Energy Design Update

The Newsletter on Energy-Efficient Housing

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IN DEPTH

Airtight Done Right

Sealing With Aerosol – Advances and New Developments

The American home is responsible for about 23% of energy use in the United States, and 43% of that energy use is dedicated to heating and cooling (DOE 2014; see Figure 1). For current homes, the US Department of Energy (DOE) estimates that 29% of space conditioning use results from air infiltration. Of the 135,000 homes in the US Residential Diagnostics Database (ResDB; *http://resdb.lbl.gov*), there was a geometric mean leakage of 11 air changes per hour at a pressure difference of 50 Pascals (ACH50). This unintended air infiltration results in additional space heating and cooling equipment loads, as well as loss of comfort and uncontrolled airflow in homes.

How to get homes airtight is not only a debate in the laboratory, but also a constant challenge in the field. Even the best traditional sealing methods are manual, making them costly in time and labor and hard to verify. A builder must rely on contractor personnel to visually identify and manually seal leaks individually, which means that the ultimate airtightness level is

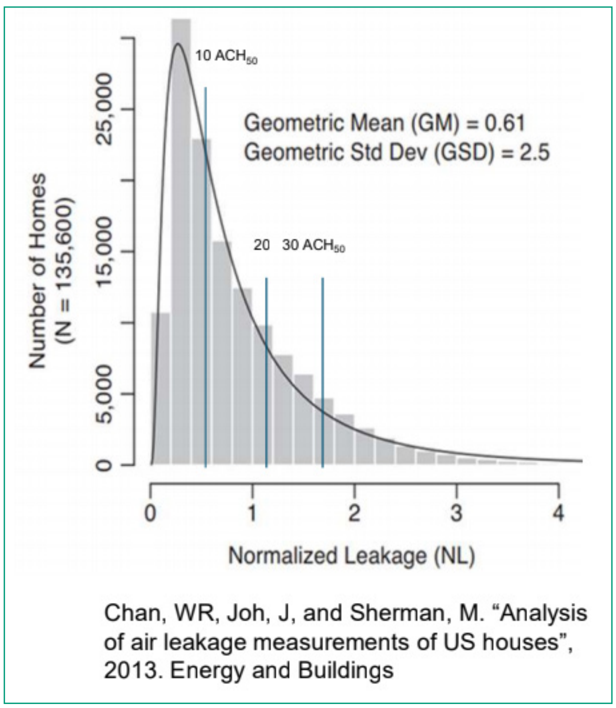

Figure 1. Heating and cooling is responsible for a large fraction of US energy use; it accounts for 43% of the total usage in residential. Infiltration is responsible for 30% of that figure (Chan, WR, Joh, J, and Sherman, M. "Analysis of air leakage measurements of US houses", 2013. Energy and Buildings.) Figure courtesy Western Cooling Efficiency Center and Center for Energy and Environment.

Figure 2. Curtis Harrington, Senior Engineer at the Western Cooling Efficiency Center, and Dave Bohac, Director of Research at the Center for Energy and Environment, are leading teams investigating aerosol and its possibilities for addressing current challenges in envelope sealing. Figure courtesy Western Cooling Efficiency Center and Center for Energy and Environment.

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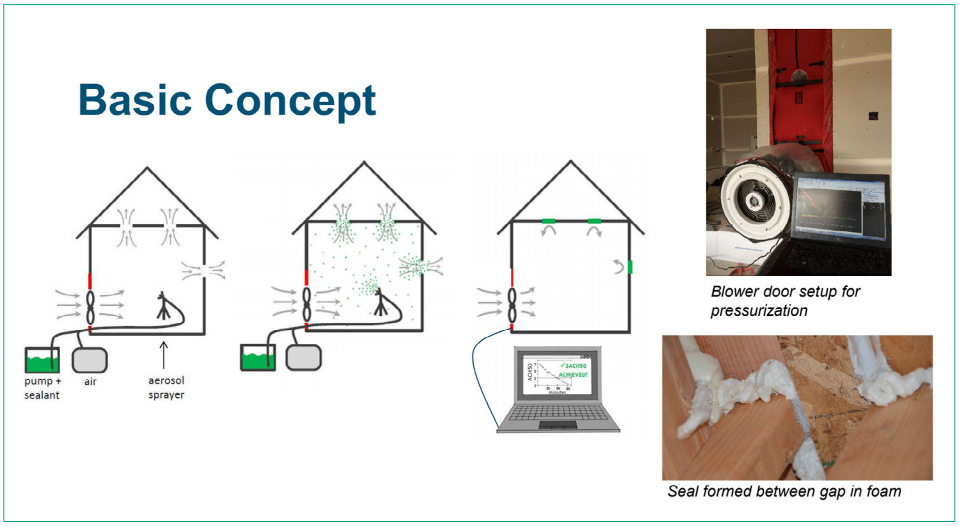

Figure 3. The aerosol sealing process. Figure courtesy Western Cooling Efficiency Center and Center for Energy and Environment.

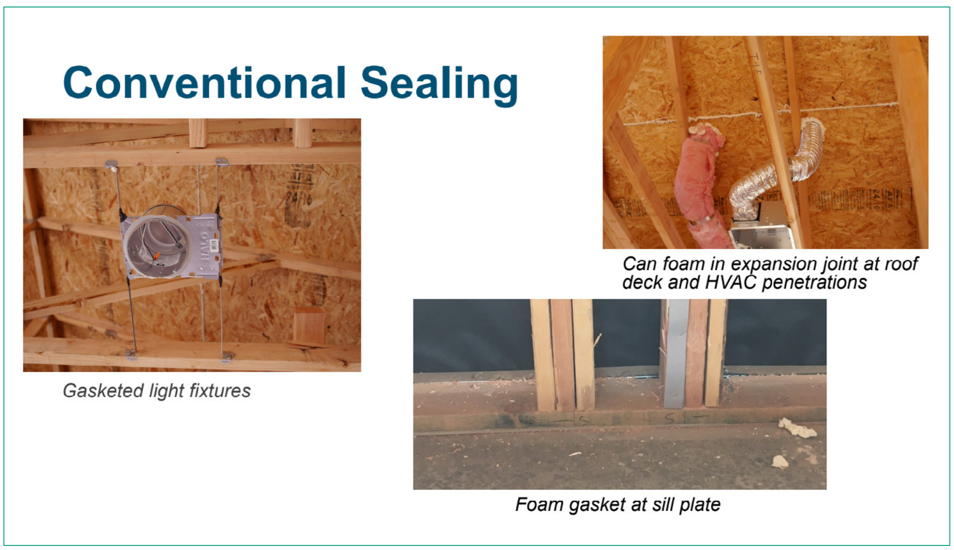

Figure 4. Areas needing sealing under the conventional home building methods. Figure courtesy Western Cooling Efficiency Center and Center for Energy and Environment.

highly variable. Often, airtightness verification is performed by yet another contractor after the sealing work, and after most (or all) of the construction is complete. This provides limited opportunity for feedback on the effectiveness of the air sealing, making it difficult for the sealing contractor to ensure that a specific level of tightness has been achieved. "Even a 10% to 30% reduction goal is challenging," says Dave Bohac, director of research for the Center for Energy and Environment (CEE). CEE is also one of the DOE's Building America research teams, working to further develop the aerosol envelope-sealing technology.

An Aerosol Primer

Enter: aerosol. Originally developed to seal ducts more than 15 years ago, aerosol sealing technology was adapted by the Western Cooling Efficiency Center (WCEC) at the University of California, Davis (UC Davis), to try and address current challenges in envelope sealing (see Figure 2).

After highly successful trials in which an automated application improved envelope tightness by up to 90%, the product AeroBarrier™ was commercialized in 2017. With both existing and new construction utilizing the technology, ***Energy Design Update*** checked in to see the latest results.

This technology involves air being blown into a unit while an aerosol sealant

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Editor
Amanda Voss

Design and Layout
Design Services

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Editor's Contact Information: Amanda Voss, Energy Design Update, 7948 Berkshire Lane, Castle Pines, CO 80108. 303-856-7842, *avitaproverum@gmail.com*.

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"fog" is released in the interior and controlled via automated software (see Figure 3). All openings not intended to be sealed, such as exhaust ducts, door seams, and open plumbing connections, are blocked with tape or plastic. Depending on the construction stage of the building during application, horizontal surfaces such as floors and countertops may need to be covered with plastic to protect them from sealant that settles during the process.

"The sealant is a synthetic acrylic, typically rolled or sprayed on for a monolithic elastomeric exterior air barrier," Bohac explains. "It is diluted 8-to-1 or 10-to-1 for aerosol application." A standard house or duct air leakage test fan is used to pressurize the building and provide real-time feedback and a permanent record of the sealing. As air escapes the building through leaks in the envelope, the sealant particles are carried into the leaks, where they impact and stick to the edges of the leaks, eventually sealing them. "Aerosol seals the small and hard-to-find areas," said Bohac. "It is designed to deposit in areas with gaps and leaks, and not on vertical surfaces." Typical application takes 60 to 90 minutes. The technology promises to simultaneously measure, locate, and seal leaks in a building. The aerosol sealant is also GREENGUARD certified.

Initial proof-of-concept testing of the aerosol sealing process showed excellent results, sealing 40 square inches of leakage in a small-scale enclosure in less than 10 minutes (Harrington, C., and M. Modera, 2012. *Aerosol Sealing of Building Shells and Envelopes.* KNDJ-0- 40343-00. Washington, DC; Building America Building Technologies Program, U.S. Department of Energy).

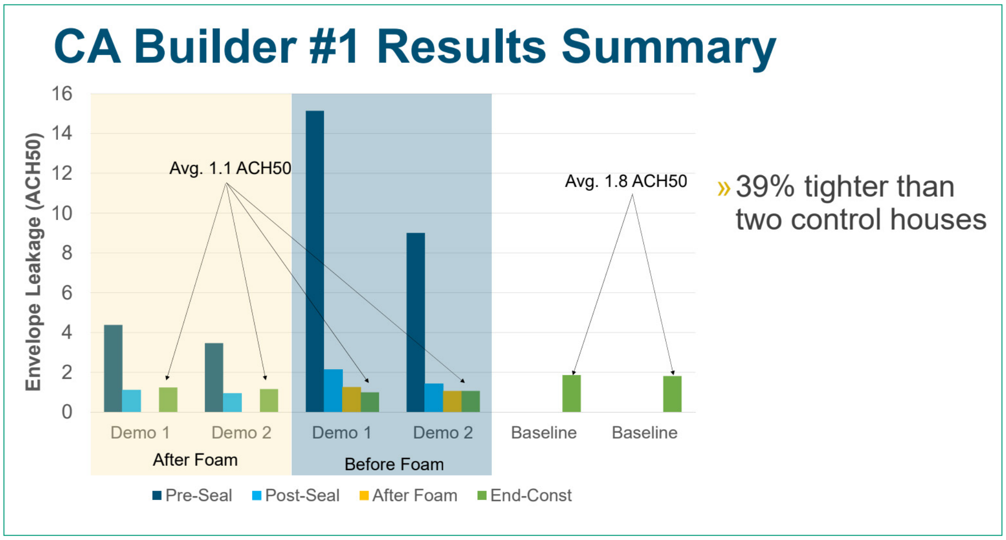

Figure 5. Results from aerosol testing of new home construction in California. Figure courtesy Western Cooling Efficiency Center and Center for Energy and Environment.

Testing Aerosol Sealing Approaches in New Construction

A number of demonstrations in single-family new construction homes showed aerosol had the ability to seal 60% to 85% of available building leakage within 2 hours of sealant injection (Harrington and Springer 2015). A sealing project demonstration of four multifamily new construction units showed that the process was capable of sealing at least 80% of the air leaks in less than 2 hours (Maxwell, Burger, and Harrington 2015). Another project sealed 18 units in three new construction multifamily buildings, with an average reduction of 81% and average post-sealing leakage of 0.69 ACH50 (Bohac et al. 2016).

So far, the aerosol envelope sealing process has not only produced tighter homes, but also demonstrated a potential opportunity for cost savings in the construction process. A review of the standard air sealing efforts performed by builders in the United States shows several areas in which efforts can be reduced or eliminated by applying aerosol sealing. By reducing other sealing work (see Figure 4), builders can: (1) minimize material used for sealing a building, because aerosol sealing only applies material where leaks are present; (2) reduce the possibility of redundant sealing (e.g., sealing on both external and internal wall surfaces) while assuring a continuous air barrier is applied; and (3) reduce the number of trades involved in the air sealing process.

Working directly with builders in California and Minnesota, WCEC and CEE launched new research in 2017 to identify the best stages for incorporating aerosol sealing with regard to cost, performance, and seamless integration into the construction process. With the product's efficacy no longer in question, data were now needed to pinpoint ideal application strategies.

In California, Curtis Harrington and his team at the WCEC partnered with two separate residential builders.

Builder #1 was already constructing sealed attics to meet California's new high-performance attic requirement and using open cell spray foam under the roof deck and at rim joists. Harrington wanted to test whether sealing was best after or before spray foam application.

Two houses that were aerosol sealed before spray foam had a leakage of 1.8 ACH50 prior to the application of spray foam. According to Harrington, this indicates that the air sealing benefit of spray foam is not necessary when aerosol sealing is applied. When construction was complete, the four aerosol-sealed houses had an average tightness of 1.1 ACH50, 39% tighter than similar control houses (refer to Figure 5).

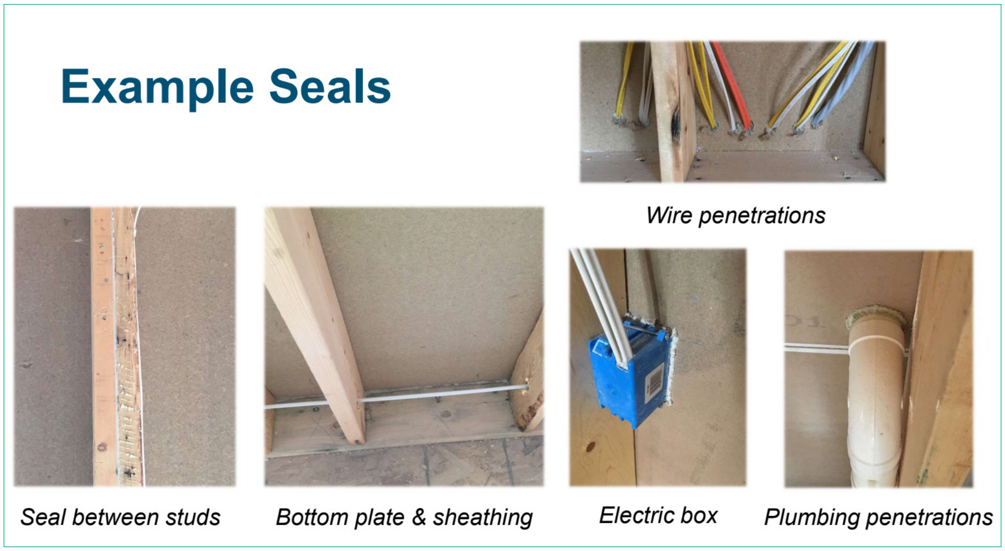

Figure 6. Example seals achieved by aerosol process. Figure courtesy Western Cooling Efficiency Center and Center for Energy and Environment.

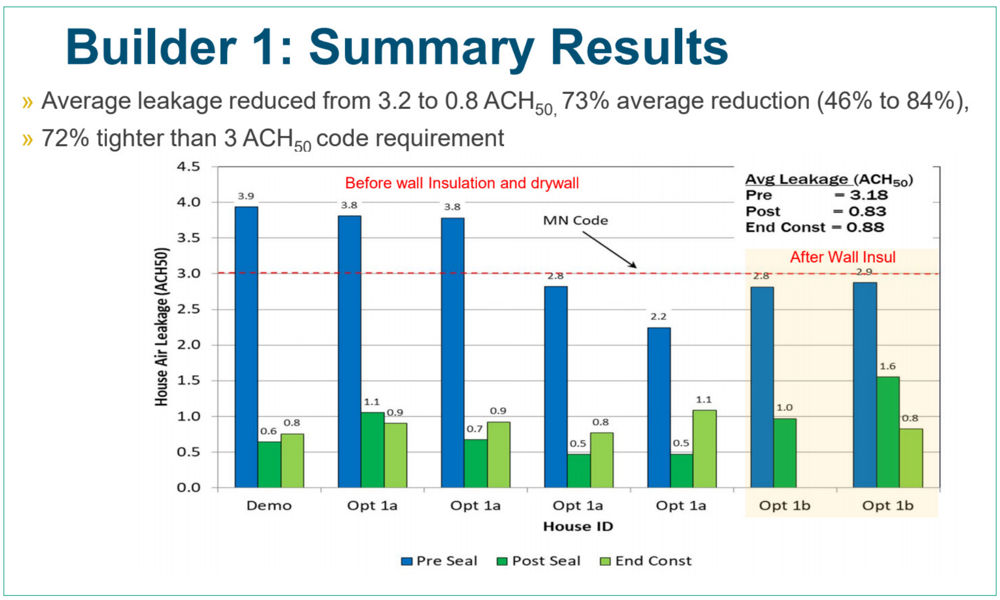

Figure 7. Results from a Minnesota builder participating in the new construction aerosol sealing study. Figure courtesy Western Cooling Efficiency Center and Center for Energy and Environment.

Homes with vented attics were also tested. Demonstration homes had a vented attic with blown-in insulation, mineral wool in the wall cavity, and an integrated heat recovery ventilator. In five demonstrations, homes that were aerosol sealed had an average tightness of 3.1 ACH50, 33% tighter than three control homes.

For Harrington, there are definite advantages to sealing before drywall: the aerosol application can address issues on outer wall surfaces, seals are less prone to damage in the wall cavity, and it allows for easier aerosol distribution.

"Curtis worked with a builder using spray foam under the roof deck, and applied AeroBarrier sealing both before they did the spray foam sealing and after," explains Bohac. "WCEC was able to get houses down to their target air leakage even before the spray foam was applied. AeroBarrier sealing was able to accomplish tightness without spray foam. We also did a few homes for a builder using netted insulation and were able to get down to their target levels of air leakage, 2.7 ACH50 and 3.3 ACH50, before any drywall or insulation was put up. Those are nice results there – we only expect a tighter blower door test post-drywall." (See Figure 6 for pictures of aerosol seals achieved in the homes.)

Bohac spearheaded CEE's project in Minnesota. A total of 13 of the 15 houses in Minnesota were sealed with aerosol prior to drywall installation. They had an average tightness of 0.81 ACH50, and four were tighter than the passive house standard of 0.6 ACH50. At the end of construction, the average tightness for the first builder was 0.88 ACH50, which was 34% tighter than similar control houses.

"We're wrapping up our new construction DOE work, which has been really successful – we're finding typical reductions of 75% to 85% from aerosol sealing," Bohac concludes (see Figure 7). CEE also ran a stretch goal with several Minnesota builders to test how many standard new construction homes could reach a Passive House tightness goal of 0.6 ACH50. The team was able to get more than half of these standard construction homes down to that goal, with all homes scoring at least a 1 ACH50.

Bohac also was able to determine that aerosol sealing did perform to standard during winter conditions. Scheduling application to coincide with spraying of rim joists proved a natural fit.

"Three years ago, when we started this project, almost all aerosealing was done toward the end of construction, after drywall, and we wanted to see if you could do it earlier," Bohac summarizes. As seen in test houses in both California and Minnesota, by conducting aerosol sealing prior to drywall, the air barrier is created toward the exterior surface, instead of toward the interior drywall or sheathing. "That's where we were able to get down below 1 ACH50, even without drywall," says Bohac. "That was all really successful. This gives contractors the ability to apply aerosol at any stage of construction, once they have a fairly complete air barrier." Sealing before drywall also resulted in a lower increase in leakage reported after sealing.

Typical infiltration reductions were between 75% and 80%. CEE and WCEC found that an experienced crew could seal two homes per day, with aerosol sealing able to replace many conventional, manual sealing tasks. The report also concluded that there are multiple opportunities for the aerosol application: helping builders adapt to new code or leakage requirements; achieving higher house performance; helping benefit from higher incentives; and reducing HVAC system size.

"When we started, Aeroseal was just starting to commercialize," says Bohac. "At the end of our first research stage, AeroBarrier had 20 plus contractors in place. For the last set of aerosol research we did, we partnered with a local AeroBarrier contractor who has the equipment and was performing independent work."

Aerosol Sealing in Existing Homes

After putting aerosol to the test in new construction during their last research cycle, WCEC, CEE, and Aeroseal, LLC, are taking aim at a new frontier: solving airtightness in existing homes.

"We're so excited about this opportunity," says Bohac. This research is necessary because existing houses are notoriously leaky, Bohac notes, with unintended airflow from outdoors that results in additional space heating and cooling equipment loads. The findings of this project will be used to drive market transformation and develop a best practice guide for cost-effective aerosol envelope sealing of unoccupied, existing homes and multifamily units. Beginning in 2020, researchers at CEE and WCEC will identify the best methods for aerosol envelope sealing of unoccupied, existing residences to improve tightness by 75%. The team will also test possibilities for improved sealant formulations that are better suited to existing buildings, surface protection methods that allow successful sealing while limiting cleanup costs, inspection procedures to identify larger gap leaks the aerosol will not seal, alternative spray configurations (for example, introducing spray in the attic with house depressurization), and possible approaches for sealing exterior duct leaks.

The project will focus on field demonstrations of the technology in existing Midwest and California residences, applying the technology when the residence is unoccupied. Bohac detailed the scope of work, which is grouped into three distinct efforts.

First, researchers conduct laboratory testing of new sealants that dry clear, instead of the current gray, which makes them more appropriate for retrofit applications. UC Davis will work with Aeroseal to identify and test clear, non-tacky sealants that will reduce setup/cleanup costs and be visually acceptable to homeowners for retrofit applications. Appropriate sealants will be tested by forming seals on test samples formed in the laboratory and subjecting them to durability testing guided by ASTM E2357. Then, field testing of the most promising sealants will be conducted, and feedback from the installers will be used to further evaluate the performance of the modified material.

Second, the team will conduct scaled field testing of the sealing process in existing single-family homes and multifamily units, tracking the entire process from setup to sealing and cleanup.

Third, the research will use EnergyPlus™ or BEopt™ modeling of the energy implications of the measured reductions in leakage.

For test homes, building selection will consider a number of variables that impact the sealing process, including envelope tightness, construction type, ductwork location relative to the envelope, garage type, and window vintage. The change in envelope tightness will be measured for all residences and additional measurements will be performed, as appropriate, to document the impact on specific envelope leaks (for example, those at windows, between house and attic, and between house and garage). Qualitative assessments will also be used to document existing leakage and the impact of the aerosol sealing. For residences undergoing remodeling, the air leakage will be measured at the end of remodeling to determine the impact of work that occurred between the aerosol sealing and end of remodeling.

Once a new sealant formulation is selected, the team hopes to test it on a total of eight homes in at least two states. Following that research, WCEC and CEE will perform aerosol sealing on an additional 20 residences and develop a protocol for cost-effective air sealing.

The project also wants to document non-energy benefits of sealing for existing homes, including improved occupant comfort by reducing drafts, improved indoor air quality by reducing the intrusion of outdoor air contaminants into the house, and seeing how air transport through walls is limited, avoiding moisture damage.

"We recognize tackling existing homes comes with challenges," says Bohac. "When we do aerosol sealing, it leaves a film of sealant on any horizontal surfaces. For new construction, that's not an issue and minimal preparation is needed. It's a totally different story for existing homes." CEE and WCEC will develop strategies to identify the best opportunities for existing houses and multifamily units when they are not occupied and if the owners would be interested in performing energy improvements.The team will focus on three situations, according to Bohac: (1) time of turn-over or change of occupancy of rental housing, particularly subsidized housing; (2) after the sale of a new home or condominium is complete, but before owners move their belongings into the residence; and (3) residences undergoing remodeling. "We'd love to see sealing become a 'normal' time of occupancy change step," Bohac says. "We're thinking outside of the box, like how we can pair aerosol sealing with lead abatement or refinishing practices."

The promise for existing homes is there. In limited testing with multifamily buildings undergoing renovation, Bohac achieved a 70% to 75% reduction in leakage. This is almost three times better than results from typical weatherization or performance programs, which usually accomplish a 25% to 30% reduction. "This is exciting because it means we can raise existing home performance levels up to those of new homes," Bohac says.

Testing Protocol for Homes

In 2020, in the field, aerosol envelope sealing will be performed on 8 to 10 residences. Bohac notes that assessments of envelope leakage will be conducted before and after the aerosol envelope sealing. These assessments will include a quantitative whole-house or unit envelope leakage test and qualitative visual assessment of leakage with smoke puffers. An infrared scan may be used to assist with identifying smaller leaks likely to be sealed with the aerosols and larger gaps that are best sealed prior to aerosol sealing. The leakage of individual leaks or sections of the envelope may also be measured by zone pressure diagnostics, guarded leakage tests, and/or individual leakage site tests. The results of the pre/post-sealing assessments will be included in a report for each residence, and a summary report will be produced for all sealing completed in the first year of the project.

"We really want to develop a timely and efficient way to protect surfaces prior to sealing, versus cleaning up afterward," says Bohac. "We also need to investigate the challenges of preparatory work. The rule of thumb for aerosol sealing is it will plug gaps of 1/4" or less. You can even get to 3/8" up to 1/2" if you let the sealing go beyond an hour or so. So we need to seal as many of the big leaks as possible, because we will be left with those anyway and will lose a bunch of sealant in the process if we don't adequately address them. I think that pre-sealing inspection will be interesting to develop into a protocol, which should make sealing go more quickly and be more effective."

In the final year of the project, the group of test homes will be expanded to 20 to 25 more residences.

From the total survey of 30 to 35 homes, CEE and WCEC will provide best practice guides for cost-effective aerosol envelope sealing of existing residences, including best methods to protect interior surfaces and to allow sealant to reach leak sites, inspection procedures to identify larger leaks that will not be sealed by the aerosol sealant, alternative spraying configurations, and any techniques for sealing exterior duct leaks.

"The end goal is to give air sealing contractors procedures to apply the aerosol sealing technique to existing houses," said Bohac. "While previous projects have demonstrated sealing two to four times greater than conventional methods, work is needed to enable cost-effective sealing in finished, existing houses that will produce improved airtightness in an economic manner and help reduce moisture issues from convective air leakage that deposits high quantities of moisture."

IN BRIEF

Around the Industry...

Updates to PHIUS+ 2018 Space Conditioning Criteria Calculator v2

When Passive House Institute US (PHIUS) partnered with the US Department of Energy (DOE) and Building Science Corporation to develop PHIUS+ 2015, one driving tenet was that the standard must be updated periodically to reflect technological, market, and climate conditions. As data and real-world experience rolls in, the team wanted to fold this feedback into the standard.

Over the past year, PHIUS gained invaluable feedback and data, thanks to all the teams that have certified to PHIUS+ 2018. Their feedback enabled the team to tweak space condition targets to reflect a different statistical fit from the original space conditioning target-setting – shifting to an 'Inclusive Fit' rather than 'Best Fit' line.

The PHIUS+ 2018 Space Conditioning Criteria Calculator v2 has been updated to reflect this shift.

PHIUS officially launched the PHIUS+ 2018 Passive Building Standard just over a year ago, in 2018, at the 13th Annual North American Passive House Conference in Boston, Massachusetts. The most notable upgrades from the PHIUS+ 2015 standard add nuance to the space conditioning targets, adjusting them for building size and occupant density. Another notable upgrade provides tiered source-energy targets and methods to hit those targets, depending on project goals.

The passive building market seems to approve: not only have we gotten a lot of positive feedback from CPHCs and other design professionals, the Passive House Alliance® notes, but PHIUS+ Certifications continue to increase.

Through the end of September 2019, PHIUS certification staff had the discretion to grant an exception for one of the four main space conditioning target criteria, as outlined in PHIUS+ 2018 Passive Building Standard-Setting Documentation, page 6. This allowance gave teams with projects already in planning some assurance that their efforts would not be wasted if their designs could not be revised to meet the new targets. If a project was severely constrained on meeting a target, a "mulligan" could be granted based on majority vote from the certification staff. This also allowed flexibility in case the targets didn't pan out in the real world even for clean-sheet designs.

For full details on changes, *visit https://www.phius.org/Tools-Resources/TechCorner/PHIUS+%202018%20Space%20Conditioning%20Criteria%20Mid-Cycle%20Evaluation.pdf.*

Record Year for the Building America Solution Center

The Building America Solution Center (BASC), DOE's repository for residential building construction best practices, is expected to have another record year by reaching more users than ever before. In 2018, the BASC received more than 640,000 page views. In 2019 to date, the BASC has already had more than 520,000 page views, a 28% increase over last year. Since launching in 2013, the BASC has had more than 1.5 million users, with 3.2 million page views.

To visit BASC online, go to *https://basc.pnnl.gov.*

In the News…

UMaine Composites Center receives three Guinness World Records related to largest 3D printer

On October 10, 2019, more than 250 federal and state officials, business executives, University of Maine System leaders, and community members were on hand to witness the UMaine Advanced Structures and Composites Center (see Figure 8) receive three Guinness World Records for the world's largest prototype polymer 3D printer, largest solid 3D-printed object, and largest 3D-printed boat.

The new 3D printer is designed to print objects as long as 100 feet by 22 feet wide by 10 feet high, and can print at 500 pounds per hour. The one-of-a-kind printer will support several ambitious initiatives, including development of biobased feedstocks using cellulose derived from wood resources, and rapid prototyping of civilian, defense, and infrastructure applications.

To demonstrate the new printer's capabilities, UMaine 3D printed a 25-foot patrol boat with a hull form developed by Navatek, a leader in ship design and a UMaine Composites Center industrial partner. The 5,000-pound boat was printed in 72 hours – from Thursday, September 19, 2019 to Sunday, September 22, 2019. The massive printer, with both additive and precise subtractive manufacturing capabilities, enables rapid prototyping for both defense and civilian applications.

UMaine also showcased a 3D-printed, 12-foot-long US Army communications shelter. The new printer will support programs with the US Army Combat Capabilities Development Command (CCDC) Soldier Center and its mission to develop rapidly deployable shelter systems for soldiers. Other

Figure 8. A research collaboration with Oak Ridge National Laboratory (ORNL), the US Department of Energy's (DOE) largest science and energy laboratory, culminates in the world's largest prototype polymer 3D printer at UMaine Advanced Structures and Composites Center. Figure courtesy UMaine Advanced Structures and Composites Center.

Figure 9. Systems Analysis allows Revit users to quickly group building regions into thermal zones and connect those to different types of HVAC systems. In this image, the "Core East" zone is connected to a VAV air handler. Figure courtesy US Department of Energy, Building Technologies Office.

use areas include concealment applications, structural shelters, and high-temperature fire retardant materials for vehicle-mounted shelters.

A research collaboration with Oak Ridge National Laboratory (ORNL), the US Department of Energy's (DOE) largest science and energy laboratory, will support efforts to study key technical areas in large-scale biobased additive manufacturing, including cellulose nanofiber (CNF) production, drying, functionalization, and compounding with thermoplastics. The partnership between UMaine and ORNL will advance efforts to produce new biobased materials conducive to 3D printing of large, structurally demanding systems. The research will focus on cellulose nanofiber (CNF) production, drying, functionalization and compounding with thermoplastics, building on UMaine's leadership in CNF technology and extrusion research. By placing CNF from wood into thermoplastics, bioderived recyclable material systems can be developed with properties that may rival traditional materials, possibly even metals.

Rapid Prototyping of Large New Systems

The new printer with both additive and precise subtractive manufacturing capabilities is a game changer, enabling rapid prototyping of large civilian and defense platforms.

The research collaboration will support fundamental research in key technical areas in large-scale, biobased additive manufacturing. The partnership between UMaine and ORNL will advance efforts to produce new biobased materials conducive to 3D printing of large, structurally demanding systems. The research will focus on cellulose nanofiber (CNF) production, drying, functionalization and compounding with thermoplastics, building on UMaine's leadership in CNF technology and extrusion research. By placing CNF from wood into thermoplastics, bioderived recyclable material systems can be developed with properties that may rival traditional materials, possibly even metals.

"This is an exciting achievement in our partnership with the University of Maine," said Moe Khaleel, associate laboratory director for Energy and Environmental Sciences at ORNL. "This new equipment will accelerate application and integration of our fundamental materials science, plant genomics and manufacturing research to the development of new sustainable bioderived composites, creating economic opportunity for Maine's forest products industry and the nation."

Biobased feedstocks are recyclable and economical, providing competitive advantages for manufacturing industries, including boatbuilding. By 3D printing plastics with 50% wood, boat molds and parts can be produced much faster and are more economical than today's traditional methods.

About the Advanced Structures and Composites Center

The University of Maine's Advanced Structures and Composites Center is a world-leading, interdisciplinary center for research, education and economic development encompassing material sciences, manufacturing, and the engineering of composites and structures. The Center is housed in a 100,000-square-foot ISO 17025-accredited testing laboratory with more than 240 full- and part-time personnel. More information is available at *https://composites.umaine.edu.*

Autodesk Brings Detailed EnergyPlus HVAC simulation to Revit

Autodesk's Revit building information modeling (BIM) software is the most commonly used 3D building design and construction documentation tool in the United States.

For several years, Revit allowed designers to analyze the annual and peak heating and cooling loads of their designs using EnergyPlus, the US Department of Energy (DOE) Building Technology Office's (BTO) open-source building energy modeling engine. Loads analysis uses an idealized HVAC system that simply tabulates these loads at each time interval and then meets them with unlimited capacity. It provides architects with directional guidance, steering them towards the load-reducing building shapes, space plans, and envelope designs that are the bones of any energy-efficient building.

On September 30, 2019, Autodesk released Revit 2020.1. One of the main new features of this update is Systems Analysis, the ability to simulate designs with detailed HVAC systems. Systems Analysis allows designers to group building areas into thermal zones, and then connect those zones to any one of a number of standard HVAC systems, providing the ability to define anything from packaged single- and multi-zone systems with gas or electric heating and DX cooling, to larger complex systems with heating and cooling coils served by hot and chilled water from central plants, to radiant systems with dedicated ventilation units. Systems Analysis provides default component efficiencies that are typical to high performance systems, which the designer has the option to override. EnergyPlus then automatically sizes the components to meet heating, cooling, and ventilation loads.

With detailed, rather than idealized HVAC systems, designers can calculate energy use and cost, in addition to zone conditions, that serve as the basis for occupant comfort. These details can paint a more realistic picture of actual building performance and provide feedback that is not only directional, but also supports quantitative project decision making. Reducing thermal loads is a good directional strategy, but how low do these loads need to be? Without simulating an HVAC system, it is difficult to know whether a building can meet an energy use target. Similarly, it is difficult to compare the costs of additional load-reducing envelope features, like higher-performance windows against the costs of the smaller HVAC components they enable (see Figure 9).

The decisions that architects make early in the design process orientation, like shape and height and envelope characteristics, largely determine the energy efficiency of the final building. There is only so much an HVAC system can do to overcome a poorly designed envelope. Systems Analysis will allow architects and engineer to make these decisions – and those related to system selection and sizing – with greater confidence from a more realistic and quantitative footing.

"Autodesk has a long history supporting EnergyPlus and using it to develop different analysis solutions. This is by far the most significant step we've made to date – HVAC system selection, sizing, annual energy and comfort analysis is now an integral part of Revit," said Ian Molloy, a Senior Product Line Manager at Autodesk. "Systems Analysis isn't just about doing the same analysis you can already do in other ways, it's about closing the critical gap between architect and engineer. We believe it will help deliver better buildings through more collaborative and integrated workflows."

To develop this new capability, Autodesk used the OpenStudio Software Development Kit (SDK). OpenStudio imports Revit data in gbXML format to create the basic model, then applies OpenStudio Measures to articulate HVAC systems and create variants for parametric analysis. As with other OpenStudio-based tools, users can create their own custom Measures for model transformation or reporting. Autodesk leveraged a Technology Commercialization Fund (TCF) award to obtain integration assistance from the DOE's National Renewable Energy Laboratory (NREL).

For more details, see *https://www.energy.gov/eere/buildings/articles/autodesk-brings-detailed-energyplus-hvac-simulation-revit.*

IN REVIEW

Trends that Will Define Us

Figure 10. Dr. Roderick Jackson, laboratory program manager for buildings-related research at the National Renewable Energy Laboratory (NREL) (*https://www.nrel.gov/research/roderick-jackson.html*). Figure courtesy NREL.

Looking Forward to 2020 and Beyond with Dr. Roderick Jackson

As 2019 takes its place in our rear view mirror, the American building industry greets the dawn of 2020 with a measure of cautious optimism about the opportunities ahead.

Energy Design Update spoke with Dr. Roderick Jackson (Figure 10), laboratory program manager for buildings-related research at the National Renewable Energy Laboratory (NREL) (*https://www.nrel.gov/research/roderick-jackson.html*), to hear his insights about the future.

And just what is Jackson most excited about? In a phrase: Innovation through integration.

What excites you most about where the industry is going?

Our long-standing focus has been taking a single building and making it as efficient as possible; how the power flowed to the building from the grid wasn't a consideration.

Now, as the make-up of the grid changes and the grid adapts to a mix of sources, including solar (Figure 11) and wind, if we don't change how buildings use energy, we'll miss an opportunity. For example, if your neighborhood relies mostly on solar for energy generation, that's a time variant generation source. So, the question becomes: how can buildings change to better harness the grid?

We're starting to see the necessity of not just energy efficiency in regard to a single home, but efficiency defined by when power is needed in buildings and how that power is provided.

What big picture seems to be taking shape for 2020 and beyond?

At NREL, our big picture is understanding how buildings interact with the grid. This encompasses not just consumption, but goes beyond to evaluate how we provide services and how buildings can interact dynamically, in a way that makes the whole system better. We're moving to a world where buildings interact with the grid. Buildings will be more dynamic – rather than simply "smart." We want buildings to understand and have self-awareness of the needs of both occupants and the grid. These future buildings will be able to co-optimize, satisfying the needs of occupant and grid without compromising comfort. That's exciting! That's a new paradigm!

DOE's Smart Neighborhoods in Georgia (*https://www.georgiapower.com/company/news-center/2018-articles/smart-neighborhood.html*) and Alabama are early examples of this paradigm (see Figure 12). The DOE worked with utilities to study where each building can aggregate grid benefits across an entire development.

What steps do the industry, and the US building stock, need to take to reach that goal?

At NREL, now that the target has been set, we're taking a step back and asking things like: how do we design homes in light of this objective; what do we need to do differently in the field and on the grid?

The biggest focus is integration. We're taking a single building and asking how we can integrate it with a changing grid that is very different than our old grid paradigm. We have to ask how buildings themselves can adapt to operate in this system and thereby make the system optimal.

What changes does this create for equipment? We've done some initial work on dynamic load and generation response for heating, ventilating, and air conditioning (HVAC) equipment and for water heating in individual homes; now, what does this integrated picture look like? What about cities and districts? How does load management in a single home ripple throughout its community?

When integration is the focus, we have to ask questions like, "If I change the material in a building envelope, how does that impact the community?" Could additional insulation mean our home can contribute to energy generation for a neighbor's electric vehicle? How can the thermal nature of a building better allow for this provision? What about thermal storage coupled with electrical storage? We need to drive towards a holistic and comprehensive approach. Can we do more than we could before?

How do we connect the goal of integration to new material development?

First – storage.

There has been a lot of interest and activity centered around storage for renewable energy, but the conversation has usually drifted to – and ended at – battery storage (see Figure 13). However, just focusing on battery storage misses a larger opportunity for thermal storage. Developing thermal storage can create a complement for batteries, or reduce the need for battery storage.

Buildings use a lot of thermal energy within their overall mix. In the past, thermal storage was used more to create energy savings. Now, if we start to use thermal as a complement to battery storage, the properties and dynamics of thermal storage have to change as well. It requires us to rethink thermal storage.

A new type of research and development is happening to answer this gap. We know we need storage – let's broaden the conversation beyond battery or electric. Changing the performance needs of thermal storage will allow us to better complement the whole system and take full advantage of thermal capabilities.

Second, we need a better understanding of how different appliances integrate in the broader system.

We need to ask, "How can my HVAC or water heating use its controls to allow me to have greater control over

Figure 11. Metcalfe Federal Building photovoltaic (PV) arrays in Chicago, Illinois. The 84 solar panels on the roof of the Metcalfe Federal Building are contributing to the building's energy supply and to Chicago's campaign to make the city a center for green technology. Photo by Patrick Engineering and courtesy National Renewable Energy Laboratory.

when I use power?" Peak load and demand response approaches are not as forward-looking as we need them to be. What could be done better? HVAC and other companies are looking at being proactive and examining extreme circumstances to better plan how to use power and to minimize total use.

For materials, we have a whole new paradigm of how we approach building consumption, and how materials and other systems interact with other buildings and the grid.

Figure 12. Alabama Power's Smart Neighborhood consists of 62 homes in Hoover, Alabama. Each home is equipped with enhanced energy-efficient home technologies. Photo courtesy: Southern Company.

Figure 13. To harness renewable energy for use at flexible intervals, battery storage has entered the mainstream conversation. Pictured is the AES Lawai Solar Project- Kauai. The solar array won 2019 Best Storage Application of the Year for the world's largest battery plant paired with solar generation. Photo by Dennis Schroeder and courtesy National Renewable Energy Laboratory.

What other product advancements do you think we'll see?

We're moving away from an analysis of the components of an individual building and verifying the additive worth of each, to how we can use new resources and techniques to help the overall system. As a national lab, we need to be at the forefront of seeing and understanding the knowledge gaps. By working to investigate these fundamental knowledge gaps, we can make sure the industry takes our research and runs with it, creating better products and systems.

A major gap the industry is facing is in controls. In order to have this future complex, integrated system we envision, you have to have a model to connect the operation of a device to the system. You need that integrated ecosystem model to understand how best to do that, and that model has to have a validated approach.

What we're doing, as national laboratories, is building that layer of validation by modeling simulations from the material all the way up to the integrated scale. This allows us to quickly investigate different scenarios, and experiment using a multi-scale approach. That research means we can generate system level integrated outcomes. Previously, we haven't had to tie all these things together to make sure we have a fully integrated picture.

What does the shift toward off-site construction mean for buildings?

If you look overseas, particularly in the Asian market, they've really taken advantage of prefabrication in building construction and are shipping either whole form or sub-sections to be built on site. Prefab is a clear trend because of two things: technology improvements and skilled labor shortages.

While prefabrication is happening to improve productivity, we need to ask how prefab can help the building be more efficient and dynamic. Given the need that we have for buildings to be more efficient, how can we take advantage of factory building and incorporate more controls and make a structure more grid interactive?

How do we address advancing existing buildings?

Prefabrication leads us to retrofits.

We're looking at prefab and panelized construction for existing exteriors, more as a near term solution. One of the things we're challenged to do is to find ways that enhance existing building performance in a way that is less costly. We're seeing advancements in thinner insulation panels for continuous exterior insulation with a lower profile. But these still have a way to go to demonstrate mass applicability in a way that creates a compelling value proposition.

Figure 14. Innovation through integration: the future looks to be collaborative. Miramar ZnBr Flow Battery Simulated MicroGrid, in the Energy Storage Lab (ESL) at the Energy Systems Integration Facility (ESIF). Photo by Dennis Schroeder and courtesy National Renewable Energy Laboratory.

Equipment, particularly in water heating and refrigeration, continues to improve, so this will help as older units are replaced by newer, more efficient "smart" units.

With that being said, we're still challenged, and have to be really aggressive, to find existing building envelope solutions. We really have a challenge to try to not make incremental steps towards our end goal, but to make big leaps. That's going to require bringing new science and new engineering approaches to the table.

What outside actors are going to force change in the industry?

Renewables are a major force of change. Because of renewables securing a larger foothold in the grid mix, we're moving beyond efficiency to how buildings interact with the grid.

Especially in areas like California, with more renewables online and higher energy end goals for buildings, people are rethinking metrics and targets. Traditionally, our focus has been to rely on energy within an individual building, without time sensitivity, and we've focused on minimizing the energy consumption over the year for that building. Because the grid doesn't actually operate like that, we're starting to see more of a resolution to rethink metrics and targets beyond an overall annualized target. It's forcing us to understand the balance of how you optimize a building's intelligence.

Given the future efficiency wave sending us towards multi-building strategies and the importance of interaction with the grid, what new products are going to shape the industry in the years ahead?

Product development, which is a harbinger of things to come, points toward several interesting answers.

First among these is addressing thermal storage. Typically, we've defined thermal storage in buildings as a passive approach that stores energy through diurnal cycles, with limited control over when you use it. That means a homeowner is only able to utilize those assets a small percentage of the time. Usually the highest benefit comes during extreme weather in the summer or winter season. You don't have control over a material that buffers loads throughout the whole year. New thermal storage asks, what about a phase change material that actually tunes the storage mechanism, so you can store in winter and summer? The question becomes, what can we create to use throughout the whole year, and can we use it as a complement for battery storage? Can we make the load flexible? How do we release energy into the building? How can we control stored energy in the envelope?

Looking into the future also means imagining new products at the cutting edge. Buildings will have new science and opportunities to leverage. Can we have a thermal switch that turns on and off? Can thermal storage move beyond passive? We're rethinking how we store energy in the envelope.

Additionally, controls in the built environment are becoming more commonplace, but today's controls are designed to optimize for occupants – how do I provide energy to meet occupants' needs in the most optimal way? The future transition will be to ask, how do we also optimize our building responding to grid needs. Optimization becomes multi-parameter. So how does that change the way we control at the building level, component level, and community level? What does the urban scale look like?

Not just material engineers and systems developers, but mathematicians and other disciplines need to be brought into our research space (see Figure 14). It will take broad and diverse skills, working super close, to develop the technology we need and to understand all of these goals in context of the bigger picture.

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