Building Envelope Advancement Under the U.S.-China Clean Energy Research Center for Building Energy Efficiency

By Diana E. Hun, PhD

The U.S.-China Clean Energy Research Center (CERC) was launched in 2009 by U.S. Energy Secretary Steven Chu, Chinese Minister of Science and Technology Wan Gang, and Chinese National Energy Agency Administrator Zhang Guobao.[1] This five-year collaboration emerged from the fact that the United States and China are the world's largest energy producers, energy consumers, and greenhouse gas emitters[2] (*Figure 1*), and that their joint efforts could have positive repercussions worldwide. CERC's main goal is to develop and deploy clean energy technologies that will help both countries meet energy and climate challenges. Three consortia were established to address the most pressing energy-related research areas: Advanced Coal Technology, Clean Vehicles, and Building Energy Efficiency (BEE).

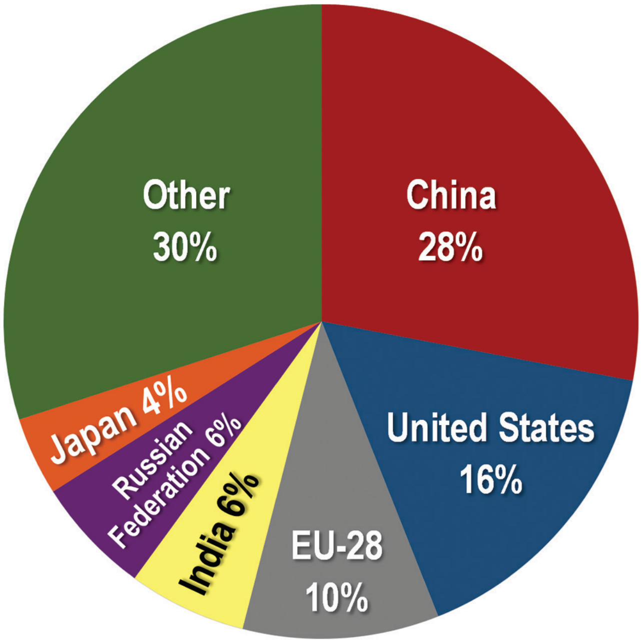


Figure 1 – 2011 Global CO_2 emissions from fossil fuel combustion and some industrial processes.

In 2014, the United States and China renewed their commitments to the U.S.-China CERC for an additional five years, from 2016 to 2020. Under CERC BEE 2.0, Oak Ridge National Laboratory (ORNL) will be leading a project on the advancement of building envelopes. This article provides an overview of the main tasks that will be conducted in this project.

BUILDING ENVELOPE ADVANCEMENT

The main objective of this project is to improve the energy efficiency of commercial building envelopes in both new and existing construction. Estimates from the U.S. Department of Energy (DOE) indicate that in 2010, the primary energy consumption attributable to fenestration and building envelope components in commercial buildings was close to 6 quads of energy per year, or nearly 6% of the total energy used in the United States.[3] Consequently, technological advancements in this area can significantly reduce U.S. energy consumption. Similar opportunities are expected in China, given its fast construction growth and large numbers of existing buildings.

NEW COMMERCIAL BUILDING ENVELOPES

One of the main factors affecting the contribution of building enclosures to energy use in new structures is the quality of workmanship exercised during the installation of envelope components, such as air barriers, water barriers, thermal insulation, sealants, transition membranes, fasteners, and cladding. Deviations from proper installation techniques can lead to unanticipated and uncontrolled air infiltration and thermal conduction loads, which can influence the thermal and moisture durability performance and the longevity of the building envelope. Off-site assembly of most of these components can significantly improve quality control, enhance durability, reduce field installation time, and significantly decrease on-site waste.[4]

Under CERC BEE 2.0, we aim to improve the energy performance and reduce the environmental footprint of precast architectural insulated panels because these panels are one of the most successful types of off-site construction for commercial buildings

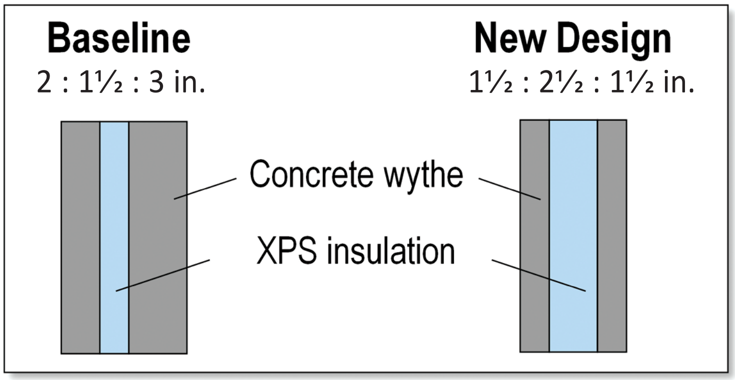
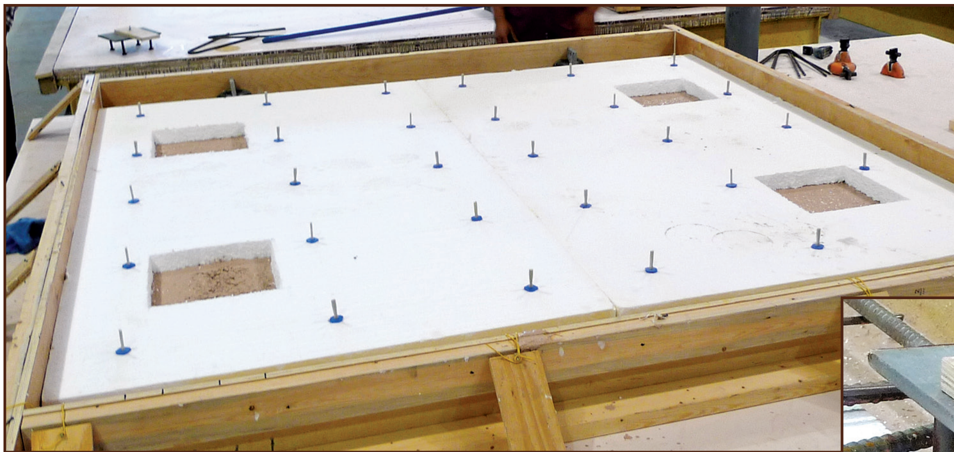


Figure 2 – Layout of the baseline precast insulated panel and the proposed new design that will decrease the thermal loads through the panel by about 40% and reduce the panel weight by about 30%.



Figures 3A and 3B – Voids in the insulation foam board (3A) are made to accommodate steel embeds (3B) that are needed to connect the panel to the structure of the building. Depending on the thickness of the insulation, the void may span part of or the entire depth of the insulation board.

in the United States, and they are gaining momentum in China.[5] To accomplish this objective, we will take advantage of ORNL's diverse expertise in building construction, advanced composites, material science, and 3-D printing. ORNL researchers will be guided by an Advisory Board from the Precast/Prestressed Concrete Institute (PCI).

Our targeted energy performance enhancement is to decrease the heating, ventilation, and air-conditioning (HVAC) loads of precast insulated panel walls by 40% without increasing the overall cost of the panel. As shown in *Figure 2*, our baseline consists of a 1½-in. extruded polystyrene (XPS) insulation board sandwiched between a 2-in. and a 3-in. concrete wythe, which has an effective R-value of 7.9 h ft^2 °F/Btu.[6] We will increase the effective R-value with thicker XPS insulation boards fabricated with blowing agents that comply with the U.S. Environmental Protection Agency's (EPA's) Significant New Alternative Policy Program (SNAP).[7] This measure seeks blowing agent substitutes that are evaluated based on environmental and health risks, including factors such as ozone depletion potential, global warming potential, toxicity, flammability, and exposure potential. Commonly used blowing agents containing hydrofluorocarbons (HFCs) and HFC blends—such as HFC-134a, HFC-245fa, and HFC-365mfc—have

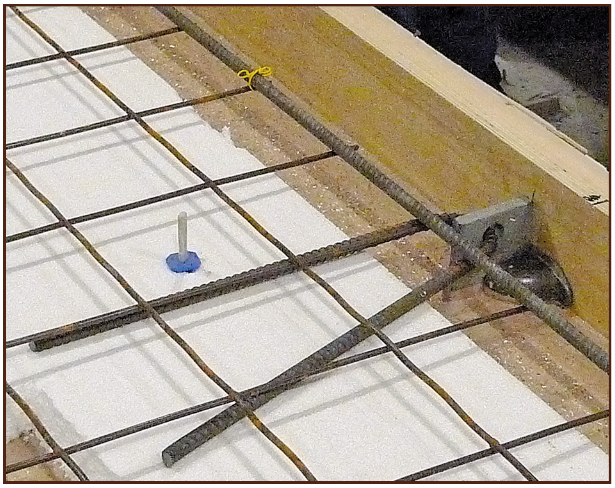


Figure 4 – The top right of the picture shows a discontinuity in the insulation foam board that is needed so that the steel lifting insert is fully embedded in concrete.

global warming potentials about three orders of magnitude greater than that of CO_2. Their use in XPS board stocks will not be allowed after January 1, 2021. Dow Chemical will lead the research on XPS insulation that is SNAP-compliant.

We will also increase the effective R-value by reducing the thermal bridging through the precast panels due to solid concrete blocks that steel embeds (*Figure 3A* and *3B*) and lifting inserts (*Figure 4*) need to develop the required strength, but create discontinuities in the insulation. We will redesign these precast components using long-fiber thermoplastics reinforced with carbon and/or glass fibers (*Figure 5*) so that we either reduce the size of these solid concrete blocks or completely eliminate them. This effort will be led by Dr. Uday Vaidya, who has a joint appointment at the University of Tennessee at Knoxville and ORNL and serves as the chief technology officer for the Institute for Advanced Composites and Manufacturing Innovation.

We will offset cost increases caused by improvements in the effective R-value by lowering delivery, site installation, and labor expenses, which account for about 60% of the total cost of precast architectural insulated panels (*Figure 6*). More specifically, we will reduce delivery and site installation costs by decreasing the thickness of the baseline concrete wythes to 1½ in. This 40% decrease in weight will reduce transportation cost, as more panels can be delivered per truck; lower installation costs, because cranes can be downsized; and bring down the cost of the precast connectors and lifting inserts and building structural systems, because the dead load they will need to support will be lower.

To achieve 1½-in.-thick wythes, we will develop a concrete mix design that has high early tensile strength and provides the finishes needed in architectural precasting. We aim to decrease the Portland cement content by 20 to 40% compared with what is typically used in concrete mixtures for precast walls because cement contributes to about 50% of the CO_2 emitted throughout the manufacture of precast wall assemblies.[8] Panels with the new concrete mix design will have similar or better structural performance compared with the baseline wall. This task will be headed by Catherine Mattus, who is a researcher at ORNL's Nanosystems, Separations, and Materials Research Group.

Reducing the thickness of the concrete wythes to 1½ in. will also require changes to their reinforcement. A substitute for steel reinforcement is needed because steel must be protected against corrosion with a ¾-in. concrete cover, which is currently one of the main impediments to achieving thinner concrete wythes. Therefore, Dr. Vaidya will also use LFT composites to design a thin reinforcing mesh that is noncorroding, complies with fire code requirements, has the ductility needed for reinforced concrete applications, and can resist the expected loads.

To decrease labor costs, Randy Lind of ORNL's Additive Manufacturing Group will investigate using 3-D printing to manufacture molds for casting architectural precast panels. A complex piece of

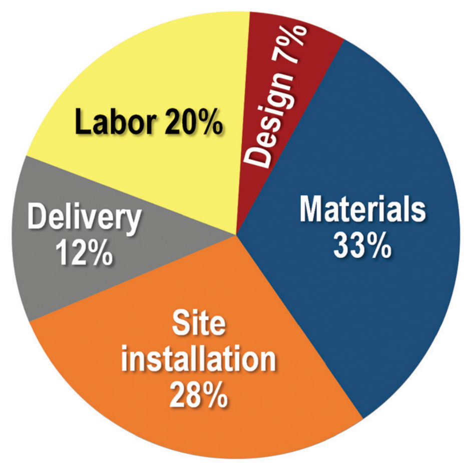


Figure 6 – Approximate cost distribution of precast architectural insulated panels.

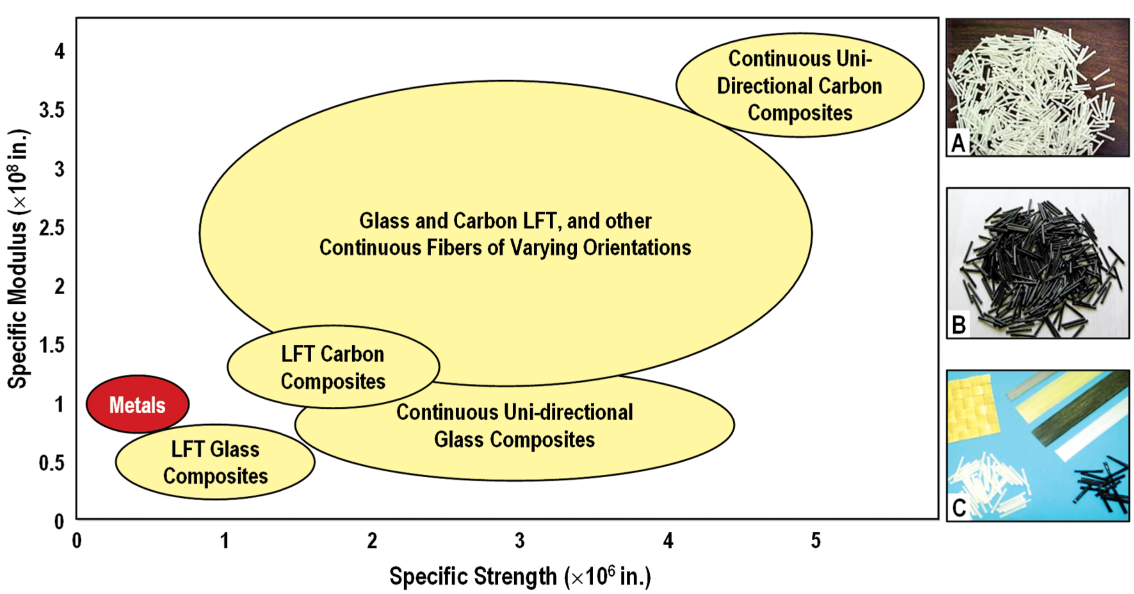


Figure 5 – Comparison of specific modulus versus specific strength, illustrating the superior performance of long fiber thermoplastic (LFT) composites over metals. (A) glass/polypropylene LFT, 1-in. pellets with 30% fiber weight fraction. (B) carbon/polyamide 6 LFT, 1-in. pellets with 30% fiber weight fraction. (C) combination of tapes, long fibers, and woven fiber forms that can be tailored based on load paths and space restrictions.

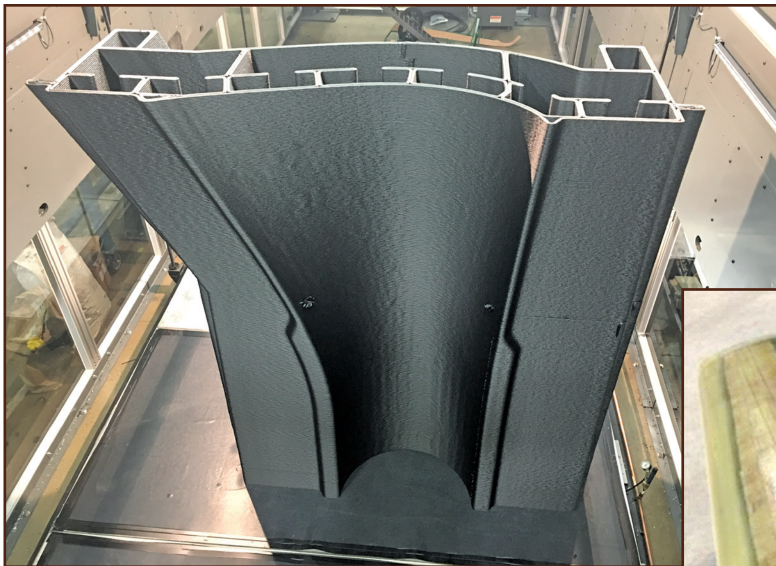


Figure 7A – Inner view of a 3D-printed mold section for a wind turbine blade skin. It took 19 hours to print this 6-ft.-tall piece from carbon-reinforced acrylonitrile butadiene styrene (ABS) polymer. The mold surface will be machined to make it smooth.

formwork can take one to two weeks to build, as this is primarily a manual task. Furthermore, personnel with the craftsmanship skills to do this work are becoming scarce. Our goals are to use 3-D printing to decrease the mold manufacturing time by at least 50% and to provide architects with a much wider selection of shapes. Lind's team is currently working on 3-D printing molds for wind turbines, and they aim to shorten the mold creation process by about 67%—from six months to two. *Figure 7* shows one of the eight mold sections needed to make a 43-ft. blade skin.

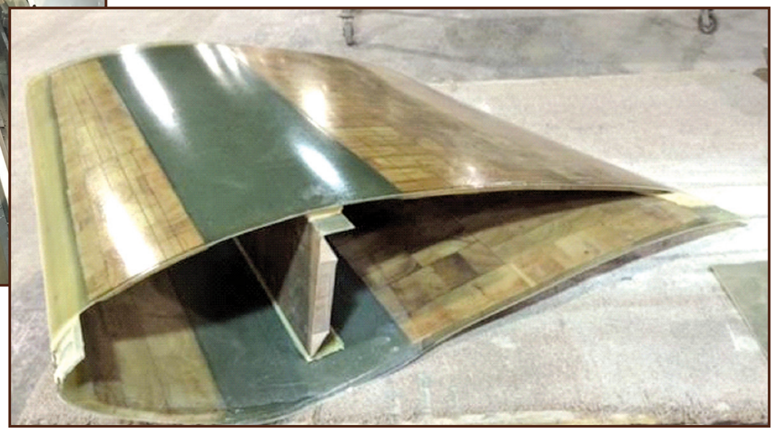


Figure 7B – Short demonstration piece of finished wind turbine blade. Upper and lower skins are formed in molds and later joined together at the leading and trailing edges. Skins are made of fiberglass with balsa wood cores.

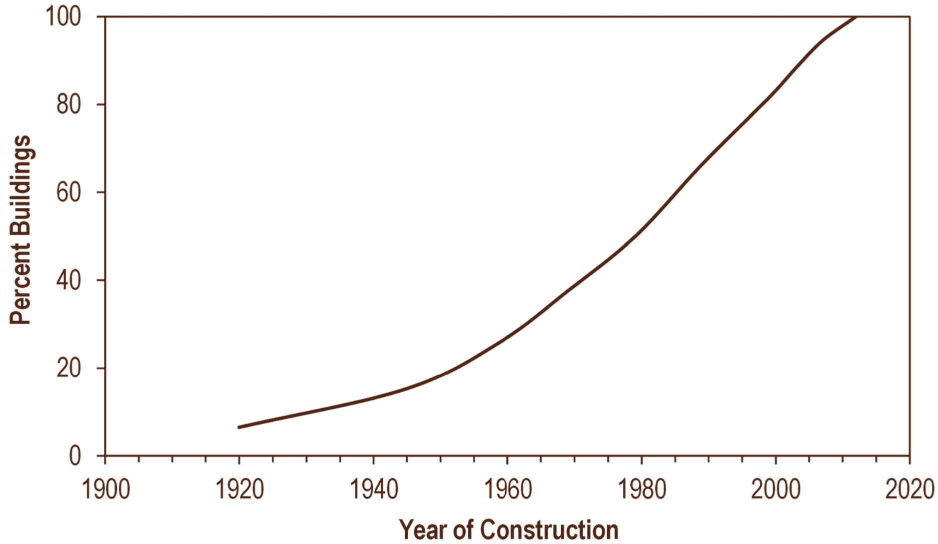


Figure 8 – Cumulative distribution of commercial building construction in the United States.

Under U.S.-China intellectual property and technology transfer agreements, ORNL will share relevant findings from its investigations with the China State Construction Engineering Corporation (CSCEC), which is its Chinese research partner. CSCEC is the largest construction and real estate conglomerate in China, as well as the largest transnational construction company in developing countries. CSCEC is heavily interested in improving precast construction practices, partly because of labor shortages. Consequently, CSCEC will be an ideal partner that can deploy advances in precast insulated panels with speed and scale.

RETROFIT OF EXISTING COMMERCIAL BUILDING ENVELOPES

At least half of the commercial buildings in the U.S. have underperforming envelopes. According to data from the Commercial Buildings Energy Consumption Survey, represented in *Figure 8*, about 50% of commercial buildings were constructed before 1980.[9] Most of these buildings either lack or have only minimal thermal insulation, given that such requirements were first issued by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) in 1975 when it published Standard 90-75, *Energy Conservation in New Building Design*. In pre-1980 buildings, at least 25% of the building envelope contribution to HVAC loads is due to thermal conduction through opaque walls.[10]

Another deficiency among existing commercial building envelopes is that those that were constructed before 2005—90% of this sector's stock—are unlikely to have air barrier systems because air leakage rate requirements first appeared in ASHRAE 189.1-2009, *Standard for the Design of High-Performance Green Buildings*. Similar air barrier language later appeared in ASHRAE 90.1-2010, *Energy Standard for Buildings Except Low-Rise Residential Buildings*, and the 2012 International Energy Conservation Code. Note that all of these documents specify the same three paths to compliance, and only one of these paths involves a field evaluation through a blower door test. Approximately 20% of the building envelope contribution to HVAC loads is due to air infiltration.[11] This percentage has been increasing because adding insulation has become a routine task in new construction and building retrofits, whereas improvements in airtightness have lagged behind.

ORNL used the opportunity offered by DOE's Lab-Corps program to gather information on the retrofit market for commercial building envelopes. Lab-Corps is a new DOE program that helps researchers better understand the commercialization process for new technologies in order to accelerate the development and deployment of clean energy technologies.[12] As part of the first Lab-Corps cohort, Dr. Diana Hun (Principal Investigator), Dr. Som Shrestha (Co-PI), and Dr. Mahabir Bhandari (Entrepreneur Lead) were mentored by Linda Jeng from Dow Chemical. We conducted 75 interviews in which we talked to various segments of the construction industry, such as building owners and managers, architects, engineers, auditors, contractors, and manufacturers of building products. The following are some of our findings:

1. Few case studies are available that provide reassurance regarding expected energy savings and lessons learned that could decrease the perceived complexity of the retrofit process. Given the lack of data, the payback period is commonly assumed to be long, although the estimates provided by the interviewees were usually based on minimal analyses.
2. Financial incentives are welcomed, although few of the interviewees were aware of the federal 179D Commercial Building Tax Deduction, which offers a tax deduction of up to $0.60/ft^2 for building envelope retrofits that show 10% energy and power cost savings with respect to ASHRAE 90.1-2007.[13,14,15] When these energy saving efforts are combined with lighting and HVAC retrofits, the tax deduction can be up to $1.80/ft^2. Note that in the case of public or government-owned buildings, the building owner can allocate the deduction to the building designer, since government buildings are not taxed. A building designer is defined as "anyone who creates the technical specifications for installing the qualifying property and its subsystems; it can include architects, engineers, contractors, environmental consultants, energy service companies (ESCOs), or others." Moreover, a building designer must employ a third-party independent certifier to review the property's eligibility, model the energy use, verify actual implementation of the energy-savings installations, and provide the required Internal Revenue Service compliance certification. Fees from certifiers can range from about $0.043/ft^2 to $0.10/ft^2 depending on the energy savings strategies being pursued. Although 179D could expire at the end of this year, it has been continuously renewed since 2005.
3. Auditors that evaluate potential retrofit strategies for existing buildings tend to be mechanical engineers who are more comfortable with assessing HVAC equipment and lighting. Consequently, many tend to disregard the envelope in their assessments.
4. One of the main drivers behind future envelope retrofits in federal buildings will likely be compliance with Executive Order 13693, *Planning for Federal Sustainability in the Next Decade*,[16] which mandates 2.5% energy reductions per year, using FY 2015 as the baseline. Many fed-

Figure 9 – ORNL is currently seeking owners of commercial buildings who plan to retrofit their buildings' exterior walls in the next three years.

eral buildings have already tackled lighting and HVAC equipment; consequently, the remaining area of retrofit is the envelope. Ideal retrofit solutions for these buildings would improve thermal and airtightness performance and implement power generating techniques, such as solar panels, because federal buildings also must comply with a mandate on renewable energy.[17]

5. The main reasons owners of private buildings consider retrofitting the envelope are to increase the real estate value of their property (as they can raise rents if they can advertise lower utility bills and superior comfort compared with other buildings) and to increase the number of customers that are attracted to a retail venue by the façade of the building.
6. A payback period of less than 15 years is needed.

Based on finding number 1 above, under CERC BEE 2.0, we will conduct case studies to gather data that will allow us to estimate energy savings and payback periods from building envelope retrofits. ORNL is currently seeking owners of commercial buildings who plan to retrofit their buildings' exterior walls in the next three years. ORNL will offer free-of-charge data collection before and after the retrofit, hygrothermal analysis of the proposed renovation, simulations that estimate potential energy savings, and discounts on some air barrier and insulation materials and windows. Those interested in participating in the case studies can contact Diana Hun, the project lead, at hunde@ornl.gov for further information.

Similar efforts on building envelope retrofits will be pursued in China. Although we often hear about the rapid growth of new construction in China, commercial and urban residential buildings that were constructed before 1996 amount to floor space of about 110 billion ft^2.[18] Therefore, a large number of inefficient buildings were constructed before reductions in energy consumption grew in importance. Given that commercial and urban residential buildings share comparable construction practices in China, similar retrofit techniques could be implemented in both sectors. ORNL will potentially explore opportunities in the Changning District in Shanghai because that district intends to promote deep retrofits of commercial buildings in the near future.

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Diana E. Hun, PhD, is a research and development staff member of the Building Envelope Systems Research Group at ORNL. She is currently evaluating the performance of easy-to-install air barrier technologies, examining the feasibility of new air leak detectors for building enclosures, and assessing the cost-effectiveness of using advanced manufacturing in building envelopes. Hun has a PhD in Civil Engineering from The University of Texas at Austin and is a registered professional engineer (inactive) and LEED Accredited Professional.

