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Mind the Gaps: Making Existing Buildings More Airtight

Leaky building enclosures create health hazards, comfort problems, and high energy bills. Fixing them isn't rocket science; but you'd better know your building science.

by Nadav Malin and Peter Yost

Sealing air leaks in any building can make it more comfortable and efficient. But owners of existing buildings often resist spending the time and money to address the problem. In fact, addressing air leaks in existing buildings is like the Rodney Dangerfield of Rodney Dangerfields. In the words of the late comedian, "they just don't get no respect."

Even without air leaks, existing buildings don't get no respect unless they are historic or otherwise noteworthy.

And when there are air leaks, most owners don't pay attention until the signs are impossible to ignore: ice dams building up, mold growth, or people near the windows are shivering. At that point an expert might be recruited to scope out the problem and recommend a solution.

Drivers for Air Sealing

Leaky buildings are often ignored in the face of other problems that are perceived as more critical, reports Jenny Carney of WSP in Chicago. "In larger commercial buildings, even if they know that they have an air leakage problem, it's rare that fixing it rises to the level of capital investment," Carney says. "When it does," she continues, "it's driven by occupant comfort or other issues."

To make things worse, "most people don't even realize that they have a leaky building unless they are getting drafts or have freezing pipes, cluster flies, or icicles coming out of the curtainwall," reports building forensics expert Terry Brennan of Camroden Associates.

In Canada, many architects are aware of the general importance of airtightness in building enclosures thanks to the network of provincial Building Enclosure Councils. Seeking to establish similar councils in the U.S., architect and building enclosure consultant Wagdy Anis of Wiss Janney Elstner Associates connected the American Institute of Architects with the National Institute of Building Science to jointly convene the groups. This model began in Boston, according to Anis, and "there are now thirty around the country."

These councils are mostly focused on designing new buildings, according to Anis, who helped establish the groups. "Consultants get called in for forensic work due to problems in [existing] buildings," he says. "Architects don't typically get called in for that."

Performance problems

Owners don't often seek out air-sealing improvements to save energy. "We would love to convince our clients of the long-term value of our approach based on energy benefits alone, but often the driver is some other problem," says Catherine Muller, president of Air Barrier Solutions, a company dedicated to air sealing and insulating existing buildings.

Image courtesy Goody Clancy

Built in the 1970s, the 280,000 ft^2 Gant Complex at the University of Connecticut will receive a new exterior skin and improved insulation. Preliminary air infiltration testing of the proposed modifications indicates an astounding improvement of 99.7%.

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Air Barrier Solutions is typically called in due one of these common performance problems:

- Ice dams: warm air leaking into roof cavities melts snow on the roof. The water runs down and freezes at the eaves, where it builds up, resulting in puddles behind it and potentially dangerous icicles along the edge.
- Thermal comfort complaints: leaking air makes it hard to keep people near the perimeter comfortable, either because they're getting drafts directly from outdoors or because the whole perimeter zone suffers from cooling and heating systems that can't keep up with the load.
- Humidity control problems: air that leaks in isn't conditioned for appropriate indoor humidity levels.
- Window condensation: cold air leaking in near windows lowers their surface temperature to the dew point of indoor air.
- Mold or mildew: condensation on cool surfaces inside the building or within building cavities supports microbial and fungal growth, which can release allergens or toxins, and damage building materials.
- Noise from outside sources: sound travels via pressure waves in the air, so leaking air means more noise transmission.
- Odors: smells from outdoors bypass a building's filtration systems when they leak in through the walls. In multifamily buildings, compartmentalizing individual units to prevent odor from spreading is a common challenge.

Buildings with tight performance requirements, such as an historic building with old finishes or a museum housing humidity-sensitive art, are especially at risk. "It might be deteriorating plaster now that a historic building is air conditioned or controlling temperature and humidity for museum exhibits—it is amazing how many problems trace back to a defective air barrier," notes Muller.

Photos: Air Barrier Solutions

North Prairie Junior High School Case Study: Damage from water intrusion regularly experienced during the winter with a snow load on the roof. This problem was pretty widespread throughout the facility. The foil-faced fiberglass insulation batts looked pretty well-installed along the roofline, but air leakage testing revealed "highways" throughout the roof insulation. All of the fiberglass roof insulation was removed to allow installation of the spray foam insulation as the continuous air and thermal barrier for the trussed roof assembly. In the school's gym, spray foam was used to seal off each of the air leaks of the fluted metal roof deck.

For more on the problems associated with leaky buildings and strategies for making new buildings tight, see our previous article: Making Air Barriers that Work: Why and How to Tighten Up Buildings.

Aesthetics

Buildings can also fail—at least in the commercial sense—by not keeping up appearances. In certain markets, owners will invest in reskinning a building to update its look and to keep it competitive with newer peers.

Lorne Ricketts, a building science engineer with RDH Building Science in Vancouver, British Columbia, has studied the drivers for building envelope upgrades. The Belmont is a high rise apartment building he investigated that had enclosure elements wearing out, and was starting to look old and dated. "The building is in a high-end neighborhood and the owners wanted something that reflected a more modern design while also providing needed renewal," he explains about the building's owners.

Once the owners started looking into upgrading the look of the building, they saw the opportunity to improve it in other ways. Now that the project is completed, the owners are pleased with the energy savings, but even happier with how comfortable and quiet the apartments are.

Energy savings

Saving energy is usually a fringe benefit to a building envelope upgrade that is driven by other factors, but sometimes an audit points to air sealing specifically as a worthwhile energy conservation measure. "For existing buildings, infiltration is often the biggest envelope energy driver," reports Andrea Love, building science cirector at Payette in Boston. "Unfortunately," she continues, "very little data exists on large scale commercial buildings infiltration, and it is difficult and expensive to test whole buildings so it very rarely happens."

Energy audits are one common way that leaky buildings are identified if their other symptoms haven't already raised air leaks as an issue. Jenny Carney is also founder of the BIT Building program, which aims to encourage and support managers of existing buildings—including under-performing buildings where resources are limited—to improve their energy, water, and waste footprints. In BIT, as in LEED, the required energy audit will show strategies that will lead to performance improvement, according to Carney. "The assessment would determine if envelope measures are part of the solution," she explains.

Images: RDH Building Science Inc.

The Belmont, a 13-story residential building in Vancouver, British Columbia, was constructed in 1986. It got a comprehensive air-sealing and insulation upgrade when the building enclosure needed repairs and an updated look, reducing overall energy use by 19%. The building is seen here before (left) and after (right) the upgrade.

Even audits tend to undervalue envelope improvements, however, because they're often done by people whose expertise—and sometimes incentives—are tied to mechanical systems. "If software like Air Barrier Solutions' CHIEF$_{Plus}$ were available to more people doing audits, they might identify air leakage as an opportunity more often," says Carney.

How big is the energy opportunity?

According to the latest Commercial Buildings Energy Consumption Survey (CBECS), in 2012, the U.S. had more than 5.5 million commercial buildings. These buildings collectively use nearly 7 quads of energy—that's quadrillion—or 7 x 10^{15} Btu. Pushing for net-zero energy in new buildings is great, but without addressing this huge energy load in existing buildings we won't make much of a dent in near-term carbon dioxide emissions.

Only 670,000 of those 5.5 million buildings are over 25,000 ft^2 in floor area, but those larger buildings are responsible for nearly 70% of the energy use. The larger buildings also contain most of the floor area, but that doesn't explain all of their energy appetite: their average energy use intensity (EUI) is just over 84 kBtu/ft^2, compared to 80 for all commercial buildings.

Almost 36% of this energy is used for heating and cooling, for a total of 1.7 quads. Adding in the energy lost during conversion and transmission, that number is 2.8 quads, or about 3% of total U.S. energy consumption.

The handful of studies that have measured air leakage in large buildings find that they vary widely, from quite tight to very leaky. When they were built and where they are located doesn't seem to matter much, but tall buildings do tend to be much tighter than short ones.

Units of Measure: Quantifying Air Leakage or Tightness

Tests that quantify air leakage yield a building total, expressed in a variety of ways:

- CFM75: cubic feet per minute at 75 pascal pressure (Pa) difference between the indoors and outdoors. This metric is specific to building geometry but it is the primary output of blower door testing. A 10,000 square foot, 10 story office building, built to meet the widely used and respected US Army Corps of Engineering air tightness standard would measure 3,425 CFM75.
- CFM75/ft²SA: cubic feet per minute at 75 Pa per square foot of surface area of the building enclosure. This metric normalizes for the surface area of the building, allowing comparisons between buildings of different sizes, shapes, volume. The same office building as above would meet the US ACE standard of 0.25 CFM75/ft²SA.
- ACH50: air changes per hour at 50 Pa difference between the inside and outside of the building (commonly used for smaller residential buildings). This metric normalizes for the size or the volume of the building and is considered the simplest and most "friendly" of air tightness metrics. The same office building as above would have an ACH50 of about 1.8.

A downloadable spreadsheet from the Air Barrier Association of America provides conversions between these values and others.

A study that modeled the air sealing opportunity in U.S. Army barracks found that tightening them up from 1 CFM75/ft²SA (cubic feet per minute of air leakage at pascals of pressure per square foot of building shell area) to 0.25 would save between 6% and 52% of total energy use. In a military office building those numbers are lower, ranging from less than 1% in a mild climate to 14% in a very cold climate. A 2005 U.S. Department of Energy-funded study of commercial buildings predicted energy cost savings ranging from 3% to 36% by sealing up buildings from typical levels to a high standard of tightness. The low ends of these ranges, in hot humid climates, don't account for the full energy load of dehumidifying outside air—so the actual savings are higher.

Diagnosing Leakiness

Some symptoms are easy to diagnose. If you feel a cold draft coming through a crack between window panes, you know where the problem lies.

Others are a little trickier—general draftiness near the outside wall could indicate problems with the windows themselves, with the window-to-wall connections, or at the junctions between walls and ceilings or floors. If it's cold enough outside, the draft could even be a convection current generated by the cold surface of the window—a sign of poor thermal performance, but not necessarily air leakage.

Some symptoms might be obvious to people who have seen similar problems in other buildings, but not to the casual observer. Icicles forming at the weep holes in a curtainwall, for example, are a tell-tale sign of humid air escaping the building. "You have to look at the whole building as a system," explains air-sealing consultant Henri Fennell of Thetford, Vermont.

As building owners and their tenants get more sophisticated about monitoring indoor air quality, other clues can emerge. In one commercial office, for example, the facilities team noticed an increase in fine particulates when local forest forest fires were active. The higher PM2.5 (particulate matter 2.5 micrometers or smaller) readings were happening in perimeter zones during off hours, when the building was under negative pressure. That gave the clear evidence that air pollution was leaking in through the enclosure, bypassing their filtration systems.

Air tightness testing

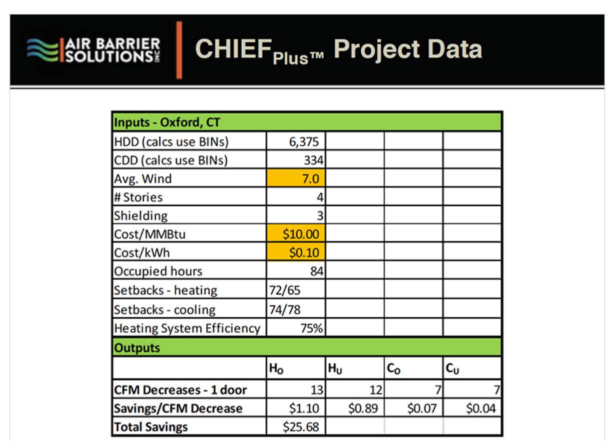
All too often, the leakiness of a building is determined by an educated guess. "Most of the time it ends up being a guess based on our professional intuition of a building looking to be leaky or not, to determine if infiltration is a big deal," reports Love. "There is definitely lots of room for improvement."

Testing can be time-consuming and expensive, but it's the best way to figure out what's really going on. If you're working on a comprehensive energy audit, for example, testing is the best way to find out how much of the heat lost (or gained) through the enclosure is due to air leakage. "Pre- and post-retrofit testing drives our Quality Assurance program," says Larry Harmon, co-founder of Air Barrier Solutions.

There are a number of testing protocols—defined by ASTM and other standards—that can be used to guide the process (see sidebar: ASTM Testing Standards Decoded).

The bigger a building is, and the leakier it is, the harder it is to measure, however. The standard technology involves setting up fans—"blower doors"—to pressurize or depressurize the building. By measuring how much air the fans have to move to maintain a certain pressure difference between indoors and out, you can tell how much air is leaking at that pressure.

That works fine for houses and other small buildings, or for very tight buildings, because the fans don't


CHIEF Plus™ Project Data

Inputs - Oxford, CT				
HDD (calcs use BINs)	6,375			
CDD (calcs use BINs)	334			
Avg. Wind	7.0			
# Stories	4			
Shielding	3			
Cost/MMBtu	$10.00			
Cost/kWh	$0.10			
Occupied hours	84			
Setbacks - heating	72/65			
Setbacks - cooling	74/78			
Heating System Efficiency	75%			
Outputs				
	H_O	H_U	C_O	C_U
CFM Decreases - 1 door	13	12	7	7
Savings/CFM Decrease	$1.10	$0.89	$0.07	$0.04
Total Savings	$25.68			

Image: Air Barrier Solutions

CHIEF$_{Plus}$ is a proprietary calculation tool that Air Barrier Solutions uses to translate air leaks into costs of work (per lineal or square foot), energy savings for each lineal or square foot, and track results against their budget/bid.

Photo: Alex Wilson

Blower door testing underway at the Brattleboro Food Co-op building.

have to move that much air. But a large, leaky building might require an industrial-scale fan, or array of fans. "The most we've used was 22 fans on engineering building in Florida," reports Brennan.

Fans as diagnostic tools

Blower doors are good for more than just measuring total air leakage. While they're running it's easy to walk around with little smoke sticks and see where the air is moving in or out. And by measuring air pressure in different parts of a building you can tell if some areas are more leaky than others.

"We do confidential and proprietary at-risk inspections when people are interested in having us fix their buildings without shopping the job to other contractors," says Harmon. Air Barrier Solutions's inspections always include blower door tests to identify leakage sites, and may also include whole-building blower door testing to quantify pre- and post-leakage rates and/or more targeted testing on individual building components, such as windows or doors.

The residential tower under construction on Cornell University's Roosevelt Island campus in New York City, for example, is being built to Passive House standards. Because it met that high standard, it was easy to test, reports Brennan. "The building tested at 0.04 CFM75/ft^{2}SA—four times better than the Passive House threshold," Brennan said.

Stop blowing and listen

An innovation that builds on the sound detection option within ASTM E1186, SonicLQ uses sound to locate and size air leaks in a building's exterior envelope. The system can be used to test any building, during construction or after the building is completed or occupied, and during any season of the year. Acoustic data are presented to the user in a visual format that identifies where air leaks are located on the building façade—as well as the size of specific leaks—so that informed decisions can be made to seal the largest leaks and realize the greatest energy savings while minimizing assessment and diagnostic costs.

In the SonicLQ system, a low-frequency sound (about 60 decibels or so, roughly the same as conversation in a restaurant or background music) is generated from a speaker inside the building. Sound that leaks out is picked up by the small microphone array just outside the wall. The microphone array is lightweight enough that it can be carried on a drone to track with the speaker location.

The sound data are wirelessly sent to a laptop computer, which translates the data into a visual map of leakage that can be overlaid onto an image of the building. Testing a single 12 foot by 12 foot room within a building would take 2–4 minutes, according to the company.

"Distant" acoustic measurement identifies target areas of air leakage; these measurements currently

ASTM Testing Standards Decoded

Architects and, particularly, specifiers need to be familiar with these terms and the most common standards cited for building air leakage or tightness.

- ASTM E779 10: "Standard Test Method for Determining Air Leakage Rate by Fan Pressurization" – This is the older standard, which involves testing for air leakage rates several times, at a range of pressure differences. The standard includes a method for extrapolating from a series of measurements to predict the airflow at other pressure differentials, including the conditions under which a building might typically be operating. This standard is strictly quantitative in nature.
- ASTM E1827-11: "Standard Test Methods for Determining Airtightness of Buildings Using an Orifice Blower Door" – This is the newer standard, which only tests the baseline and pressure at either 50 or 75 Pa, using assumptions about the equation relating pressure and air flow.

Qualifying air leakage or tightness

While it's important to know how leaky a building is, the goal in existing buildings is to identify and fix the leaks. The sum total air leakage does not really help us with where and how big the individual leaks are.

That's where a different standard comes into play, one that includes leak identification tools in addition to blower door building pressurization.

ASTM E1186 - 03(2009): "Standard Practices for Air Leakage Site Detection in Building Envelopes and Air Barrier Systems" – This standard includes seven different tools that can be used for detecting air leakage. Below are the four most common.

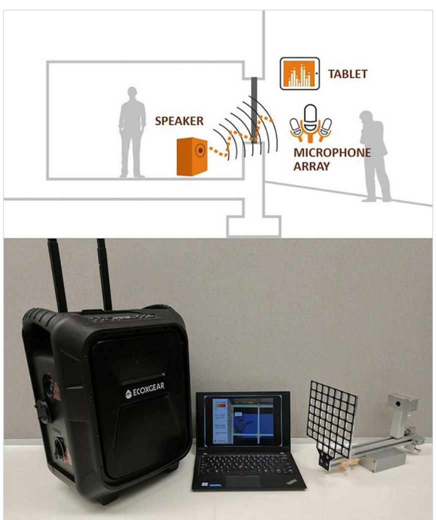
1. Infrared scanning with blower door – The blower door exaggerates air leakage and therefore convective heat loss that the IR camera picks up as "plumes" that identify the air leakage.
2. Smoke pencil with blower door – A smoke pencil makes the air leakage visible.
3. Blower door with anemometer – Anemometers measure air flow so the air leakage can be characterized by just how much air is flowing in a specific leakage site.
4. Generated sound with sound detection – Sound travels like heat, transmitted conductively through solids or kinetically through air or other fluids. The air pathways are called flanking sound pathways. Some of the first air-tightening of homes were as part of noise control in homes built close to airports. If you have a sound source and a receiver, you can detect and even measure the sound transmission associated with air leakage.

And you can download the USACE Air Leakage Test Protocol for Building Envelopes from the Whole Building Design Guide website.

cover about 100 square feet of exterior enclosure but the goal is to increase this significantly. The near-field acoustic measurements assess 3 foot by 3 foot areas of leakage.

SonicLQ has published its patent application, started testing a field prototype, and procured funding from the Department of Defense to do field testing alongside a conventional blower door, according to Inventor Ralph Muehleisen, principal building scientist at the U.S. Department of Energy's Argonne National Laboratory, "We will be ready for pilot projects within the next nine months," he predicts.

Upon learning about this new technology, Brennan was impressed. "This is definitely real," he said. "The math holds up. I am not sure that this approach will be a real advantage over existing approaches for new, tight, buildings—such as the Cornell University 27-story building, which tested with just one blower door—but for big existing buildings, this has real promise."



Images: Argonne National Laboratory

SonicLQ's speaker projects low-frequency sound from the interior to the exterior enclosure. The sound makes its way through leakage sites to be both quantified and located by the microphone array. The array sends received acoustic data wirelessly to the tablet for processing and expression of results. The bottom image shows the three real components of the SonicLQ system. On the right is the commercially-available high-quality speaker, which generates the test sound; on the left is the microphone array that receives the sound waves; in the middle is tablet or laptop with a screen depicting the acoustic data overlaid on a digital image of, in this case, a window in the exterior enclosure.

Brennan has some particular questions regarding how well SonicLQ will do with complex, circuitous air leaks—for example, air leaks through steel stud with fiberglass and gypsum sheathing into the cavity behind brick veneer at the top of wall into soffit or coping—but he also says that the SonicLQ might do better than existing pressure techniques for features such as trash chutes.

The real test, according to Brennan, would be to have experienced blower door experts working with SonicLQ on the testing.

How Leaky Are Existing Buildings?

"There is a huge range in air-tightness performance of existing buildings," reports Ricketts. For example, "a highly glazed commercial building is likely pretty airtight," he predicts.

Steven Emmerich and Andy Persily at the U.S. Department of Commerce National Institute for Standards and Technology (NIST) collected data on 200 buildings from several sources and concluded that they are, on average, very leaky. How leaky? About 1.5 CFM75/ft^2SA. But their average might have been skewed by a bunch of super leaky small commercial buildings in Florida.

Actual measurements of larger buildings found that many of them aren't so bad. An ASHRAE study of 16 relatively new buildings in the eastern U.S., all built between 2000 and 2010, measured a ten-fold difference in leakage rates from the best to the worst, but even the worst was only half as leaky as the average building from Emmerich and Persily's study. Most of the buildings tested, including both the tightest and the leakiest, were either LEED or Energy Star certified.

A 2014 International Energy Agency report entitled "Energy Efficient Technologies & Measures for Building Renovation" assumes 1 CFM75/ft^2SA as a baseline for existing buildings. This figure doesn't so much represent a "typical" building—because actual air tightness in existing buildings varies so widely—but it may be a reasonable approximation of an average. For the 23,000 ft^2 four-story rectangular office building modeled for that report, this leakage rate translates to about 1 air change per hour (ACH) at normal pressures (4 pascals).

Sealing Up Buildings

Improving very leaky buildings isn't hard

"We've had good success on before and after retrofit infiltration of historic buildings in the range of 50,000 ft^2, even with remarkably simple measures," reports Z Smith of Eskew Dumez & Ripple in New

How tight is tight?

Less than one cubic foot per minute (CFM) of air flow may not sound like much, but it adds up quickly as one multiplies that number by the size of the building.

Note, however, that these numbers are at 75 pascals of pressure (Pa) difference, or 0.3 inches of water column (enough pressure to draw water up a tube 0.3 inches). Unless there are strong winds or a large staff effect at play, typical pressures in most buildings are closer to 4 Pa (0.016 inches water column—the default amount assumed for energy models that take air leakage into account).

How much air leakage happens at those normal pressures in a building that has been tested at high pressure depends mostly on the size of the cracks or holes involved. If all the leakage is happening through one large wide-open hole, the air movement will be more or less proportional to the pressure differential. Seventy-five CFM at 75 Pa will become about 4 CFM at 4 Pa.

In a more typical scenario, however, where the leaks are happening through a series of small holes or narrow cracks, there will be less leakage at lower pressures than a simple comparison of leakage area would imply. That's because there is friction causing resistance to air movement near the edge of each hole, so it takes more pressure to drive air through a space near those edges.

Because it's not feasible to measure the air leakage through the envelope at 4 Pa directly, blower door technicians estimate it by measuring air leakage at a range of pressures leading up to the 75 Pa level, and then extrapolating the results down to 4 Pa.

Orleans. Smith reports reducing infiltration levels from about 1.5 CFM75/ft^{2}SA, nearly four times the International Energy Conservation Code new construction limit of 0.40 CFM75/ft^{2}SA, down to compliance with that target.

"In a moderately leaky building, you could get 10%–20% improvement without really invasive retrofits," reports Ricketts. "It depends on how easy it is to find and seal the holes."

There's profit in soffits

Anis has some simple rules of thumb: "You have to go through the whole building starting at the top because the top is most leaky," he suggests. "Then you go into the elevator shafts and stairwells, and look at any penetrations. Then look at exterior walls."

The single best resource for understanding and assessing air barrier continuity is the US ACE Air Barrier Continuity Guide, a 16-page downloadable pdf. The guide prioritizes the most common air leakage pathways diagrammatically, and then provides 12 pages of photos of the most common examples of air leakage pathways—for each priority area—and how to air seal them. It's building science or physics that drives the prioritization, but it's identifying and sealing the holes that deliver the results. This guide has both.

Getting tight buildings even tighter is harder

The take-away from air sealing the 26 buildings in Minnesota is that it's expensive to eliminate the last bit of infiltration from buildings that are already tight. The roof-wall junction was responsible for most of the leakage that they found.

Not every company does careful testing to check on its work, but for the most dedicated, it's a matter of principle: "Performance-based work is driven by measurement and verification; this drives every member of our team, from company owners to project managers to the building envelope specialists who install the work," says Harmon.

Challenges with Air Sealing Existing Buildings

Along with all the glamour of crawling into crawl spaces and slithering through mechanical spaces, there is some serious technical know-how involved with a good air-sealing job. The challenges include understanding a building's ventilation strategies to avoid creating problems, justifying the time and cost to building owners, and ensuring good craftsmanship.

Photo: Air Barrier Solutions

Pulaski Gym Case Study: At the top of an exterior wall in the gymnasium, a big air leak where a massive steel I-beam sits on top of the exterior brick wall caused air to pour through the unsealed joint. Two-part spray foam closed off and air sealed this same leak.

Sealing off large holes often involves building and installing some kind of a barrier, often out of plywood or sheet metal. Small cracks are best filled with caulk. And isolated gaps, such as the spaces around pipe or duct penetrations through a wall, can often be filled with one-part polyurethane foam from a small can.

But to create reliable air barriers across large surfaces that lack one, nothing works like two-part spray-foam insulation. Unfortunately, no material is more vulnerable to shortcomings in quality control during installation.

Spray foam debacles

Two-part polyurethane foam is a construction material that is manufactured on the job site. There are two kinds: open-cell, which is less dense, less costly, remains flexible, and is permeable to moisture. And closed-cell, which has a higher R-value and cures into a solid, durable layer. Closed-cell foam is commonly used

Air-Tightness Requirements

Standard	Whole Building Air Leakage Allowed @ CFM75/ft^{2}SA enclosure
U.S. Army Corps of Engineers (2008)	0.25
Washington State (2010)	0.25
U.S. General Services Administration (2010)	0.25
ASHRAE 189.1-2009	0.40
International Energy Conservation Code (2012)	0.40
International Green Construction Code	0.25
Passive House (U.S)	0.16*

* Approximate value, converted from air changes per hour threshold.

Air-tightness requirements for a selection of standards and codes. Note that ASHRAE 90.1 is not listed here, because its air-tightness standard of 0.04 applies to assemblies, not to whole buildings.

Source: BuildingGreen, Inc. from Wagdy Anis and other original sources.

Two Air Barrier Solutions Case Studies

Air Barrier Solutions (ABS) specializes in fixing problem buildings by fixing defects in building enclosures, and air barriers in particular. The company works on about 50 million square feet of buildings a year all over the U.S., including both private and public sector structures. It sees itself as a trusted advisor to building owners with enclosure performance problems, conducting ASTM air leakage testing to diagnose and deliver enclosure performance improvement by way of a custom and proprietary quality assurance program.

Over the last 20 years, ABS has worked on a wide variety of building types, including airports, dog pounds, museums, secure federal facilities, commercial offices, multifamily housing, schools, hospitals, and hotels.

[See related images in the main article for reference.]

1. Pulaski Gym, Town of New Bedford, Massachusetts

Project Description: This project was part of a performance contract with Siemens. The project was driven by getting capital improvements paid for by realized energy savings. The blower door testing documented their measurement and verification plans to meet energy savings projections. Quantitative testing sometimes also helped convince utilities/regulators that rebates for air sealing made sense and/or that savings projections needed to trigger release of rebates had been met.

Pre-work air tightness testing results (ASTM E779): 0.585 CFM75/ft^{2}SA

Post-work air tightness testing results: 0.452 CFM75/ft^{2}SA

Air tightness improvement: 23%

2. North Prairie Junior High School, Winthrop Harbor, Illinois

Project Description: The main building of this school had ice dams, freezing pipes, and premature roof failures. The scope of work was simple but difficult to execute: remove about 40,000 square feet of fiberglass insulation and replace with 4 inches of closed-cell spray foam and then cover with an intumescent barrier, all while protecting and scheduling around administrative and maintenance workers over the summer.

Pre-work air tightness testing results (requiring 15 blower door units): 0.657 CFM75/ft^{2}SA

Post-work air tightness testing results (requiring 4 blower door units): 0.203 CFM75/ft^{2}SA (below the USACE threshold of 0.25 CFM75/ft^{2}SA)

Air tightness improvement: 69%

to spray onto exposed surfaces. Either one can also be injected into closed cavities—with careful controls to prevent rapid expansion that could bust apart the assembly.

Polyurethane foam is highly reactive when it comes out of the spray gun, but—if prepared and sprayed properly—quickly cures to a relatively safe, inert condition. It's far from an ideal material—see BuildingGreen's [Spray Foam Insulation Product Guide] for more info—but nothing else is currently available that does the job. And it's a better choice than the formaldehyde-based foam insulations that are still used in some areas despite serious occupant health concerns.

Installing spray foam well isn't so easy, however. Many installers don't seem to understand that they are creating a sensitive chemical reaction in difficult-to-control conditions. "I have had more failed foam cases in the last five years than in the preceding twenty," says Brennan. "There are so many people installing this stuff who really aren't experienced," he adds. "It could eventually kill a very useful product."

"Most of my work is trouble-shooting problem installations around the country," reports Fennell. There are many ways a spray-foam installation can go wrong. (See [Foam-In-Place Insulation: 7 Tips for Getting Injection and Spray Foam Right] for details.)

The underlying problem, according to Fennell, is that manufacturers provide instructions telling installers what the ideal parameters are, but they don't specify tolerances for their requirements. "The manufacturer doesn't say where the line is between good and bad, so installers don't have any way to verify if they're doing it well enough," Fennell says. "Manufacturers don't want the liability to shift from installers to them," he explains. A good installer will provide submittals before doing the work proving they know what they're doing, and also quality-control samples during and after the installation, according to Fennell.

Buildings that depend on leakiness for fresh air

Many people have a visceral reaction to the idea of sealing up a building tightly—they're concerned that won't allow in enough fresh air. For buildings with mechanical ventilation systems, the opposite is true—only by preventing uncontrolled air flow can you ensure that fresh air is actually being delivered as intended.

But many older buildings lack mechanical ventilation, so it's essential to plan for ventilation when sealing up the enclosure. "Some buildings rely on leakiness for fresh air—that is how they were engineered," says Brennan. For example, prior to ducted fresh air, it was common to engineer buildings with exhaust-only ventilation fans and provide fresh air via intentional gaps around the windows, Brennan explains.

In situations where getting fresh air to occupants depends on a certain amount of leakiness, it's important to install mechanical ventilation when tightening up the enclosure.

Time and money

Air sealing a building may be the most cost-effective energy-saving strategy available for a leaky building, but that doesn't mean the owner will make the investment. Air sealing almost always is done from the interior, so in addition to the cost and hassle of contracting for the work, there is the loss of use of the space while the work is underway.

"Without doing anything invasive, we're always going to be a bit limited in terms of amount of impact that we can have," reports Ricketts. He has found it an easier sell to intervene when they need to replace the windows, or replace cladding, or even upgrade the HVAC system—with an upgraded enclosure the replacement mechanical system can be smaller, and cheaper.

Brennan sometimes gets called in to create a proper air seal between units in a multifamily building, but only when the apartment is changing hands. "Even then the opportunities are limited because the building owner wants a quick turnover. A lot of the time, building owners won't let me take a day to compartmentalize a units—even if they know it would help solve their roach infestation problem," Brennan says. "They don't want to take the day to do that extra sealing."

Fringe Benefits: from Pest Control to Odor Control

Addressing pest infestations is one of the many ancillary benefits of tightening up a building, or the units within it. Increasing comfort, reducing spread of odors, and reducing noise are others. A few other advantages that might come along with a good air sealing job include:

- Improved indoor air quality—when polluted air is leaking in from outdoors, or if the ventilation system can't distribute air reliably because it can't control air pressure due to leaks.
- Doors work better—especially in tall buildings where stack effect pressures together with air infiltration can put a lot of pressure on doors, making them hard to open or close.
- A teaser for deep energy retrofits—once an owner experiences the benefits of reducing air leakage, the possibility of going even further to upgrade building performance becomes intriguing. On the other hand, it can be harder to justify the cost of adding insulation to a building enclosure after the low-hanging fruit of energy savings from air leaks has already been harvested.
- Improves new construction—retrofitting older buildings to solve problems might eventually lead an owner with multiple buildings to get it done right the first time. The Army Corps of Engineers has retrofitted hundreds of buildings to meet its performance standard for air tightness, and now enforces that standard consistently on new buildings. Universities can also learn this lesson, according to Brennan: "Fix enough of their buildings and eventually they say 'let's have these guys involved in design'."

Photo: Perkins+Will

The LEED Platinum Great River Energy Headquarters in Maple Grove, Minnesota, designed by Perkins+Will, was studied as part of a research effort to determine the airtightness of existing buildings. It measured at an impressive 0.18 CFM75/ft^{2}SA, well below most current standards.

Wrapping Up

Any energy audit should include at least a visual inspection for potential air leakage. This might involve seeing the actual gaps, but more often relies on noticing the tell-tale signs of chronic air leakage, and the high energy bills that go along with that leakage. If the audit indicates that air leakage is a problem, then addressing it as a stand-alone conservation measure might be feasible.

With today's low energy costs, air sealing an existing building just for the energy benefits is a tough sell. Occupant comfort is valued more highly, at least in some settings. And when safety is at stake it's a no-brainer. The opportunity in that case is to encourage the use of whole-building diagnostic tools, both to ensure that the source of the problem has been addressed, and to leverage the intervention to save energy and address other potential problem areas.

Similarly, any retrofit or renovation that involves the building envelope represents an opportunity to check for air tightness and seal up the enclosure as much as possible.

As building diagnostic tools get better and less intrusive to use, it should become easier and cheaper to test buildings on a routine basis, both for overall airtightness and to locate specific problem areas. For those who don't know where to start, local Building Enclosure Councils are a good place to look for the expertise to help make this happen.

Lots of existing buildings are out there, waiting impatiently, for the attention.

NEWS ANALYSIS

Designing the Culture of a Zero Waste City

Design plays a key role in helping cities overcome the logistical and social barriers to eliminating waste.

by James Wilson

An increasing number of U.S. cities have adopted zero waste goals, including San Francisco, Seattle, Minneapolis, and Austin, Texas. In New York City, the Department of Sanitation's (DSNY) 0x30 campaign is designed to eliminate landfilled waste by 2030. According to DSNY, New Yorkers generate a total 18,500 tons of waste every day and the city sends 3,000,000 tons of residential waste to landfills each year.

Reaching zero waste, in New York City and other cities, will require infrastructure that facilitates the reduction, diversion, and management of waste. But what's also needed is a shift in cultural mindset that reinforces waste reduction practices like recycling and composting. The design and building industry can address both of these elements to help fuel the trend toward zero waste cities.

San Francisco as leading cultural model

Steven Cohen, executive director of Columbia University's Earth Institute, writing in The Huffington Post (*Zero Waste in San Francisco and New York: A Tale of Two Cities, 2016*), cites San Francisco as a city that's made significant progress toward reaching zero waste. In 2016, the city was diverting 80% of its waste from landfills. For comparison, New York City diverted only 16%.

Cohen credits a large part of the city's success to its culture that supports and reinforces personal habits of waste reduction, recycling, and reuse. He writes, "People in that city behave as if reducing waste and recycling are important social behaviors." He is skeptical that larger, more diverse, and faster-paced cities like New York City can achieve the same success as San Francisco without first undergoing a significant cultural shift. He indicates that design, by providing creative and strategic solutions, could drive the necessary large-scale changes in mindset and behavior.

Design could improve everything from the receptacles used for sorting and storing different waste types—finding ways to make recycling and composting a "no-brainer"—to city-wide waste collection and transportation systems.

Recent initiatives in New York City serve to highlight the role of design in eliminating waste, and are examples of how cities can raise awareness among both the public and the building industry.

A dialogue on design's role

Open House New York (OHNY), a non-profit organization that aims to foster greater awareness of the architecture and urban design of New York, has launched "Getting to Zero: New York + Waste," a year-long education program exploring the city's waste management practices and infrastructure. According to OHNY's website, the program is meant to both provide the public with a better understanding of how the urban environment has been shaped by waste management, and drive discussion of the ways in which waste is an opportunity for design intervention. The program is organized around both online resources like "Waste Journeys"—a series that teaches New Yorkers about where and how waste is transported after it is discarded—and an ongoing series of events, including lectures and tours of the city's waste facilities.

The series kicked off with a lecture and discussion entitled, "The Future of Waste in New York," where Kathryn Garcia, commissioner of DSNY, spoke about design's role in waste management. "When someone designs a kitchen, everyone always thinks about how you're moving between the refrigerator and the stove and

New York City's campaign to eliminate landfill waste is raising the question: how might the design and building industry create the infrastructure and culture needed to achieve zero waste?

the sink and the counter. They're not thinking about, 'Well, if they're cutting something on that counter, where are they putting the food waste, or where are they even putting the recycling?' I think that there is a real opportunity for design."

Facilitating waste reduction through design

Recognizing that many of the logistical issues related to eliminating waste can be solved by design, the AIA New York Chapter's Committee on the Environment (AIANY COTE) has been developing "Zero Waste Design Guidelines,"—"an interactive manual of design strategies and case studies for a zero-waste city."

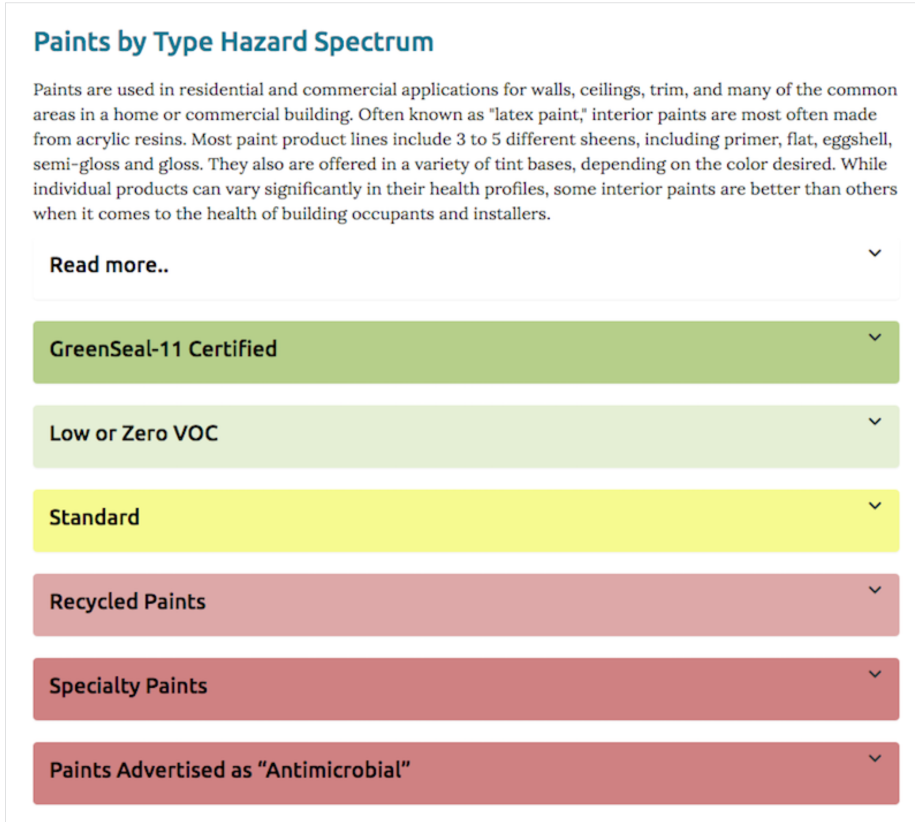
Over the past months, AIANY COTE has organized several multi-disciplinary workshops to promote discussion of design's role in reaching zero waste and to support development of the guidelines. Several sessions focused on design issues, tackling questions like how to assist architects with incorporating strategies from biomimicry, design and systems thinking, and design for social innovation.

The manual—available October 2017—will outline best practice strategies for waste management for various building and space types. Architects and urban designers can use these to create conditions throughout the waste system that facilitate reduction and diversion.

The ripple effects of cultural change

Greater awareness of the various components of waste management, the issues related to achieving zero waste, and the ways in which design offers solutions could contribute to a shift in the culture of a city. Such a shift could lead to changes in both the public and private sectors as people become more engaged and begin demanding progressive policies (like restrictions on practices like using plastic grocery bags) and responsible industry practices (like maintenance-centered circular manufacturing).

Design will have a role in these areas as well. In collaboration with government agencies and manufacturers, designers can help develop creative strategies to be applied at "leverage points" throughout the larger material lifecycle system to get closer to zero waste.



Infographic: Healthy Building Network

The HomeFree website uses 'stoplight' colors to rate products, such as paints, from the healthiest to the most hazardous.

NEWSBRIEFS

Healthy Building Network Launches Online Forum

The forum invites affordable housing designers to join HBN experts and others to ask questions and share information on material health.

by Nancy Eve Cohen

The Healthy Building Network's HomeFree database recently launched an online forum on healthy building materials—an idea exchange that brings together practitioners in affordable housing with HBN's researchers.

"It is a great place to ask individual questions and be able to get more specific information from the Healthy Building Network team," said Jess Blanch, an enterprise Rose architectural fellow with Capitol Hill Housing in Seattle.

The forum builds on the HomeFree database, which compares the toxicity of products using 'stoplight' colors to identify healthy and less healthy choices. For example, under cabinets and millwork, the site rates solid wood as green—the healthiest—and standard formaldehyde resins as red, at the bottom of the healthy scale. The health assessments come from HBN's extensive chemical material library, the Pharos database.

Anyone can use the site and participate in the forum, as long as they register.

HomeFree is "interpreting data in a way that people who aren't technical experts can absorb and understand," said Gina Ciganik, HBN's CEO.

HBN's goal is to get healthier products into affordable housing. "And then, ultimately, people are healthier because they are not exposed to toxic chemicals, especially children," said Ciganik.

HBN has used HomeFree to help six affordable housing demonstration projects choose healthier building materials.

The Liberty Bank Building, a 115-unit building for low-income households in Seattle, is one of the demonstration projects. When the design team from Mithun used HomeFree to compare flooring for Liberty Bank, they learned the vinyl that had been chosen did not have phthalate plasticizers, a class of chemicals associated with endocrine disruption and other health concerns. "To know that we are spec'ing a product that is as green as it can be, within our price point, that's really helpful for us," said Jess Blanch of Capitol Hill Housing.

Rendering: Mithun

Liberty Bank Building in Seattle is one of HomeFree's six affordable housing demonstration projects.

Leigh Avenue Senior Apartments in San Jose, California, designed for low-income and formerly homeless seniors, is another demonstration project. Hilary Noll, now with Mithun, was the design director on Leigh Avenue for First Community Housing. Noll says HomeFree helped the project assess the feasibility of incorporating solid surface counter-tops instead of plastic laminate plastic. Compared to going to the web or to the manufacturer, "you are getting something that has been through some level of evaluation from your peers [in affordable housing]," said Noll. "So, it is a more trusted way."

HBN hopes HomeFree's new online forum will be an additional place to leverage the knowledge of HBN experts and others who build and renovate affordable housing.

New York State Launches Initiative to Scale Net-Zero Retrofits

The state has budgeted $30 million to develop a self-sufficient, private sector-based market for deep energy retrofits of multifamily buildings.

by James Wilson

Multifamily Performance Program. RetrofitNY is part of Governor Andrew Cuomo's energy plan, "Reforming the Energy Vision," which includes an effort to perform deep energy retrofits on 100,000 affordable housing units by 2025.

Photo: Jim.henderson. License: Public domain.

The RetrofitNY program is meant to accelerate deep energy retrofits of New York State's existing building stock, starting with multifamily affordable housing projects.

The core of the initiative is an ongoing design-build competition—starting in August 2017—for affordable, replicable retrofit solutions that are able to reduce energy use by 70% or more. The state will subsidize the implementation of selected solutions on pilot buildings within New York's affordable housing portfolio.

The results of these initial pilot projects will inform the next iteration of the competition. NYSERDA will organize successive competitive rounds until performance goals are met and the retrofit solutions become cost-effective. When that milestone is met, the goal is for the private sector to retrofit these buildings without additional public subsidies.

RetrofitNY is based on the Dutch program Energiesprong ("energy leap"), which developed a method for rapidly renovating the existing public housing stock in the Netherlands to achieve net-zero energy performance. The RetrofitNY program is working with Energiesprong International to adapt this approach for New York, and to address regulatory and financial challenges particular to the state.

For more information

NYSERDA
nyserda.ny.gov

Petal Certifications Help the Living Building Challenge Jump in Scale

With recent and upcoming certifications, the Living Building Challenge breaks out of its boutique building typology.

by Nadav Malin

The stereotype of a Living Building has been an environmental education classroom or visitor center that's not much bigger than the average American house. That stereotype wasn't too far off during the program's first five years—until the 10,700 ft² Phipps Center for

Rendering: WRNS Studio

This rendering shows the design for the expansion and renovation of Microsoft's Mountain View, California, campus. The project is seeking Water Petal certification through the Living Building Challenge.

Sustainable Landscapes and the 50,800 ft² Bullitt Center were certified in March 2015, the average certified project was 3,700 ft² (see chart).

The Bullitt Center remains an outlier among Living Buildings—in the early days of the Living Building Challenge the perceived risk of pursuing such an aggressive goal was just too much for most owners and developers of larger projects. No certified project since the Bullitt Center has exceeded 20,000 ft², and it might not have a peer until the 42,000 ft² Living Building at Georgia Tech is certified around March 2020.

In the meantime, however, petal certifications are expanding, and extending to much larger corporate facilities. Petal certification under the Living Building Challenge involves achieving all of the imperatives under the Place and Beauty petals, along with one of these three petals: Energy, Water, or Materials. Just this year two enormous commercial interiors projects achieved Petal certification via the Materials Petal: Etsy's Brooklyn headquarters and Google's Chicago office. Both of these are around 200,000 ft²: almost twenty times larger than the average size of all previously certified projects.

As if to prove that these are not flukes, ILFI announced in May 2017 that Microsoft intends to pursue Petal certification with a focus on the Water Petal for its 640,000 ft² Silicon Valley campus in Mountain View, California. This combination of existing buildings and new construction will include office space, labs, and conference facilities, with integrated food services and other amenities.

2017 Top Ten: Performance Metrics

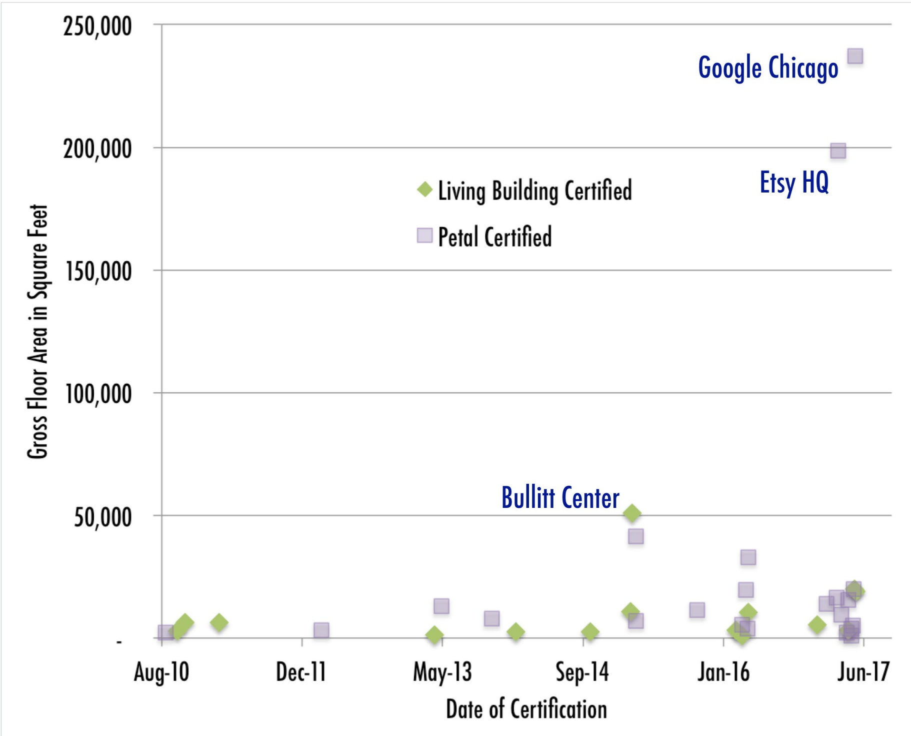


Chart credit: BuildingGreen, with data from ILFI chart

All 15 certified Living Buildings and all 22 petal certified buildings, as of June 2017, arrayed by date of certification and size.

The project is anticipating a 55% reduction in water use, even though the gross floor area is growing by 40%, the landscaped area by 300%, and the population by more than 50%, according to Katie Ross, sustainability program manager for Microsoft Real Estate & Facilities. The water savings amount to 3.9 million gallons per year, nearly enough to fill six Olympic-sized swimming pools.

The focus on water and ecosystems is especially motivating to Pauline Souza, AIA, principal at WRNS Studio, design architects for the project. The project team includes ecologists to guide restoration of wildlife habitat in an adjacent creek, and hydrologists to design storm-water infiltration to mitigate the intrusion of saline water from the San Francisco Bay into the area's ground-water. "What a great opportunity to showcase both innovative and tried-and-true technologies that save water without sacrificing beauty, productivity, growth, and user experience," exclaims Souza.

It will be a few years before the Microsoft campus can submit for certification, but the idea that a Living Building should not be much bigger than a house is already outdated. These large project examples will help put the Living Building option on the table for many teams that might not have otherwise considered it, and raise the bar for the entire industry.

More on Living Building certification

[How to Succeed with the Living Building Challenge: 12 Teams Share Tips]

For more information

International Living Future Institute
www.living-future.org

PRODUCT NEWS & REVIEWS

A New Halogen-Free Polyiso Insulation from GAF

GAF now offers a full line of polyisocyanurate foam insulation that is free of toxic halogenated flame retardants.

by Alex Wilson

I first learned about GAF's new halogen-free polyisocyanurate insulation when I was teaching a workshop on resilient design at the GAF headquarters in Parsippany, New Jersey, in March, 2017. Having called for manufacturers to develop such products several years ago (see Getting Flame Retardants Out of Foam Insulation), I am particularly attuned to such developments.

It so happened that I was also looking for rigid insulation material to insulate the roof of a small cottage in Brattleboro, Vermont. I had thought of polyiso for this application, because of the high R-value. Here was a chance to install a product I could feel good about relative to chemical ingredients as well as energy performance. I reached out to GAF, and we ordered the product. (Disclaimer: GAF provided me with a discount on the material and covered the shipping cost.)

But let me back up.

The problem with halogenated flame retardants

For many years, most polyiso insulation contained the halogenated flame retardant TCPP (tris (1-chloro-2-propyl) phosphate) to improve its fire-resistance properties. TCPP is a chlorinated organophosphate, a class of chemicals that has long been used as pesticides, flame retardants, and other products. According to the American Public Health Association, TCPP "can accumulate in the liver and kidneys and affect nervous system development, and it is under study by the National Toxicology Program as a possible carcinogen." A number of environmental organizations, including the Healthy Building Network and the Green Policy Research Institute, have been working to get halogenated flame retardants out of foam insulation.

BuildingGreen first wrote about halogenated flame retardants in 2004 (see [Flame Retardants Under Fire]), and we have long advocated reformulating foam insulation materials to avoid the use of these chemicals. Johns Manville responded in 2014 by introducing the first polyiso boardstock insulation material produced without a halogenated flame retardant, which [BuildingGreen profiled in June 2014].

A safer option for all polyiso applications

GAF, the nation's largest roofing manufacturer, has followed suit, with its EnergyGuard-NH product line ("NH" for "no halogen"). While Johns Manville's halogen-free polyiso is limited to one product line, the GAF product is available across the company's entire polyiso product line, according to Jeanine Mulcahy, GAF's product manager for insulation and fastener systems. It is available in all thicknesses, densities, and with the company's full range of facings.

GAF hopes to eventually transition their entire production to this new formulation, according to Mulcahy, but for now it's a "made-to-order" product. That means planning for a lead time that depends on the season; typically at least three to four weeks. All three of GAF's polyiso factories have the capacity to manufacture EnergyGuard-NH, though its Gainesville, Texas factory was the first to actually produce the material.

While GAF didn't share the exact chemistry with BuildingGreen, the halogen-free flame retardant is a phosphate chemical (as is Johns Manville's). Unlike TCPP, the flame retardant becomes part of the polymer backbone of the insulation—so there is no free flame retardant that can leach out, according to GAF's director of sustainability Martin Grohman. TCPP, by contrast, is not chemically bonded

Photo: Alex Wilson

Installing sheets of 2½" thick, halogen-free, GAF EnergyGuard polyiso insulation on a roof in Brattleboro, Vermont.

to the polyiso polymer, so it can more readily escape.

Cost of the new EnergyGuard-NH depends on quantity and location, but Mulcahy told BuildingGreen that it's "competitively priced." Adds Grohman: "We worked hard to make it competitive; we're proud of this product and we want to see it used."

EnergyGuard-NH has a [Declare Label from the International Living Future Institute] (ILFI), signifying the absence of chemicals from the Living Building Challenge Red List, and a Health Product Declaration (HPD) that is available in the [HPD Public Repository]. Neither the Declare label nor the HPD list any flame retardant at all, however, despite the fact that "proprietary flame retardant" is listed on the product's Safety Data Sheet, raising questions about how complete these disclosure documents are. Johns Manville's halogen-free polyiso also has an HPD that omits reference to any flame retardant.

Handles just like the regular stuff

As for installation, insulation and roofing contractors who have used it perceive it to be identical to the company's conventional EnergyGuard polyiso, according to GAF. "You can't tell the difference," says Grohman, though there is a slight difference in the marks on the facing used for fastener spacing—on the NH product the marks are circles rather than plus signs.

Our builder, Chad Mathrani, of Vermont Natural Homes, was pleased to use a foam insulation product that had a better environmental profile than conventional polyiso. We ordered 2½" foil-faced EnergyGuard-NH and installed two layers on the roof, achieving 5" of insulation (about R-30), though the insulating value was compromised somewhat by let-in 2x4 nailers flush with the outer layer of the foam. Mathrani and his crew found no difference in the material from other polyiso they have worked with.

Polyiso manufacturers led the insulation industry in eliminating ozone-depleting chemicals from their products in the 1990s, and now they are leading the industry in offering product with safer flame retardants.

For more information

GAF
www.gaf.com

Heat-Pump Energy Recovery Ventilation Gets an Update

Build Equinox and Minotair Ventilation Inc. (MVI) have updated their heat-pump-based energy recovery ventilation systems, providing better control of humidity, heating, and cooling in a smaller footprint.

by Brent Ehrlich

Balancing indoor air quality and energy consumption in ventilation is no easy task. Bringing in fresh air keeps us healthy and alert, but heating, cooling, and adjusting its humidity (also known as conditioning the air) requires energy, and much of that energy is lost when stale air is vented.

The Conditioning Energy Recovery Ventilator (CERV) from Build Equinox and the Boreal 12000 from Minotair Ventilation Inc. (MVI) are engineered to maximize the energy efficiency of indoor/outdoor air exchanges by conditioning fresh air using air-source heat pumps—effectively heating, cooling, and even dehumidifying incoming air while capturing energy from the outgoing/incoming airstreams. Engineered primarily for residential use (and potentially multifamily), these innovative systems have been available since 2014, but are being updated for fall 2017 to improve performance and simplify installation.

How they work

CERV and Boreal 12000 work similarly to an HRV/ERV: ducts bring in fresh air from outdoors and return air from indoors, energy is transferred from one air stream to the other across a special media, the conditioned air is supplied to the home, and exhaust air is vented. The big difference? Unlike HRVs/ERVs, the CERV and Boreal 12000 contain no transfer media (metal fins, ceramic wheels, or other materials). "Instead of a conventional ERV/HRV core, we use a heat pump to transfer heat from one air stream to another," said Ben Newell, president of Build Equinox.

These systems are not as simple as Newell makes it sound. Standard heat pumps use a refrigerant loop, similar to an air conditioner (see How Air-Source Heat Pumps Work), with indoor and outdoor heat exchanger coils that transfer heating and cooling energy between our homes and the outdoors using a vapor-compression cycle. Air source heat pumps mainly provide heating and cooling, however, and do not supply fresh air.

But the heat pump components in the CERV and Boreal 12000 systems are both located indoors inside the units, and work in tandem with dampers and fans to bring fresh air into the home, condition it, and control its flow and distribution.

Fresh air is conditioned in summer as follows (vapor compression cycle omitted for brevity):

- Incoming hot, humid air flows over a cold heat exchanger in the unit, transferring its heat energy to a refrigerant in the coil. This cools the air and removes moisture through condensation.

Credit: Minotair Ventilation Incorporated (MVI)

Engineered to improve indoor air quality, the Boreal 12000 (shown here) and updated CERV contain heat pumps that help control a home's heat, humidity, and airflow.

- The *dehumidified*, cooled air is then blown through the supply duct into the home.
- The heated refrigerant flows to the other heat exchanger coil, where the heat is picked up by the return air and vented outside, cooling the refrigerant. And the heat pump cycle repeats.

In winter, the process is reversed:

- Heated air from the return ducts inside the home flows over the heat exchanger coils, transferring heat energy to the refrigerant.
- The cooled air is vented outside through the exhaust duct.
- The heated refrigerant flows to the heat exchanger in the fresh air duct where it warms the incoming air before it is blown into the house.

If indoor air quality is good enough, then the systems can shut off the dampers to the outside and recirculate the indoor air, communicating with the primary heating/cooling system to help maintain temperatures. Sensors can detect moisture from showers and other sources so it can be vented (primarily in summer) or recirculated to maintain relative humidity (primarily in winter) in the home. When outdoor conditions are ideal, the units will shut off the heat pump entirely and just bring in fresh air from outdoors.

These systems require sophisticated sensors, controls, fans with energy-efficient electronically commutated motors (ECM), filters, and dampers to manage all this. And they are able to do so while controlling the airflow, balancing the air coming into and out of the house, and circulating the air to where it is needed in the home. To communicate that the systems are running as intended, CERV will show error codes on its display if a sensor is not functioning or there is a problem with the system. This information is also available online so the company can look at the data and help troubleshoot. Boreal also shows sensor errors on its display, and sets off an alarm in case of serious problems.

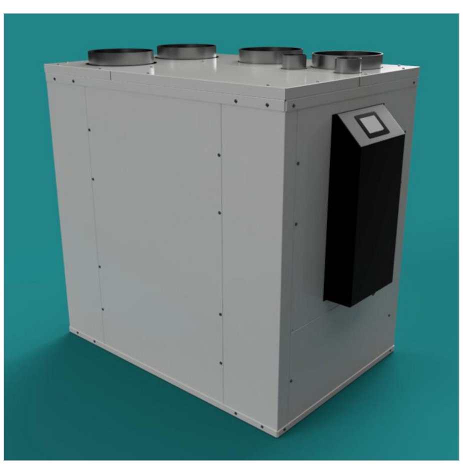
Engineered for indoor air quality (IAQ)

The standard CERV unit can provide up to 8,500 Btu/hr heating and 5,000 Btu/hr cooling, and the Boreal 9,400 Btu/hr heating and 8,700 Btu/hr cooling, according to the companies. But for those who want better heating/cooling performance, CERV is available with a 5 kilowatt (about 17,060 Btu/hr) auxiliary duct heater and Geo-Boost, a small ground-source loop that can be added onto the heat exchanger to increase heating/cooling capacity by about 1,200 Btu/hr (note the loop is not fully integrated into the heat pump itself as with standard ground source heat pumps). Customers can boost Boreal's heating capacity with an optional 3 kilowatt (10,236 Btu/hr) electric heater.

These booster technologies could help make these systems potential all-in-one HVAC options for small high-performance homes, but neither the CERV nor Boreal are sold as a stand-alone heating/cooling solution. They are intended to be used primarily for ventilation, providing a maximum 250 cubic feet per minute of conditioned air. They just happen to also provide efficient supplemental heating and cooling, and efficient air distribution.

"We are focused on air quality," says Newell. CO_2 and VOCs are known to cause health problems and cognitive decline at high concentrations (see VOCs: Why They're Still Here and What You Can Do About It and Clean, Fresh Air: Getting What We Need). His company's CERV manages IAQ using self-calibrating CO_2 and VOC sensors. Air exchanges are triggered when CO_2 and VOC readings hit a chosen set point, which can be adjusted by the occupant. According to Newell, the company uses 1,000 parts per million for CO_2 and VOCs as standard, and can monitor alcohols, aldehydes, aliphatic and aromatic hydrocarbons, amines, carbon monoxide, methane, ketones, organic acids, and other compounds.

The Boreal, on the other hand, uses humidity and temperature sensors to trigger its air exchanges, i.e., it will kick on if humidity gets too high in summer or the temperatures get too low in winter (CERV also removes humidity and integrates those set points into its system). "ERVs are not able to manage humidity," according to Alexandre De Gagné, co-owner and vice president of sales and marketing at MVI. "We can remove 88 pints of water a day," he says. This is especially important in warm, humid climates, where a standard ERV simply can't sufficiently manage humidity as part of ventilation.



Credit: Build Equinox

The second generation CERV is no longer modular, making the unit more compact and easier to install.

As with CERV, the Boreal 12000's set points can be fine-tuned by the owner, but the system will not allow humidity levels above 60% in summer and recommends 45% in winter. According to De Gagné, the Boreal 12000 brings in a minimum of ten minutes of fresh air per hour, but ventilation rates can also be adjusted.

To further improve IAQ, both systems use air filtration: MERV 13 is standard for the CERV, and MERV 15 will be standard on the Boreal beginning in fall 2017, with the system self-adjusting ventilation rates in case of dirty filters, duct crimping, and other factors.

Installation and end uses

According to Newell, installation of the CERV (the Boreal is similar) is "no different than [how] a conventional HRV or ERV system would be laid out in a home." (the Boreal is similar) In new construction, they use standard 6" ductwork to connect rooms to the unit. These systems can then pull air from rooms with odors or moisture (such as bathrooms or kitchen areas), filter and/or vent it, and supply fresh air to bedrooms and living areas. In winter, for instance, they can recognize showers running and recirculate that heat and humidity throughout the house. And CERV will increase ventilation when CO_2 sensor levels get too high, such as when guests are over. They can also be integrated into forced air systems, though performance will be less nuanced.

CERV and Boreal 12000 might seem like they are meant for high-performance, Passive House homes where ventilation is critical, but Newell argues that it is not important that the home be high performance, or even well sealed. "We are open to any house that does not now have mechanical ventilation," he says. "Even in a leaky house…that air is not healthy. It is coming through cracks where you don't want your fresh air and it is not distributing the air to places you need it."

So, finally, what is new with these systems?

Combining residential ventilation and heat pump energy recovery is only a few years old in the U.S., so these systems are still evolving. The first CERV systems, for instance, had a modular design that was supposed to provide design flexibility, but the separate heat pump, fresh air control, fans, and air filtration had ductwork running between the parts making them bulky (at 50½" x 46½" x 24" for a vertical configuration) and complicated to install. The new CERV— available in fall 2017— includes all the components in one 24" x 36" x 36" box and reduces the amount of ductwork required, which will make it easier to fit in smaller homes, and easier to install and commission.

MVI's systems have always been relatively compact, at 40½" x 18" x 16 ¼", but the company is now offering MERV 15 filtration, shower detection, and wall-mounted display as standard, and will have a humidification module available in late 2017, according to De Gagné.

Cost and performance

Vermod, manufacturer of "affordable, net zero, modular homes" in Vermont, was an early adopter of the CERV system. The company has installed more than 75 of them in the last three years, supplying conditioned air to high-performance 1,000–1,500 square foot modular homes. Steve Davis, owner of Vermod, says he initially tried to use mini-split air-source heat pumps, but could not get them to work "comfort-wise." His homes now incorporate a mini-split along with a CERV that runs a 300-foot, one-inch-diameter, Geo-Boost ground-source loop installed six to eight feet under the ground. The system supplies fresh air, and Davis says the Geo-Boost improves overall efficiency by significantly increasing the incoming air temperature in winter and lowering it in summer, which, according to company documentation, improves the COP from 2.25 to 2.5 (note Minotair claims a COP of 3.0). Not bad for systems intended for ventilation.

Both of these systems cost between $4,500 and $5,000. Installation is likely to tack on approximately $2,000 more, and—for CERV—a ground source loop would add more to the installation. That is a lot for a ventilation system, but MVI's De Gagné justifies it, saying, "we have a more expensive machine (than HRVs/ERVs) but it does a much better job of taking care of IAQ."

For Davis, the investment in CERV's ventilation equipment is well worth it. His homes are net zero and he says the CERV helps achieve that while reducing the number of photovoltaic panels (required to hit energy targets) and their associated costs. "A lot of people are running 10 kilowatt (PV panels) just to supplement their electrical loads alone. Ours are running on 7 kW to do everything, and people are getting a credit back," he says.

Are these heat-pump energy recovery ventilators right for your project? If you value IAQ and comfort, can justify their first costs, and have the space for them, then these systems are worth considering. For high-performance homes, in climates where humidity is a concern, these systems might just be the future of mechanical ventilation.

For more information

Build Equinox
www.buildequinox.com

Minotair Ventilation Inc.
www.minotair.com

PRIMER

Biomimicry: Designing Conditions Conducive to Life

Biomimicry offers a vitalizing framework for reconnecting designers to nature and driving innovation.

by James Wilson

The term biomimcry literally means the imitation (mīmēsis) of life (bios). At its most basic, the practice of biomimicry is about looking to the natural world and following its lead. By looking to nature and emulating it as the ultimate model of "sustainable design," architects are drawing from a rich, diverse sourcebook of ideas and solutions that have been fine-tuned over millions of years.

This idea of looking to nature to guide innovation and invention is not new. It's at least as old as the sixteenth century when Leonardo da Vinci was studying the flight behavior of birds in his attempt to solve the problem of human flight. His recorded observations eventually contributed to the Wright brothers' understanding of some of the fundamental concepts of flight. More recently, in the nineteenth century, Antoni Gaudí studied the shape of trees to inform the design of the Sagrada Familia cathedral's branching structural elements. This makes the Sagrada Famila, like the Wright Flyer, an example of "biomimetic design."

Though biomimetic design is not always equivalent to sustainable design, it is usually framed as an approach that's conducive to sustainability. But biomimicry is a process that designers can also use to develop solutions for a broad range of issues not related to specific sustainability goals. (Though it could be argued that the most effective solution, in any case, is ultimately a sustainable one.)

Practicing biomimicry

Janine Benyus, co-founder of Biomimicry 3.8 and the Biomimicry Institute, popularized the term biomimicry in her book *Biomimicry: Innovation Inspired by Nature.* The book describes biomimicry as a new discipline focused on the study of nature's "designs" as a way to inform the innovation of solutions that are sustainable and supportive of life.

To practice biomimicry is to bring nature back into the design process. Architects can use nature as a design tool by asking, as they address a project's particular challenges, "What would nature do here? How would nature deal with this?"

For example, a project team concerned with preventing moisture-related issues in their building might ask, "How does nature manage moisture?"

The team might look, for instance, at the way seeds of some plants, such as the tree lupin, regulate the permeability of their shells with a valve that adjusts according to changes in humidity.

By reviewing various strategies like this, by which moisture is managed in natural systems, the team is both seeking insights that might lead to an effective design solution and taking

The Eden Project, by Nicholas Grimshaw, is a well-known example of biomimetic architecture.

Photo: Andrew Mandemaker.

By studying nature's interconnected functions and processes, designers can develop an ecological mode of thinking that leads to integrative solutions.

a step back to open their process to questions that might not otherwise have come up. It is this method of holistic, critical inquiry that can reorient the design approach and result in innovative solutions.

Emulating nature's habits

Biomimicry 3.8's DesignLens guide offers "Life's Principles" as nature's foundational design lessons. These strategies, which represent the "over-arching patterns found amongst the species surviving and thriving on Earth," are organized into the following six categories:

- Evolve to survive;
- Adapt to changing conditions;
- Be locally attuned and responsive;
- Use life-friendly chemistry;
- Be resource efficient; and
- Integrate development with growth.

These can serve as guidelines and aspirational goals during the design process, and as benchmarks against which to evaluate different design options.

A thinking process

Besides studying nature's specific traits and strategies, biomimicry involves studying nature's mode of operating. Biomimicry involves adopting a certain mindset as a way to identify the connections, relationships, and feedback loops through which nature operates. Taking on an "ecological" perspective expands the frame of the design problem to include the interconnected factors that may have been neglected or were considered irrelevant at first. By thinking this way, designers are increasing their consciousness of how different things and processes affect one another and create a coherent, well-functioning, and self-sustaining system, or ecology. Conceiving of a building project as an "ecosystem" that is itself situated within a larger cultural and ecological system, can lead to integrative and symbiotic solutions.