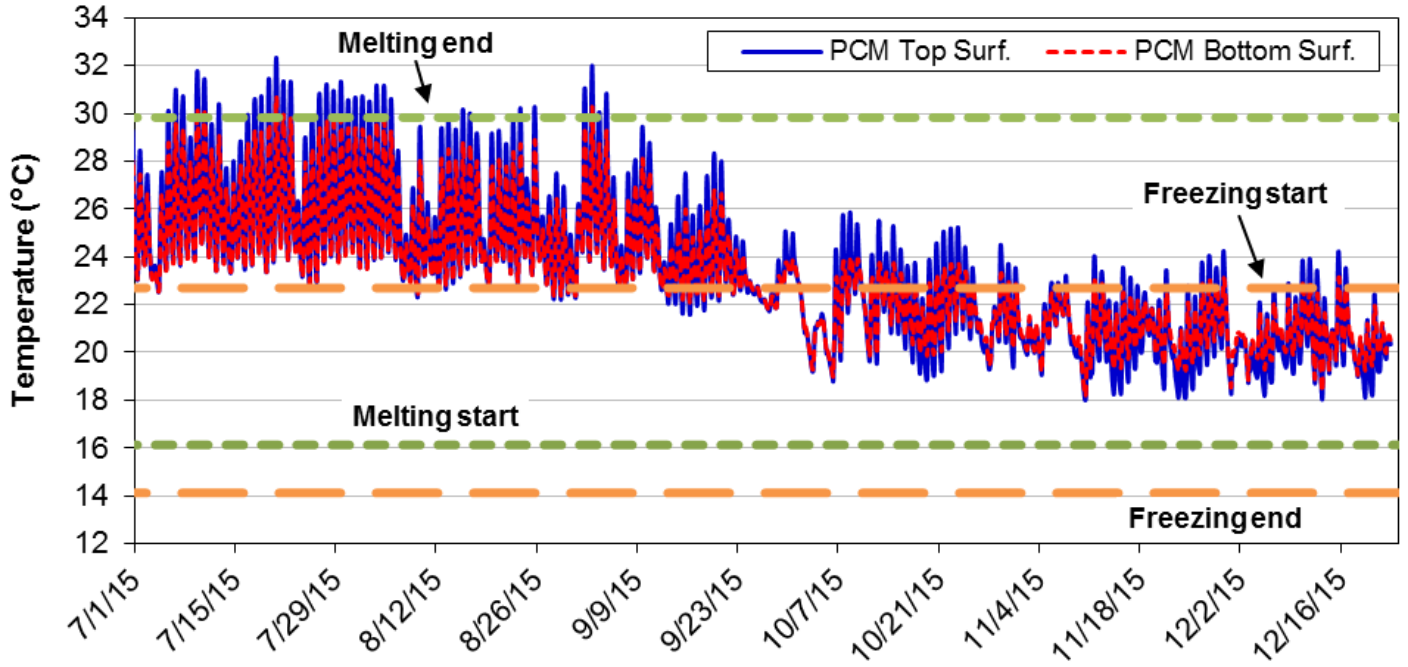
Attic temperatures and roof heat flux





- Data shown for three summer days during the three phases
  - Similar weather conditions (ambient temperatures, solar irradiance, etc.)
- As expected, peak attic temperatures and roof heat fluxes were substantially lower during phases 2 and 3.

PCM behavior

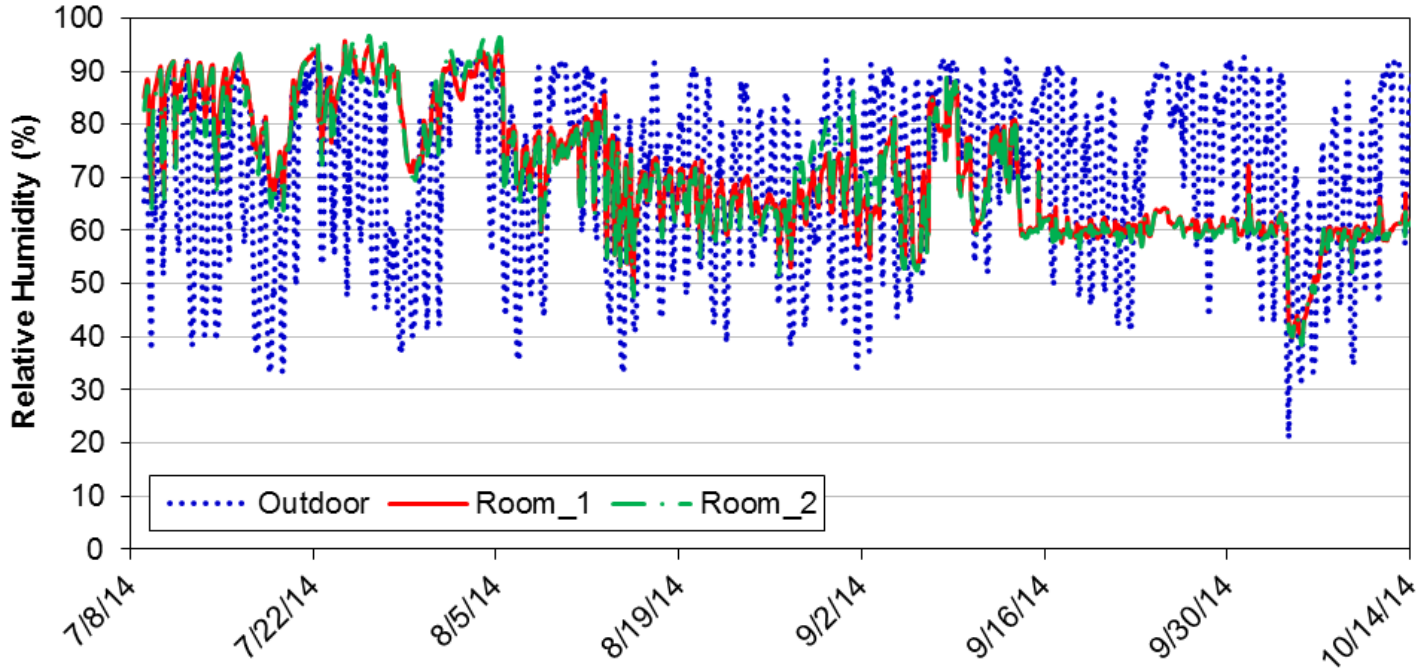


- Difficult to gauge impact of PCM from experimental data alone
- Comparison of measured PCM surface temperatures with known melting/freezing temperature ranges suggests long periods of inactivity
  - EnergyPlus modeling is underway to determine impact of PCM with current and varying levels of cellulose insulation

Building power consumption

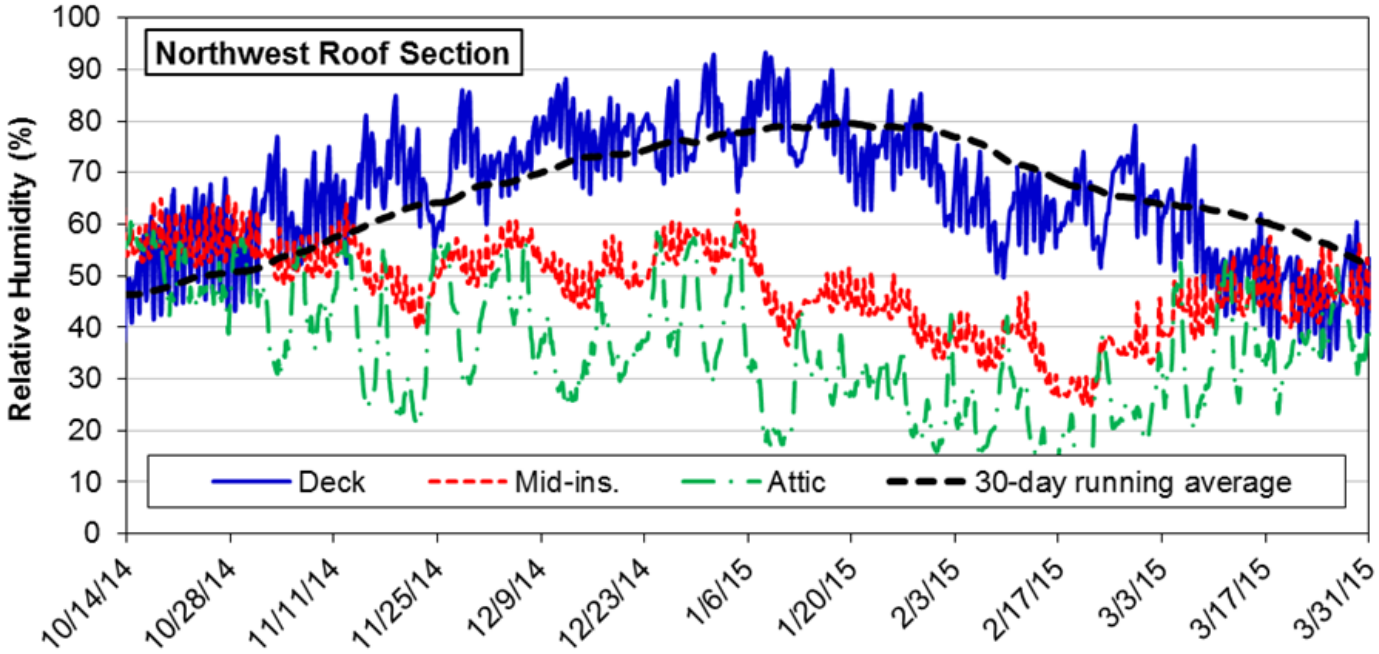
- Building is all electric including heating with electric heat pump.
- Analyses of 12 months of electricity consumption:
  - Pre-retrofit (July 2013-June 2014) - 63,764 kWh
  - Phase 2 (July 2014-June 2015) - 54,604 kWh (14% reduction)
    - Average power consumption also decreased from 7.3 kW to 6.2 kW per hour
    - Heating and cooling degree days were within 1% of each other over these time periods
  - Phase 3: (July 2015-June 2016) - 67,022 kWh (5% increase over pre-retrofit condition)
    - Average power consumption increased to 7.6 kW per hour
  - Analysis is continuing to normalize weather and occupancy effects between different phases
    - Also to identify causes of the increased consumption during phase 3 (weather, occupancy & building usage, changes in HVAC equipment duty cycle, etc.)

Indoor humidity issue



- High indoor RH immediately following the phase 2 retrofit
  - Caused by the substantial reduction in the run times of the HVAC equipment
- Two dehumidifiers were added as a temporary solution
- Duty cycle of the heat pump was increased, resulting in reduced indoor RH
  - Dehumidifiers were removed

Moisture concerns for the roof decks

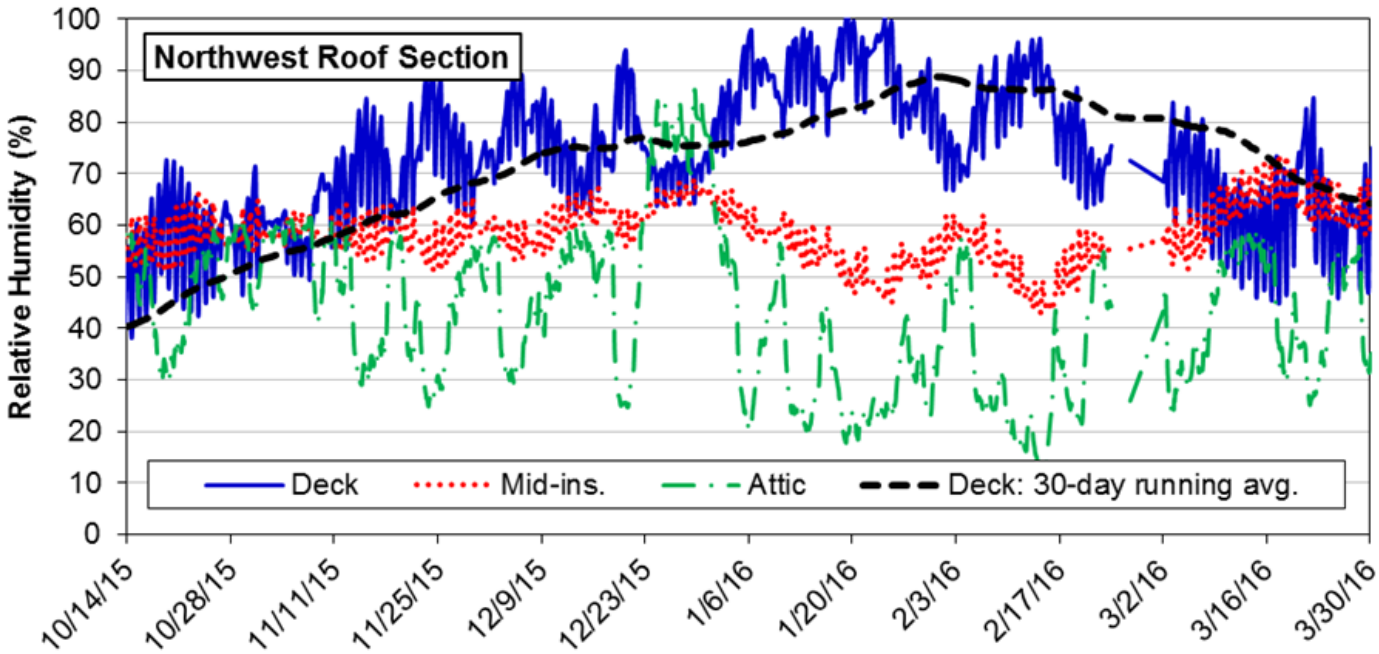


- Concerns regarding drying potential for the roof following any water intrusion due to addition of insulation
- Per ANSI/ASHRAE standard 160, a 30-day running average RH of less than 80% minimizes the risk of mold-growth
- During phase 2, the 30-day running average RH peaked at 79.6%

Moisture concerns with PCM

- Addition of the PCM layer adds to the potential for moisture issues at the roof decks
- Due to requirements at Ft. Bragg, a PCM with Class A fire rating was used
  - Permeability of the encapsulated PCM is 0.09 perms (class I vapor retarder)
  - Preliminary hygrothermal modeling had suggested use of PCM with class III vapor retarder (1-10 perms)
- To alleviate potential issues, PCM sheets were installed with ~1 inch gaps

Moisture concerns with PCM (contd.)



- Even with gaps, the 80-day running average RH peaked at 88% and remained above 80% for several weeks
- Based on this finding, it was recommended to the project team and Ft. Bragg point-of-contact to remove the PCM
  - Removed mid-November, 2016.

Summary & Future Work

- Two-phase attic retrofits of a one-story classroom building in climate zone 3 is reported
- The summer-time peak heat fluxes through the roof were reduced by 75-80% by adding the insulation and PCM
- Building energy consumption analysis indicated 14% reduction between phase 1 (pre-retrofit) and phase 2 (cellulose-only retrofit), but 5% increase during phase 3 (cellulose + PCM)
  - Analysis continuing to determine causes of the increase during phase 3
- Whole building energy simulations are underway to determine the energy benefits under different climate conditions

Thank you!

Questions?