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IN DEPTH

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IN DEPTH

2020 is Around the Corner. How Close is California to Meeting its Net Zero Energy Goals?

By Rick Duncan, PE, Ph.D

In 2012, California's Governor Jerry Brown announced an aggressive goal for the state – for all new residential construction to be Net Zero Energy (NZE) by 2020, and all new commercial construction to reach the same goal by 2030. At the time, many felt that despite California's reputation as a trendsetter in environmental stewardship, it was a lofty aim – however not altogether impossible.

Net Zero Energy construction has, over the past decade, moved well past a highly complex endeavor to something much more achievable. This shift over time is attributable to a confluence of factors, including:

- increasingly stringent building codes which mandate builders to design and construct for energy efficiency;
- growing concern among consumers about climate change;
- innovation and performance improvements delivered by the building materials sector;
- government and utility subsidies and incentive programs for energy efficiency in buildings;
- long-term consumer cost saving benefits with the use of energy generation technologies such as solar panels;
- the increasing number of projects demonstrating financial viability for building owners;
- a growing body of quantifiable research supporting NZE.

As we approach mid-2018, six years after Brown's target setting, a review of the construction within the state shows that California has made progress toward integrating energy solutions for both residential and commercial construction. However, there are many recently-constructed new home communities, along with many currently under construction that, while more energy efficient than their predecessors, still don't achieve net zero energy, nor even aim for it. Even so, the momentum toward responsible energy practices is increasing and more NZE homes, communities and commercial properties are expected to follow.

One indicator of the growing push toward NZE within the state (and beyond) is the growing coverage of the topic at industry events. California is host to the nation's largest annual conference dedicated to the movement, Verdical Group's Net Zero Conference, which will celebrate its fourth consecutive year in September 2018.

"The net zero building movement is rapidly gaining momentum – the number of net zero energy buildings nationally is on a steep upward curve and has increased 700% since 2012," says Drew Shula, founder and principal of Verdical Group. "In conjunction, the Net Zero Conference has nearly doubled in size each of its first four years and now expects more than 900 attendees at the September 12-14, 2018 event in Los Angeles."

While an increasing number of industry players are getting involved in NZE, California's stated NZE goals and target dates prioritize progress in the residential sector. Within this sphere specifically, some standout projects have recently been delivered to market. Following are two high-profile success stories.

The Jacobsen House

This Northern California home garnered the spotlight in 2017 with its unique story, notable owner, and innovative energy solutions.

The home belongs to Stanford professor Mark Z. Jacobsen. His commitment to living in an Earth-friendly home aligns with his role as head of the university's Atmosphere and Energy Program. A climate and clean energy scientist, Jacobsen is also one of the founders of The Solution Project, a program aimed at accelerating the transition to 100 percent renewable energy use in the United States. His new home enables him to practice what he preaches.

The home sits on an irregularly shaped lot near Stanford's campus. An abode designed by BONE Structure, the Canadian prefab homes company, the 3,200-square-foot modular Jacobsen house was snapped together in under a week. The frame is comprised entirely of steel and 89% of the material included is recycled-content (see Figure 1).

Jacobsen's home is also designed to use no consumer electricity and to generate zero emissions. Powered by solar panels, all excess energy is stored in large rechargeable lithium ion battery packs. There is no natural gas line leading into the property.

"This home stole the spotlight because of its tie to a world-class scientist, its attractive modern design, and its energy generating performance," said Kurt Riesenberg, executive director of the Spray Polyurethane Foam Alliance (SPFA), the educational and technical voice of the spray polyurethane

Figure 1. The Jacobsen House, located on the Stanford University campus in Northern California. Photo courtesy SDI Insulation.

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foam industry. "But equally important in net zero construction is a home's ability to conserve energy and, in this area, the Jacobsen home is also a star. The home's design leverages spray polyurethane foam insulation and high performing wall systems to achieve maximum energy efficiency in the envelope."

Metal framing improves the structural performance of the walls. However, it can create unwanted thermal by-passes. To prevent that in this home, horizontal framing was applied perpendicular to vertical framing to minimize heat loss through metal studs, while maintaining a fastening surface to the exterior cladding (see Figure 2).

Figure 2. The home's frame was designed by BONE Structure, a Canadian prefabricated home company. Photo courtesy SDI Insulation.

In an approach consistent with High Performance Walls emphasized in the state of California's soon-to-be published 2019 Building Energy Efficiency Standards for Residential and Nonresidential Buildings (Title 24), the area between the horizontal and vertical horizontal studs was insulated and air sealed with spray polyurethane foam insulation.

SIPs were used for the low slope roof structure. While they provide continuous insulation, they must be properly sealed at all joints and wall connections. Open-cell spray foam applied below the roof deck provides extra insulation and air sealing for the SIP roof structure.

The building enclosure for this home measures an air leakage rate of 0.8 ACH_{50}, which is extremely low. Minimizing unwanted air movement through the enclosure reduces exfiltration of conditioned air and infiltration of unconditioned air, reducing energy use for heating, ventilation and air conditioning. Jacobsen reports a 90% reduction in HVAC operating costs, enabling him to sell up to 2/3 of the onsite energy generated back to the local power companies. The minimized air leakage also provides the added benefit of improved indoor comfort and air quality by controlling moisture and eliminating infiltration of outdoor pollutants and allergens.

SDI Insulation, Inc., a Northern California insulation contractor, completed all spray polyurethane foam applications in the home. SDI applied Accella BaySeal® open cell spray foam in the underside of the roof panels as well as Accella BaySeal® closed cell spray foam to the outside of the exterior walls, providing extra R-value, air sealing and structural strength, while creating a rain screen between the spray foam and the exterior cladding system (see Figure 3). The air-tightness of the exterior walls minimizes transmission of outdoor noise into the home, while the open-cell spray foam used inside the home's interior walls reduces sound transfer between rooms.

Figure 3. SDI Insulation, Inc., a Northern California insulation contractor, completed all spray polyurethane foam applications in the home. SDI applied Accella BaySeal open cell spray foam in the underside of the roof panels as well as Accella BaySeal closed cell spray foam to the outside of the exterior walls, providing extra R-value, air sealing and structural strength, while creating a rain screen between the spray foam and the exterior cladding system. Photo courtesy SDI Insulation.

SDI Insulation and the Jacobsen Home recently won first place in the 2018 Industry Excellence Awards in the Residential Wall category. The awards are hosted annually by the Spray Polyurethane Foam Alliance, which remains a major proponent of net zero energy construction.

The Flex House

A VISION House by Green Builder Media and Shelter Dynamics, this 760-square-foot net zero ready home marries the growing popularity of the tiny home concept with prefabricated construction (Figure 4). Notably, the design enables the homeowner to adapt and alter the size and configuration of the abode as living needs shift over time.

Figure 4. The Flex House, on display here at the PCBC® Conference. Photo courtesy 951 Construction.

Architect Jim Gregory's concept for the home is inspired by R. Buckminster Fuller's groundbreaking work to improve human shelter through three core concepts: making shelter more economically available to a greater number of people, more comfortable and efficient, and without ecological offense.

The modular construction of the Flex House minimizes construction waste. Built in a Ridgecrest, California warehouse in two separate structures, the two pieces are transported individually and then joined into final assembly onsite. Because of the home's transportation and assembly requirements, as well as its need to dramatically reduce energy demands, the use of spray polyurethane foam proved ideal. SPF's unique properties are leveraged to join, seal, and waterproof the Flex House.

951 Construction, the insulation contractor, selected Accella's BaySeal closed-cell spray polyurethane foam for the insulation (see Figure 5). The material, with its high R-value and depth of thickness applied, minimized the wood needed for framing. Closed-cell spray foam is also the only insulation that meets FEMA's water resistance requirements and acts as an adhesive to improve resistance to structural loads during transportation. Spray foam roofing was applied to address the curved roof, an architectural design element that otherwise would have produced installation difficulty for other insulated roofing systems.

Figure 5. Because of the home's transportation and assembly requirements, as well as its need to dramatically reduce energy demands, the use of spray polyurethane foam proved ideal. SPF's unique properties are leveraged to join, seal, and waterproof the Flex House. Photo courtesy 951 Construction.

The Flex House is fully powered through its solar power system and accompanying battery storage. It can produce all of its own power and serve as a microgrid. Its advanced smart home hub platform streamlines the production, storage, monitoring, and usage of energy to create the demand-side energy management strategy.

The Flex House appeared on display in January at the annual 2018 Consumer Electronics Show (CES), one of the country's biggest technology trade events boasting an attendance of approximately 185,000 (see Figure 6). The home also appeared at PCBC® and the Solar Power International trade shows.

"Both the Jacobsen House and the Flex House have brought major awareness to net zero energy living," adds Riesenberg. "One is a high-profile, high-performing home belonging to a world-class scientist. The second has been lauded at numerous events, spreading the word among large industry and consumer audiences."

Aside from custom and prefabricated home examples, developers and production builders are also getting into the net zero ring in California. A few years ago, Meritage Homes delivered the state's first net zero neighborhood when it completed

Figure 6. The Flex House floorplan. Image courtesy 951 Construction.

the homes within its Sierra Crest community in Fontana. Some of the key features of the homes include 15 SEER, 9.0 HSPF heat pumps; spray foam insulation; 2.3 COP heat pump water heater; and, solar energy systems sized specifically for each home.

Fresno-based De Young Properties also recently partnered with the Electric Power Research Institute (EPRI), Pacific Gas and Electric Company (PG&E) and BIRAenergy to launch the EnVision community, the first grid-connected net zero energy home community to be developed in central California. The 36-unit community is located within Loma Vista, a 3,300-acre master-planned community in Clovis, California.

Five Point Communities is currently developing the 21,500-new home community at Newhall Ranch, which it claims will achieve net zero energy status. The community sits adjacent to southern California's Magic Mountain theme park and the first residents of the community could move in as early as 2020.

These players are making strides to move the needle toward NZE in the state, however it is unlikely that all new residential construction will be net zero by 2020. There remain numerous cost and technology hurdles to overcome, especially in regard to renewable on-site power generation. However, homes have a service life of about 100 years. There are enclosure technologies such as SPF available today that enable new homes to be built 'zero energy ready' at a cost that is far less than making them NZE through via energy retrofits 10-20 years from now.

Regardless of whether California meets its initial 2020 deadline for new net zero construction, Shula is encouraged by the growing interest in NZE and projects coming to market that do.

"Just as the LEED green building rating system took off on a trajectory up and to the right about 15 years ago, the net zero building movement is poised to do the same in the decade ahead," added Shula. "This growth is in large part driven by California's planned building code changes that will require net zero new construction. But get ready because this industry is about to take off."

For more information and to attend the 2018 Net Zero Conference, visit *www.netzeroconference.com*.

About the Author

Rick Duncan, Ph.D., P.E is the Technical Director of the Spray Polyurethane Foam Alliance (SPFA), the industry's leading organization representing contractors, material and equipment manufacturers, distributors and industry consultants. The SPFA promotes best practices in the installation of spray foam and offers a Professional Certification Program to all those involved in the installation of the product.

IN BRIEF

Around the Industry…

DOE Zero Energy Ready Homes – Program Update for California

As the California Building Energy Efficiency Standards and ENERGY STAR® Homes have both increased their efficiency levels in California, the goal of the Zero Energy Ready Home (ZERH) program is to continue to provide meaningful efficiency and performance benefits in qualifying projects.

Therefore, on April 24, 2018, the program drafted new requirements for DOE ZERH projects in California (Rev.07). The draft provisions are as follows:

- Achieve a compliance total with ≥ 15% savings beyond the Standard Design based on the 2016 Building Energy Efficiency Standards, or achieve a Delta Energy Design Rating ≥ 4, as determined by a CEC-approved software program.
- Meet all required DOE ZERH provisions, including ENERGY STAR Homes certification, Indoor airPLUS certification, efficient hot water distribution, and the other mandatory provisions listed in Table 1 of the DOE ZERH – California program requirements.

A draft of the updated DOE ZERH requirements for California is available for review at *https://www.energy.gov/sites/prod/files/2018/04/f51/DOE%20Zero%20Energy%20Ready%20Home%20CALIFORNIA%20Program%20Re-*

quirements%20-%20Rev07.pdf. The planned effective date for the updated DOE ZERH California specifications is for buildings permitted on or after 10/1/2018.

New North American Fenestration Standard Published

The 2017 edition of AAMA/WDMA/CSA 101/I.S.2/A440, NAFS – North American Fenestration Standard/Specification for windows, doors, and skylights (NAFS) has received final approval and was made available February 13, 2018. After years of collaboration between the American Architectural Manufacturers Association (AAMA), Canadian Standards Association (CSA) and Window & Door Manufacturers Association (WDMA), this new edition will replace the 2011 version of this standard. The 2011 NAFs is referenced in 2015 editions of the International Building Code® and International Residential Code®, and the new standard is to be included in the 2018 editions of these codes. (See Figure 7.) The 2017 standard represents a significant step towards achieving seamless trade across the US/Canadian border for those in the fenestration industry. For more information on the standard, visit *http://www.wdma.com/blogpost/1003739/WDMA-Press-Room.*

Figure 7. 2017 edition of AAMA/WDMA/CSA 101/I.S.2/A440, NAFS – North American Fenestration Standard/Specification for windows, doors, and skylights is now available. Shown here, windows at a passive solar home designed and built by Nancy Carlisle; Lakewood, Colorado. Photo by Warren Gretz and courtesy the National Renewable Energy Laboratory.

PHIUS Releases New PHIUS+ 2018 Standard

PHIUS+ 2018 is the first updated revision to PHIUS+ 2015. It will be phased in throughout 2018, and will eventually replace PHIUS+ 2015. Passive House Institute US (PHIUS) announced that this update focuses on adding more nuances for different building types and supporting an overall transition to renewable energy (see *http://www.phius.org/phius-certification-for-buildings-products/phius-2018-getting-to-zero* for further details).

What's the same…

PHIUS+ 2018 remains a pass/fail passive building standard, serving as an update to replace PHIUS+ 2015. It remains a "performance-based" energy standard that includes prescriptive quality assurance requirements.

The performance standard relies on three pillars:

- Limits on heating/cooling loads (both peak and annual)
- Limit on overall source energy use
- Air-tightness and other prescriptive quality assurance requirements

PHIUS+ 2015 recognized that there are diminishing returns on investment in energy-conserving measures and an optimum level in a life cycle cost sense. Climate plays a large role in determining where that point is. For PHIUS+ 2015, researchers studied optimization in 110 cities, and developed interpolation formulas to set heating and cooling (space-conditioning) energy targets for 1000+ cities across the US and Canada. The same criteria applied to buildings of all sizes.

The overall energy limit under PHIUS+ 2018 is based on source energy, rather than site energy, as it is a better proxy for resource consumption and emissions associated with the site's energy use.

New in PHIUS+ 2018

Under the pilot release of PHIUS+ 2018, the space-conditioning targets are less granular in terms of climate – they are instead set zone-by-zone, using the 17-climate-zone system referenced in the International Energy Conservation Code® (IECC).

Because size and occupant density influence the optimal path to a low energy building, the new space-conditioning criteria implement continuous adjustments for a range of different building sizes and occupant densities.

In PHIUS+2018, the source energy criterion is tightened, with a view toward zero, but there are more options for meeting it. There is no cap on total source energy use, as long as the predicted 'annual net source energy' use meets the new (lower) target. This 'net' source energy use is the remaining source energy use, after what is offset by qualified renewable energy measures, on-site and off-site.

The pilot program of PHIUS+ 2018 is intended to assess how the new performance requirements fit for a variety of projects. The climate and occupant sensitivity may be revisited and refined for the final program's release.

Comments on the new standard closed April 15, 2018; the pilot will begin in September 2018.

In the News...

FSEC® Releases Report on Testing of Smart Whole-House Mechanical Ventilation Control

The Florida Solar Energy Center® (FSEC) undertook an evaluation of three different approaches to ventilation control, testing whether these could enable both energy savings and appropriate ventilation levels.

"Whole-house mechanical ventilation is a critical component to a comprehensive strategy for good indoor air quality (IAQ). However, due to lack of integration with standard heating and cooling systems, as well as perceptions from a portion of the homebuilding industry about risks related to increased energy use, increased cost, and decreased comfort, voluntary and code-required adoption varies amongst regions," note authors Eric Martin, Karen Fenaughty, Danny Parker, Michael Lubliner, and Luke Howard.

Through both laboratory energy simulation and field experimental approaches, FSEC analyzed the performance of Seasonal Temperature-Based Smart Ventilation Control (STSVC), Occupancy Timer-Based Smart Ventilation Control (OTSVC), and Real-Time Weather-Based Smart Ventilation Control (RTWSV). By different means, the controls all operate to balance energy consumption, comfort, and IAQ by optimizing mechanical ventilation operation to reduce the heating and/or cooling loads, improving management of indoor moisture, and maintaining IAQ equivalence according to ASHRAE® 62.2.

"Mechanical ventilation operation could be controlled in response to singular control variables (e.g., outdoor temperature), or in response to simultaneous consideration of the effect of multiple variables (e.g., occupancy, outdoor temperature, and outdoor moisture)," the report states. "No prior published research on lab or field testing of smart ventilation control systems is available. However, developing 'smarter' ventilation systems will enable the residential sector to more reliably design, install, and operate mechanical ventilation systems to achieve best-practice IAQ while minimizing energy and comfort impacts."

In all cases, simulations and experiments showed potential to achieve heating and cooling energy savings, while maintaining indoor comfort.

FSEC is sharing its findings with stakeholders and manufacturers, as the opportunities for smart controls for ventilation are rapidly growing.

For access to the complete study, visit *https://www.osti.gov/biblio/1416954.*

BTO Posts Updates on Four Envelope Efficiency Advances

On February 7, 2018, the US Department of Energy unveiled progress on four initiatives under the Building Envelope and Windows Research and Development (R&D) group in the Building Technologies Office (BTO).

1. R25 Polyisocyanurate Composite Insulation Material

BTO is working with Oak Ridge National Laboratory (ORNL) to develop a new insulation material that is more than twice as energy efficient as any typical insulation used in buildings today. Modified atmosphere insulation (MAI) panels utilize a process where high insulation values are achieved by sucking all of the air out of panels and sealing them very, very tightly. These panels have the potential to pay for themselves from energy savings within 10 years while saving more than 1% of all of the energy used in the US today (see Figure 8).

Figure 8. R-25 Polyisocyanurate Composite Insulation Material. Figure courtesy the US Department of Energy and the Office of Energy Efficiency and Renewable Energy (EERE), from the 2017 Building Technologies Office Peer Review presentation. Available at *https://www.energy.gov/sites/prod/files/2017/04/f34/5_31395_Biswas_031617-1100.pdf*.

Lead Performer: Oak Ridge National Laboratory (ORNL) – Oak Ridge, TN

Partners:

- NanoPore Inc. – Albuquerque, NM;
- Firestone Building Products Company – Indianapolis, IN

Project Objective: The objective of this project is to develop 2-inch thick polyisocyanurate board insulation with modified atmosphere insulation (MAI) cores that have an R-value of 25 (R-12/inch) and a cost premium of no more than $0.30 per square foot for an insulation material of equivalent R-value equating to a simple payback of 10 years. MAI is a lower-cost alternative to vacuum insulation, with similar performance (R-35/inch). The cost target is expected to be refined during the project as the research work and technology-to-market analysis are performed.

The project team will develop a drop-in replacement for polyisocyanurate foam insulation that increases its R-value by a factor of 2. To accomplish this goal, production of MAI panels will be modified to produce the correct geometries, barrier materials will be evaluated that can handle the high temperatures generated during the exothermic reactions that occur during the foaming process, and a mechanism to fix the panels within the foam core will be developed. Barrier films will be further evaluated to address the required longer service life of the polyisocyanurate foam board (up to 50 years), along with development of a procedure to predict long-term performance. Foam boards will be designed so that MAI coverage is optimized to effectively yield the desired R-value cost. Foam flowability and processing to guarantee complete encapsulation of MAI panels also will be addressed. Iterations will be made to both the manufacturing process and the MAI-polyiso composite design to improve the overall performance (R-value and cost). In parallel with the research and development work, technology-to-market analysis will be performed to formulate a commercialization plan.

Project Impact: The new R-12/inch insulation product would be attractive for applications where the thickness of the insulation is important. Two applications that would clearly benefit are wall sheathing and commercial roof retrofits. Based on the DOE Market Definition Calculator, ORNL estimates the total primary energy savings potential to be 1319 TBtu for retrofit-only commercial roof and residential wall applications. The estimates are based on numerical modeling of baseline reference following the 2006 International Energy Conservation Code® (IECC) and the same buildings retrofitted using the R-25 MAI-polyisocyanurate composite insulation.

For further information, visit *https://www.energy.gov/eere/buildings/downloads/r25-polyisocyanurate-composite-insulation-material.*

2. R10 Insulated Vinyl Siding

Replacing cladding with new vinyl siding has long been a popular retrofit project with homeowners because of its aesthetic qualities. However, siding alone does not improve energy efficiency, and improving the energy efficiency of existing wall assemblies is one of the most difficult envelope improvements to do cost effectively. BTO is currently working to develop an innovative option that is both cost effective and energy efficient by integrating vinyl siding with insulation. The potential energy savings of this siding is over a quarter of a quad of energy.

Lead Performer: Oak Ridge National Laboratory (ORNL) – Oak Ridge, TN

Partners:

- Lawrence Berkeley National Laboratory (LBNL) – Berkeley, CA
- National Renewable Energy Laboratory (NREL) – Golden, CO

Project Objective: ORNL, alongside LBNL and NREL, will evaluate the performance of novel air barrier systems, and then aid the market adoption of those air barrier systems with a high potential of reducing the energy losses in buildings due to air leakage. This research will be conducted through field tests of approximately 25 buildings and homes where buildings constructed with newer air barrier systems will be evaluated with blower door testing. This work will examine the relationship between energy efficiency and costs associated with commonly used and novel air barrier systems, including variability in the performance of these air barriers to due workmanship and natural product inconsistencies.

ORNL also is supporting the development and validation of the Fraunhofer Attic Thermal Model (FATM), which is an attic and roof deck heat transfer model. The computer code for FATM will be merged into the physics engine in EnergyPlus™ to enhance EnergyPlus estimates of heat gains and losses in building attics, and thus improve the accuracy of energy and cost savings estimates from various interventions for new construction and building retrofits that aim to improve attics. Evaluation of winter and summer conditions in cathedralized attics will be incorporated into FATM in FY16 and FY17, respectively.

Project Impact: Air leakage in buildings is responsible for about 4 quads of energy use per year, the largest contributor to heating energy loss in the residential and commercial sectors. Consequently, DOE's 2014 Windows and Building Envelope Roadmap lists air sealing technologies as a top priority research area that has the technical potential to save 1,600 TBtu by 2030. Since traditional air barrier systems may be limited in reducing energy loss, researching and testing novel air barrier systems is critical to the development of more energy efficient air barrier technologies. Improved air tightness of building envelopes is also a growing requirement in voluntary and mandatory codes, which will affect the pace of market growth for energy-efficient building envelope and window technologies.

For further information, visit *https://www.energy.gov/eere/buildings/downloads/core-research-support-bto-windowsenvelope-programs-0*.

3. Polymeric Vacuum Insulation Spheres (PVIS)

PVIS is unique in that it uses individual spheres to help reduce the risk of puncture from common building materials like nails, and prevents the loss of air tightness while increasing thermal conduction. While this project is still considered early-stage, it could be one of the most significant innovations in high-performing building insulation materials in decades.

4. Vacuum Glass for R-10 Windows

This technology has the potential to reduce heat loss in typical windows by 60% to 70%, to the point that annual heating bills could be lower with windows than from a typical opaque wall. This new type of insulating glass technology uses a low-E coating with a vacuum between two layers of glass that are spaced only .01" apart.

Lead Performer: V-Glass – Pewaukee, Wisconsin

Partners:

- University of Sydney – Sydney, Australia
- National Renewable Energy Laboratory – Golden, Colorado

Project Objective: V-Glass will develop a Vacuum Insulating Glass (VIG) Unit with tiny wire whiskers as pane spacers for superior insulating performance and lifetime. The vacuum glazing will provide very low thermal conductivity, while also operating within very high compression loading created by the vacuum on tiny bearing points. Developing low thermally conductive VIG standoffs is one of the major barriers to high-performance VIG development.

Project Impact: Vacuum-insulated glazing has the potential to reduce heat loss in typical windows sold by around 60-70%. This project will also improve the knowledge base to help other VIG performers.

For further information, visit *https://www.energy.gov/eere/buildings/downloads/vacuum-glass-r-10-windows*.

Full press release courtesy BTO and Sven Mumme, and available at *https://www.energy.gov/eere/articles/4-technological-advances-keeping-your-home-warm-while-reducing-your-energy-bill*.

IN PRACTICE

Testing Latent Loads and Their Implications in High Performance Homes

Many individual home efficiency measures demonstrably offer energy savings and performance. However, holistically, the total effects and impacts of a high performance home are not as well understood.

How do advanced techniques and products add up and influence whole home health and performance? How are occupants reacting to this new environment? In a market that is rapidly changing from the standpoints of both technology and code requirements, how can we make the best decisions with regard to policies, occupants, and buildings?

One major concern for the residential construction industry is humidity and its impact on indoor air quality. Do the tighter envelopes and dramatically lower infiltration rates of high performance homes negatively impact indoor environments?

A study conducted by the National Renewable Energy Laboratory (NREL) and Oak Ridge National Laboratory (ORNL) and released April 1, 2018 (Winkler, Jon, Munk, Jeffrey, & Woods, Jason. Effect of occupant behavior and air-conditioner controls on humidity in typical and high-efficiency homes. United States. doi:10.1016/j.enbuild.2018.01.032. *https://www.osti.gov/biblio/1424450*) sets out to address the nexus between humidity, loads, and the indoor environment.

In this study, the researchers utilize established moisture-buffering and air-conditioner latent degradation models in conjunction with modeled internal gains to compare building loads and indoor humidity levels of typical new construction homes, built to International Energy Conservation Code® (IECC) 2009, against those of high-efficiency, low load homes in 10 US cities (Miami, Florida; Orlando, Florida; Phoenix, Arizona; Atlanta, Georgia; Las Vegas, Nevada; Nashville, Tennessee; Albuquerque, New Mexico; Indianapolis, Indiana; Denver, Colorado; Minneapolis, Minnesota). (See Figure 9.)

"One of the main motivations [for the study] is that the importance of loads is changing," explains Winkler. "As we increase insulation and incorporate better windows and duct work, the envelope loads are decreasing quite substantially," Winkler notes, "and infiltration has much less of an impact, despite added mechanical ventilation."

"Not only are the relative importance of loads changing, but the breakdown between sensible and latent loads are changing," Winkler explained in a webinar presentation through the US Department of Energy (DOE). While sensible loads in high performance homes, like an ENERGY STAR® certified home, are much less than sensible loads in

Key House Construction Characteristics

IECC 2009 Home

City	Climate	Wall R-Value	Ceiling R-Value	ACH_{50}	Window U-Value	Window SHGC	Duct Location	Ventilation
Miami, FL	1							
Orlando, FL	2			4.75				
Phoenix, AZ			R-30		0.37	0.30	Attic	
Atlanta, GA	3	R-13		4.6				
Las Vegas, NV								Spot vents per GIHM profiles
Nashville, TN	4						Crawlspace	
Albuquerque, NM							Attic	
Indianapolis, IN	5		R-38	4	0.35	0.44		
Denver, CO		R-13+5					Basement	
Minneapolis, MN	6		R-49					

Low-Load Home

City	Climate	Wall R-Value	Ceiling R-Value	ACH_{50}	Window U-Value	Window SHGC	Duct Location	Ventilation
Miami, FL	1		R-30					
Orlando, FL	2	R-13		3	0.37	0.25		
Phoenix, AZ			R-38					
Atlanta, GA	3				0.30	0.25		ASHRAE 62.2 + Spot vents per GIHM profiles
Las Vegas, NV				2.5			Conditioned Space	
Nashville, TN	4	R-13+5			0.30	0.40		
Albuquerque, NM								
Indianapolis, IN	5		R-49					
Denver, CO				2	0.27	0.46		
Minneapolis, MN	6	R-13+10						

Figure 9. Comparison of house characteristics used in the study. Data from December 6, 2017 presentation, "Effect of occupant behavior and air conditioner controls on humidity in typical and high-efficiency homes," and courtesy the National Renewable Energy Laboratory, Oak Ridge National Laboratory, and the US Department of Energy. Slides available at *https://www.energy.gov/sites/prod/files/2017/12/f46/BA%20webinar%20-%20occupant%20behavior%20indoor%20humidity-2017-12-06.pdf.*

Percentage of Total Load that Is Latent Is Increasing

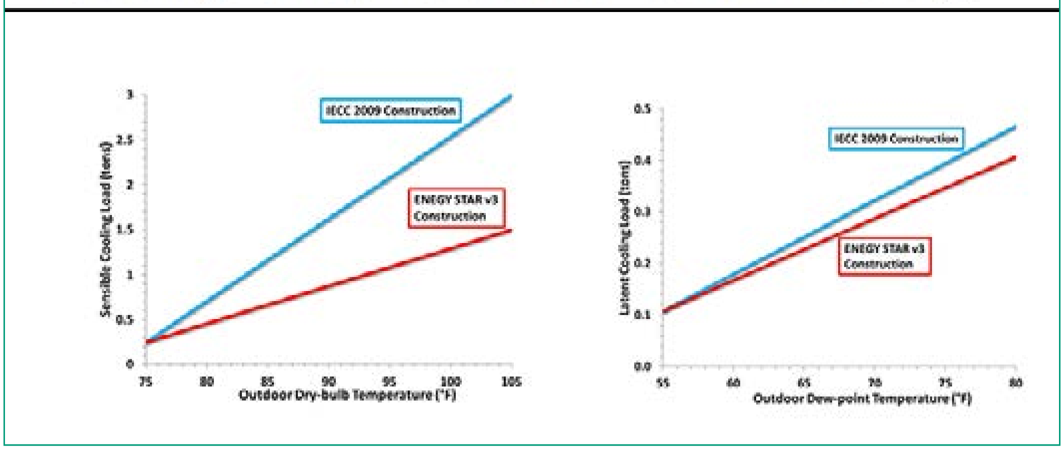

Figure 10. While the sensible load has been reduced in energy efficient homes, the latent load remains similar between more efficient homes and standard construction. The research team set out to evaluate this changing ratio of latent and sensible loads. Data from December 6, 2017 presentation, "Effect of occupant behavior and air conditioner controls on humidity in typical and high-efficiency homes," and courtesy the National Renewable Energy Laboratory, Oak Ridge National Laboratory, and the US Department of Energy. Slides available at *https://www.energy.gov/sites/prod/files/2017/12/f46/BA%20webinar%20-%20occupant%20behavior%20indoor%20humidity-2017-12-06.pdf.*

a standard home, the latent loads present in both homes are very similar (see Figure 10). Therefore, high performance homes face a different ratio between sensible and latent loads as the envelope improves.

The research by Winkler, Munk, and Woods:

1. Characterizes the sensible and latent cooling loads of typical-construction homes and low-load homes.
2. Evaluates the sensitivity of indoor humidity to variations in internal loads, window shading, and air conditioner cooling setpoint.
3. Determines how air conditioner operation affects indoor humidity to guide equipment selection and setup for equipment installers and service technicians.

Beginning with the two house profiles in each of the 10 cities, the team then modeled multiple scenarios of occupant behavior; heating, ventilation, air conditioning equipment and setpoint parameters; material buffering; and, window shading. (See Figure 11.)

The Results

Using the EnergyPlus™ simulation engine and occupant-related inputs assessing sensitivity on indoor humidity and cooling energy, the team found that high-efficiency homes in humid climates have cooling loads with a higher fraction of latent loads than the typical new construction home, resulting in higher indoor humidity for low load homes.

Winkler, Munk, and Woods used ASHRAE® Standard 55 to define high humidity as levels above 60.2°F dew point (DP), which is based on 60% relative humidity (RH) at 75°F. Baseline indoor humidity results showed that median hours above 60.2°F DP increased for all humid cities in climate zones 1-5 (see Figure 12). Median hours in low-load homes definitely exceeded those hours above DP in IECC, indicating higher humidity than standard construction. In dry climates, however, the study found that IECC and low load homes' latent

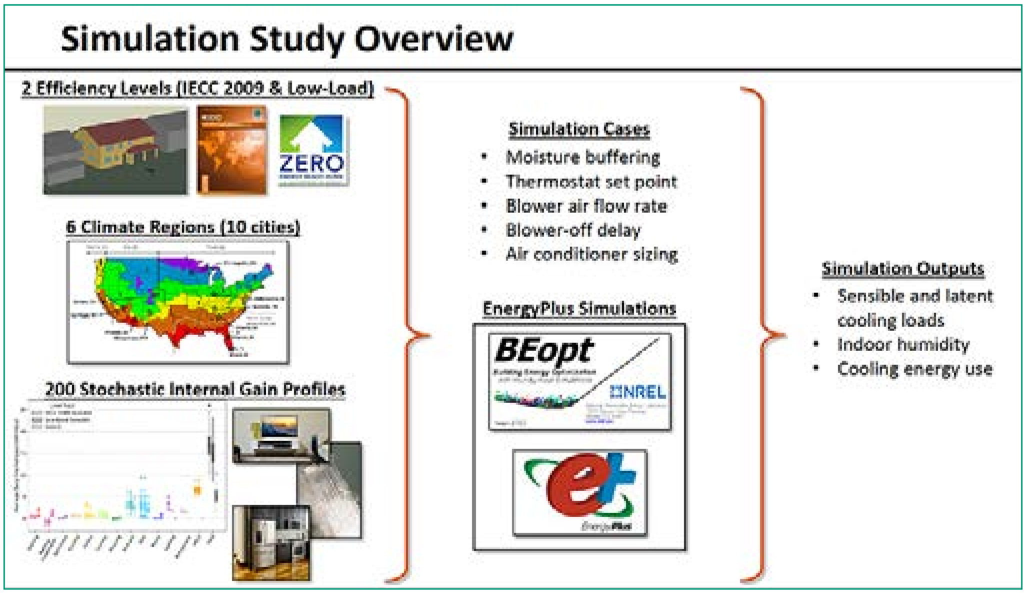

Figure 11. Simulation Study Overview. Data from December 6, 2017 presentation, "Effect of occupant behavior and air conditioner controls on humidity in typical and high-efficiency homes," and courtesy the National Renewable Energy Laboratory, Oak Ridge National Laboratory, and the US Department of Energy. Slides available at *https://www.energy.gov/sites/prod/files/2017/12/f46/BA%20webinar%20-%20occupant%20behavior%20indoor%20humidity-2017-12-06.pdf*.

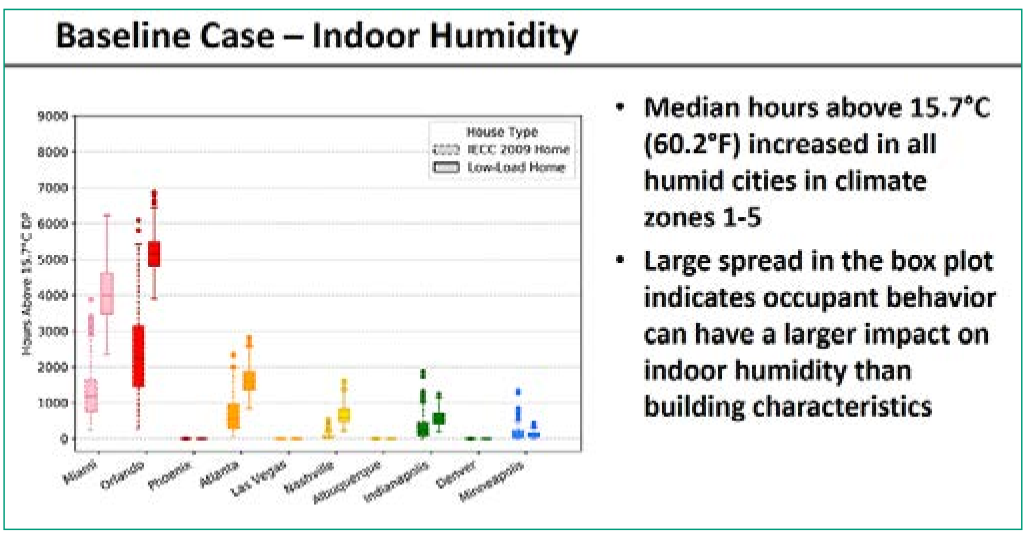

Figure 12. Baseline case comparing indoor humidity levels in between an IECC-built home and a low-load home in 10 US cities. Data from December 6, 2017 presentation, "Effect of occupant behavior and air conditioner controls on humidity in typical and high-efficiency homes," and courtesy the National Renewable Energy Laboratory, Oak Ridge National Laboratory, and the US Department of Energy. Slides available at *https://www.energy.gov/sites/prod/files/2017/12/f46/BA%20webinar%20-%20occupant%20behavior%20indoor%20humidity-2017-12-06.pdf*.

loads are very similar, versus the significant differences found in humid climates.

What can be concluded from the higher latent loads experienced by high performance homes in humid cities? The team found that sensible loads in high performance homes were reduced 16% to 25% by efficiency measures. However, low load homes saw a latent load increase due to added mechanical ventilation. Total cooling loads, therefore, appeared similar because of this latent offset. In low load homes, the sensible heat ratio (SHR) was significantly reduced. However, because of this shift in SHR, low load homes will have higher humidity than standard construction homes, all other things being equal. In dry and cold cities, there is virtually no difference, as the latent load remains a small fraction of total load.

The recommendations…

The team's research did evaluate several conventional methods to tackle latent loads.

First, reducing the cooling setpoint does successfully reduce indoor humidity. However, this method is not energy efficient, and the resulting overcooling may lead to occupant discomfort.

Three thermostat cooling setpoints were evaluated: 72°F, 75°F, and 78°F. As hypothesized, decreasing the cooling setpoint by 3°F reduces the median hours above 60.2 DP, since it results in additional air conditioner run time. "We were surprised by the order of magnitude we saw in this," Winkler comments. In the IECC 2009 home, the team saw a 90% to 100% reduction in hours above the dew point, while low load homes saw a 79% to 96% reduction. Although lowering the temperature clearly alleviates humidity issues, it obviously also leads to increased energy use, with simulations showing a median of 27% to 44% increase in energy use.

As the team notes, the "go-to" interface for comfort is often a home's cooling setpoint; occupants adjust the thermostat setpoint down and achieve better comfort, albeit with drawbacks. Dropping the temperature low enough to achieve correct indoor humidity means increased cooling energy use and the potential for occupants to become uncomfortable in the colder air required. Lower indoor setpoints also increase condensation and moisture durability risks.

Other strategies shown to reduce indoor humidity were eradicating the blower operation at the end of cooling cycles and reducing the cooling airflow rate. These had a smaller impact on energy use and comfort than lowering setpoints.

Of the two, eliminating the blower off delay had a larger impact on indoor humidity than changing the blower airflow rate. "We looked at having no blower off delay, a 45-second delay, and a 90-second delay," Munk explains. "This had a larger impact on hours above 60.2 DP than reducing the blower airflow rate, with sizable reductions in humid climates when you eliminate the blower off delay." Cooling energy use variation between +1% or -2% for all cities means a negligible energy impact from this scenario.

In looking at equipment specifically, results show that reducing the supply airflow rate and eliminating the cooling blower off delay has significant impacts on reducing RH, and only small impacts on energy use. Another nod in favor of this strategy, is that, typically, these equipment set-up items are easy to adjust and also can be used to mitigate the humidity effects of an oversized system. This is an important finding of the study, since those homes with an oversized system did have an increase in hours above the 60.2 DP standard. While equipment size is not a factor that can be readily changed, other strategies, like the reduction in supply airflow rates and eliminating the blower off delay can offset these oversized equipment issues.

A note on occupant behavior…

However, one load that is constant, whether in a standard or high performance construction project, is internal gain. The research stressed that internal moisture gains are, as would be expected, highly variable. With just 3 occupants, anywhere from 5kg per day and up to 20kg per day of moisture may be added: a large variation.

"If you want to understand humidity loads, you have to understand variance of occupant behavior," Winkler states. As demonstrated in research, field studies, and life, internal loads can have a significant impact on home humidity. The large spread in each city's simulated box plot indicates occupant behavior can have a larger impact on indoor humidity than building characteristics.

The team found that:

- The number of occupants and occupant behavior can have a large effect on the sensible and latent internal gains.
- National average internal gain profiles do not provide any insight into how indoor humidity varies due to differing occupancy.

There is a Generation of Indoor Heat and Moisture (GIHM) tool being developed at ORNL. GIHM was formulated to evaluate envelope moisture durability risks, and is similar to Building America℠ Domestic Hot Water Generator for internal loads.

The research project found that, in certain cases, occupant impacts could actually have a larger impact than building characteristics. Furthermore, with the exception of Phoenix and Las Vegas, the team found that variation in occupant behavior could have a larger impact on cooling energy than efficiency improvements.

The Takeaway…

Increasing insulation levels and improved windows are reducing sensible cooling loads in high-efficiency homes. The research by Winkler, Munk, and Woods shows that there is a resulting shift in the balance of sensible and latent cooling loads, which does, in some cases, result in higher indoor humidity for low load homes in humid climates. While there are strategies that can reduce indoor humidity – like lowering thermostat setpoints – these come with energy penalties. How this plays out in the field (reality!) is an important concern.

The research team had firm conclusions about future work needed in light of the study. First, there is a clear need for a metric that assesses comfort based on both temperature and humidity, and that also reflects residential occupant expectations and behavior. The team notes that they struggled finding the best metric and settled on ASHRAE 55, although this analytical method does not seem sensitive enough to indoor humidity, as large fluctuations have little effect on the percentage of occupants dissatisfied.

Second, and ideally, the research finds that there is a need for a method that distills hourly measurements into a simple value representing annual comfort.

For a direct link to the video presentation given by Winkler, Munk, and Woods, visit *https://youtu.be/GbnYQxeKl1s.* For a link to the presentation slides, see *https://www.energy.gov/sites/prod/files/2017/12/f46/BA%20webinar%20-%20occupant%20behavior%20indoor%20humidity-2017-12-06.pdf.*

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