Integrated Whole-Building Energy Efficiency Retrofit Solution

for Residences in Cold/Very Cold Climates

Performance Evaluation

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Introduction

U.S. residential and commercial buildings account for approximately 40% of the nation's total energy demand. Nearly 97 million U.S. housing units were built before 1999; wholebuilding energy retrofits targeting this aging residential building stock promise to achieve a dramatic reduction in total energy consumption and associated greenhouse gas emissions nationwide.

The goal of this project is to develop a transformative solution for integrated whole-building energy efficiency retrofits of residences in cold/very cold climate regions, first targeting single-family attached residences with an approach that can be extended to single-family detached homes and low-rise multifamily housing. A novel highly-insulated prefabricated exterior building envelope retrofit wall system (opaque wall target performance of R-30) represents a modularly attached to existing building enclosures, contains all windows, doors, and penetrations for mechanical services, and achieves airtightness of ≤ 1.0 L/s m^2 @50 Pa at an installed cost targeted at ≤$15/$ft^2$. An envelope-integrated HVAC system that connects to a compatible and optimally-sized modular mechanical pod to deliver heating, cooling, ventilation, and domestic hot water, and provides real-time performance monitoring to maintain less than 800 ppm of CO_2 as an indicator for IAQ. The proposed solution, that implements GPS foam as the insulation material, for mid-scale prototypes is as follows:

- Opaque structural panel
- Panel-to-panel horizontal seam
- Panel-to-panel vertical seam
- Panel-to-panel vertical seam
- Panel-to-window integrated flashing system
- Panel-to-HVAC penetration integrated flashing system

Method

Retrofit solutions are usually evaluated with laboratory measurements, numerical simulations, or a combination of both. Performance testing is important that it increases learnings from the project development. To test and validate the performance of the whole-building retrofit solution, three categories are considered:

- Mid-scale Testing
- Numerical Simulations
- Full-scale Testing

Mid-scale Testing: The Building Energy and Environmental Systems Laboratory (BEESL) facilities are used to evaluate thermal performance of mid-scale envelope system prototypes and to include different types of joints. BEESL's mid-scale assembly test facility has the capacity to test wall sections under a large indoor-outdoor temperature and pressure difference. A separate air-tightness test chamber to decouple the thermal and airtightness testing was set up because even by implementing various strategies (e.g., pressurizing the internal side of thermal performance testing chamber) the system leakage was high. Results for reference panel (opaque wall without joint) showed that heat flux measured at gypsum panel is much higher than the measurement at the panel side. Additionally, the material characteristics inside the air gap of the retrofit solution represent an uncertainty for simulation (considering thermal conductivity and air permeability). The mid-scale testing chambers includes:

- Thermal performance chamber
- Air-tightness testing chamber

Thermal performance measurement: It includes the testing box, an outdoor air simulator, and indoor air simulator, and sensors (thermocouples for temperature measurements across the test assembly, relative humidity and temperature sensors, and heat flux sensors). Data from the thermal performance testing chamber is used to characterize a baseline and then, the percentage of conductance increase for each mid-scale envelope system prototype accordingly for various pressure differences.

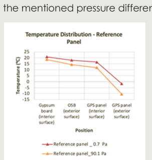
Air-tightness measurement: It includes the test frame, air supply equipment, and instrumentation of measuring the airflow and pressure difference. In addition, the data from air-tightness measurement is used to calculate and characterize the leakage flow rate as a function of the pressure difference for each of pre-mentioned prototypes.

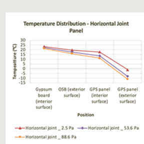
Numerical Simulations: The in-house developed CHAMPS-BES software is used to perform simulations to analyze the coupled heat, air, and moisture transfer in the retrofitting components and enclosure systems under the test conditions (based on assembly component testing and validation data from field testing) and broader climate conditions.

Full-scale Testing: A full-scale retrofit enclosure system will be fabricated for testing in the Building Envelope Systems Test (BEST) Laboratory. This task is specifically important to perform testing and modeling of a full-scale retrofit system.

Preliminary Results

This section does not represent the final results of the project. The presented results are the preliminary results to give a view on how they look like. Testing is an iterative process and under development. What is important is the learnings from the development. The temperature distributions across the specimens are shown under different pressure differences. As expected, the largest temperature drops across the test assembly from indoor to outdoor occurred in the GPS insulation panel. The difference between the panel with horizontal joint and that without the joint (e.g., the reference test) helps to calculate the conductance increase of the horizontal joint at the mentioned pressure difference.

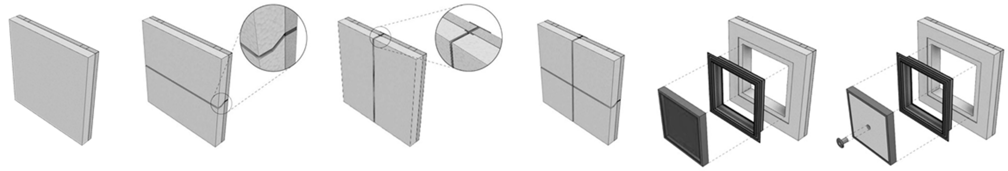




Remarks

Infrared image of the BEST lab shows the distribution of outdoor surface temperatures. While this case represents an approximately uniform because of wall insulation, it might be different for other residential cases. This data has been used for experimental design and sensor mounting. In the next stage, we will test and evaluate a full-scale integrated whole-building prototype at the BEST lab, and validate the whole-building energy model. In addition, a building energy model has been developed to predict the performance of the test case scenario. The model will be validated according to the data from the field measurements. The upcoming stage of the project will be fabrication and installation of full-scale retrofit enclosure system in the BEST lab.

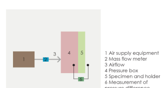
Design of mid-scale envelope system prototypes



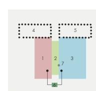
(1) Opaque structural panel
(2) Panel-to-panel horizontal seam and gasket detail
(3) Panel-to-panel vertical seam and back gasket detail
(4) Panel-to-panel vertical seam and back gasket detail
(5) Panel-to-window integrated flashing system
(6) Panel-to-HVAC penetration integrated flashing system

Fabrication of mid-scale envelope system prototypes

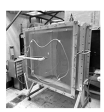
BEESL facilities for testing mid-scale prototypes



1 Air supply equipment
2 Mass flow meter
3 Airflow
4 Pressure box
5 Specimen and holder
6 Measurement of pressure difference



1 Indoor condition chamber
2 Specimen and holder
3 Outdoor condition chamber
4 Indoor air simulator
5 Outdoor air simulator
6 Measurement of pressure difference
7 Sensors

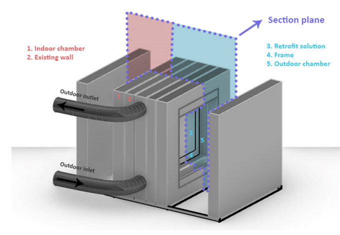


Air-tightness testing chamber

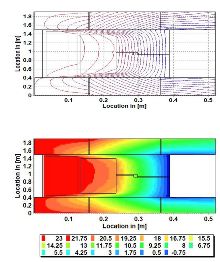
Thermal performance testing chamber

Horizontal joint panel prototypr in air-tightness testing chamber

Opaque panel prototype in thermal performance testing chamber

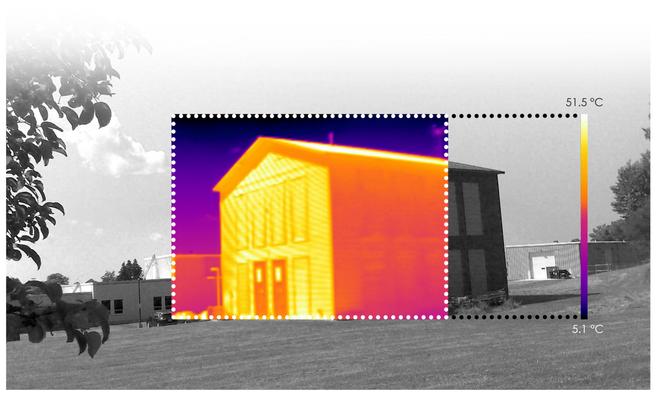


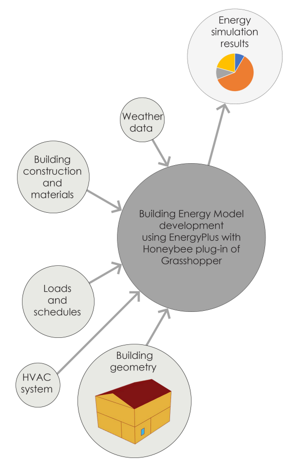
3D visualization of thermal performance testing system



Temperature contours and isotherms of CHAMPS-BES modeling results of horizontal joint panel prototypr installed in testing system.

Verification of the whole-building retrofit solution through field testing using the BEST facility





Conceptual Building Energy Model bubble diagram with inputs/outputs

Syracuse University | cocoon construct | TKF | U.S. Department of Energy | New York State of Opportunity NYSERDA | SyracuseCoE Syracuse University Environmental and Energy Systems, New York State's Center of Excellence | Taitem | Energie Sprong | Upstate HVAC | SHA Syracuse Housing Authority | conifer