HEALTH AND HOMES

Photo: Tim Healey

A Builder's Guide to Breathable Indoor Air

Homes need more ventilation than U.S. building codes require

This spring, I met up virtually with Bill Hayward, CEO of Hayward Lumber and the founder and originator of the Hayward Score (see "The Hayward Score: A Rating of Home and Human Health," page 37). Earlier this year during a conference, Bill had characterized the COVID-19 pandemic as a "trigger point," much like the energy crisis of the 1970s had been for energy-efficient housing. This new crisis has triggered a growing interest in indoor air quality and occupant health. As we all have learned a great deal more than we ever thought we would about respirable droplets, air circulation, and the spread of airborne contaminants, homeowner awareness of health, air quality, and ventilation has caught fire and is beginning to ignite a new set of demands. Advanced ventilation systems and home performance may finally be getting equal, if not greater, attention from homebuyers than granite countertops and luxury appliances.

And perhaps this is the time we will finally align ventilation codes with building science. Since 2012, we have seen strong alignment between building science and the air-sealing and insulation requirements of model building codes. But ventilation requirements feel like the poor relations nobody wants to invite for dinner. The Chapter 15 ventilation requirements of the International Residential Code are not clear to all builders, and certainly not well understood by code officials, so they aren't enforced and education is sparse. Exceptions to this do exist in multifamily construction where there tends to be a higher concern for the potential liability surrounding occupant health among developers and municipalities. There are also exceptions among a core segment of the JLC *readership that serves a very demanding clientele. But in most single-family new construction and whole-house remodeling, we seem to be mostly building tight but not ventilating right.*

Change will likely only happen when it is driven by customer demand, and that is precisely what Bill's "trigger point" is all about. To dig into the implications of this for builders, we brought Mark LaLiberte, co-founder of Construction Instruction and a frequent speaker on building science–based building practice, into the conversation to begin to formulate some clear, health-driven best-building principles. —Clay DeKorne

Bill Hayward: The pandemic certainly raised awareness of the health dimensions of our homes, and indoor ventilation especially. The lack of ventilation in homes is something that has developed gradually, and the amount of ventilation in homes is perhaps at an all-time low, since homes have gotten tighter without enough attention to controlled ventilation. A big part of the problem is that the ventilation standards referenced in the building codes are not health-based.

The first ASHRAE ventilation standard came out in 1973 and called for significantly lower airflow rates than we had seen in ventilation codes earlier last century when recommendations were based primarily on health concerns. The justification for the lower ventilation rates was driven by energy concerns [1973 also brought the OAPEC oil embargoes] and by research on controlling odors. Because of some of the justifications used in the development of the standard, you often hear it called an "odor-based" standard (see "A Short History of Established Home Ventilation Standards," page 38). This continues today: The required ventilation rate in the U.S. building code is not a health-based number.

It's time for that to change. We didn't know anything about aerosols in the country a year ago. And it took until early this year for the EPA to get more specific about ventilation guidance. Ventilation is evolving in schools that are reopening … and in restaurants. As things are opening up, people are concerned about going back in, about what's in our air, and the last place it will spill to is a deeper discussion of the air in residential housing.

BREATHABLE AIR

BH: In the past, we have heard a lot about IAQ. But I think right now, for most of us, it's not that complicated. It's more just "I need fresh air." IAQ tends to get associated with all kinds of technical specs, but right now people are saying simply, "I just need to breathe fresh air."

Health Effects Tied to Buildings

	Percentage of Respondents
Trouble Sleeping	30%
Disturbed Sleep	32%
Allergies/Sneezing	41%
Dry Eyes	22%
Moodiness/Agitation	25%
Depression	27%
Cough/Shortness of Breath	47%
Extreme Fatigue	32%
Foggy Thinking	24%
Memory Loss	17%

Source: Hayward Score Data

This table shows the percentage of all 80,000+ respondents to the Hayward Score self-reporting health symptoms that may be connected to their homes. Shown is only a selection of the 23 medical symptoms covered by Hayward Score data. Note that among the selected symptoms, a number demonstrate a clear connection to cognitive functions.

This focus on breathable air is propelling healthy homes into mainstream building. A good example of how builders are starting to change the paradigm is provided by Randy Noel, a homebuilder in the Greater New Orleans area. Randy, a former CEO of the NAHB, responded in his local market to customers asking about healthier indoor air, for home offices, for bigger spaces with families at home, and last year he entered the Parade of Homes with a home certified by Wellness Within Your Walls. It's still a long shot for a lot of production builders to ask what's in the indoor air. High-end custom builders have been having these conversations for years, but seldom with anything near the immediacy that they are now. Everywhere people are concerned. So the question is: Do we need to come at these discussions with a lot of technical recommendations or with just "I want to breathe good air"?

It's not complicated: Start with a tight building shell and a stand-alone ventilation system with energy recovery. When you have airtightness combined with energy-recovery ventilation, the house doesn't fill up with dust and dirt. If you are a production builder, could you sell that? Yes. And it's peacefully quiet inside. Can you sell that? Definitely. Builders can't sell airtightness. They probably can't sell IAQ. But we can show a customer 1) no dust and dirt; 2) it's quieter; and 3) oh, by the way, it's better for your health—you don't feel your allergies, and it affects health and longevity and mental alertness (see "Health Effects Tied to Buildings," left). When you show all that, the customer is likely to respond with, "Yes. I'd like all three of those."

A tight shell and balanced energy-recovery ventilation is a simple equation to get you there, but success from a builder's perspective requires one person to take charge of optimizing the heating/cooling systems with balanced ventilation, airtightness, and the thermal boundary, including windows.

STAND-ALONE VS. INTEGRATED SYSTEMS

Mark LaLiberte: Agreed. This may be simpler than we think if we can boil it down to some basic systems. A balance between energy use and health is found when we combine a tight, high-performance shell, so we gain control over thermal gains and losses, with stand-alone ventilation—a system that delivers balanced supply and exhaust air streams with energy recovery, and that runs continuously. When this is the default, everything gets a lot simpler.

Integrated systems, particularly in hot, humid climates, are problematic. We have huge problems right now in the Southeast with houses being ventilated with conventional supply-side or exhaust-only ventilation raising indoor relative humidity in buildings that can't properly dehumidify. So we've got condensation on clothes dryer vents and bath fan ducts and on recessed lighting fixtures. This argues for a stand-alone energy-recovery system that can help pull out some of that moisture. The basic system starts with being able to run a fan continuously to move air throughout the house. And with energy recovery, you're able to at least extract the moisture from the incoming air in hot, humid climates and reintroduce that to the outdoors.

In the work we just finished at CI [Construction Instruction], we kicked the ventilation rates up, validated fan performance, and showed that you can ventilate at 140 cfm and consume only 23 watts of electricity, recover about 85% of the energy in whichever stream you want, and reject 40% of the moisture from incoming air.

Builders need to know that the cost of ventilation with energy recovery is substantially lower than it has ever been. And I think that's the prime choice. And it's often the simpler choice. The project that we're working on in the Southeast is with a large national builder. They were running a supply-only ventilation system, taking in 60 to 100 cfm of outdoor air and running it through 500-watt, 70-pint dehumidifiers, and then introducing that air to the return side of the furnace on the air-conditioning side. This uses additional electricity and dumps dry air into the system before it hits the evaporative coil, wasting the potential of the coil to take out any of the moisture. If the builder chooses to run an energy recovery system instead, they will have a reduced need for dehumidification. In a lot of climates, dehumidification may not be needed at all. But in regions with high summer dew points, an ERV and a dehumidifier may be needed if you are selecting a higher ventilation rate.

BH: Getting the right amount of air in the house starts with putting in a stand-alone ERV that runs continuously. We breathe constantly so you want to deliver constant airflow throughout the house. An integrated system with a variable-speed fan that is turned down to low and is pumping 150 cfm so the air is mixing throughout the house *might* be OK. To my knowledge, no one has done a careful study comparing the air delivery of integrated vs. stand-alone systems, so I can only give my best WAG, but I'd wager an integrated system can deliver just 40% of what a stand-alone system can deliver. Why would you go with 40% when you can deliver fresh air everywhere in the house?

My preference is always a dedicated, stand-alone ERV. We have units that run at 80% to 90+% efficiencies. These can recover up to 90% of the heat and up to 60% of the humidity. This humidity control makes sense in most parts of the country to keep indoor humidity levels comfortable. Most of the industry is still saying that HRVs are generally needed everywhere except in hot, humid zones, but we are finding that ERVs make much more sense for most of the U.S. These units are a little more expensive, but you can eliminate the bath fans, saving some money and eliminating the extra penetrations through the roof. You now have 24/7 air moving with no cycling on and off, so you're getting the air needed for good health. And it's cheaper to run because you aren't relying on a higher wattage fan in an air handler to move fresh air throughout the house.

CONTROLLING AIRFLOW

ML: ASHRAE Standard 62-2013 provides the minimum performance criteria we should all be starting from. This is a little better than code (see "Ventilation Code Simplified," page 39). But it is still a minimum. More ventilation is good for human occupancy and the best way to provide a baseline *plus* more ventilation is to use a strategy that provides adequate flow, is quiet and efficient, and allows homeowners to engage with it as ventilation needs arise.

An example of when occupants need to control the system is when there are more people in the house, or when they get new furniture or new rugs, paint rooms, that sort of thing. If we can have ancillary support from an IAQ monitor that says "you need more air today because the PM2.5 counts are high," or that otherwise tells the occupants that they should be concerned about the VOC mix, that will certainly improve the ventilation. This level of

THE HAYWARD SCORE: A RATING OF HOME AND HUMAN HEALTH

Bill Hayward developed the Hayward Score to, as he puts it, "harness the power of consumer demand" to improve housing. It's a simple questionnaire that anyone can take for free. You log in at haywardscore.com and answer 50 questions about your house. It takes about 10 minutes.

The survey starts with questions about the materials and configuration of the home to assess its general characteristics and systems, its location, and its proximity to environmental hazards like busy roads and gas stations or dry cleaners and such. There are questions about moisture, including ones about the presence and use of ventilation fans, and indoor conditions, such as where occupants store cleaning and personal care products and other household chemicals. And then there are a range of questions about health symptoms that occupants feel may be related to their homes. These can't provide an absolute causal link between symptoms and the home, but when matched up with the presence of pests and environmental factors inside and outside the home, as well the use habits around bath fans and range hoods (or the lack thereof), Hayward Score can draw correlations and suggest improvements to indoor conditions that could alleviate the health symptoms if those conditions are in fact the cause. This all gets rolled up into an overall score and presented with a customized five-page report that gives clear action items, so participants can take steps to improve conditions aimed at transforming the indoor air quality and ultimately their health.

Hayward Score keeps in touch with participants, sending them periodic emails to help them keep up their progress and improve their score. In the process, Hayward Score gets feedback not only on how houses are improving but also on how occupant health may be improving. From this, Hayward Score is able to capture a lot of data on the link between homes and the health of occupants. It tracks 23 medical symptoms and is now the largest study on health and housing ever created, assessing more than 80,000 homes and counting. While the Hayward Score is provided to the homeowner, it proves to be a good tool for building professionals to point their clients to, as many of the improvements suggested by the report (such as installing whole-house or point-source ventilation and addressing leaks, mold, or other building failures) are often beyond the scope of DIY. *—C.D.*

A SHORT HISTORY OF ESTABLISHED HOME VENTILATION RATES

Source	Minimum Airflow
ASHVE[1.] Recommendation-1895[2.]	30 cfm (14 L/s) per person
ASHVE Guide and Handbook-1925[3.]	10 cfm (4.7 L/s) per person
Yaglou, Riley, Coggins-1936[4.]	17 cfm (8 L/s) per person
ASHRAE[5.] Standard 62-1973[6.]	5 cfm (2.5 L/s) per person in non-smoking spaces; 10.6 cfm (5 L/s) per person in smoking spaces
ASHRAE Standard 62-1989	15 cfm (7.5 L/s) per person
ASHRAE Standard 62.2[7.]-2003[8.]	7.5 cfm (3.5 L/s) per person + .01 cfm/sq ft (.05 L/s/m2) of occupiable area
CEN[9.] Standard 13779 -2007	Lowest class: 10.6 cfm (5 L/s) per person; highest class: 42 cfm (20 L/s) per person
ASHRAE Standard 62.2-2013[10.]	7.5 cfm (3.5 L/s) per person + 0.03 cfm/sq ft. (.15 L/s/m2) of occupiable area

1. American Society of Heating and Ventilation Engineers
2. Cf. "The History of Ventilation and Temperature Control," by John E. Janssen (ASHRAE Journal, Sep/1999). These ASHVE recommendations were based on studies by J. Billings, author of Ventilation and Heating (1893) and a physician concerned with reducing the transmission of disease, especially tuberculosis, in enclosed spaces.
3. According to Janssen, by 1925, 22 US states had ventilation codes that required a minimum of 30 cfm (14 L/s) per occupant of outdoor air. However, many heating engineers were either concerned by the energy impacts of reconditioning so much incoming outdoor air, or were inclined to view ventilation as more of a comfort concern than a health issue. Both concerns argued for reducing ventilation rates, and in response, ASHVE published "A Code of Minimum Requirements for Heating and Ventilation of Buildings" in the 1925 ASHVE Handbook and Guide.
4. Yaglou, et. al. was a more comprehensive study of work begun by Lemberg, Brandt and Morse who studied ventilation rates needed to control odors in buildings. The Yaglou study correlated minimum ventilation rate with net air space per occupant, setting the stage for ventilation codes based on occupant response, and underpinning the push to base ventilation rates on comfort control rather than health concerns. Cf. "Challenges in Developing Ventilation and Indoor Air Quality Standards: The Story of ASHRAE Standard 62" by Andrew Persily (Build Environ 2015, National Institute of Building Standards).
5. American Society of Heating, Refrigerating, and Air Conditioning Engineers (the name changed following the 1959 merger of the ASHVE with ASRE, the American Society of Refrigerating Engineers).
6. In addition to requiring this minimum flow rate, the Standard recommended from 7.5 cfm (3.5 L/s) to 21.2 (10 L/s) per person ventilation air flow.
7. ASHRAE split the Standard to address commercial requirements (62.1) separately from residential requirements (62.2).
8. "Per person" is defined in the Standard here by the number of occupants expressed as the number of bedrooms plus one (assuming two people in the master bedroom and one in others).
9. European Committee for Standardization
10. This rate remains in the most current iteration, ASHRAE 62.2-2019

occupant engagement must be based on knowledge of what is in their environment. But for the most part, the system should be set to run continuously at the baseline without occupant intervention.

BH: Ventilation, in my opinion, is the builder's best friend because it is helping them reduce risk. When I talk to production builders in particular, and we mention risk management, the light goes on. One thing you taught me years ago, Mark, is that you can't control occupant behavior. They don't run the bath fans, they don't run the range hood. They fill the place up with moisture and then the builder gets claims for humidity condensing on surfaces.

Occupants don't know what they're doing, especially with a sophisticated system like an ERV. Most people, including people that we train, don't pay attention to their ERV. So when somebody hits the "boost" button, it stays on boost for too long. Or they say, "I want to save a little energy, so I'm going to turn it off at night." But that is exactly the time you need it! On the other hand, if I put in a system that runs 24/7, I don't run into problems because I forgot to turn it back on. I'm mitigating elevated chemical exposure from new construction (ventilation is about the only way to cost-effectively remove concentrations of harmful chemical off gassing from materials, and it's virtually impossible to eliminate all chemicals from building materials), I'm mitigating moisture problems, and I've got a healthier indoor environment—all that just totally makes sense for the homeowner *and* for the builder.

Occupants have their needs—to breathe fresh air—but the house also has needs: To remain stable and to age well, a house needs a consistent source of fresh air, as well as consistent levels of temperature and humidity. Of all the ways to provide ventilation, I'd rather put in a dedicated system that delivers the right amount of fresh air throughout the entire house and leave it running. I want to give occupants some control. But from a builder's standpoint, you don't want occupants to be able to turn it off for periods of time and then have them come back to the builder and say, "Well, my daughter's having trouble breathing at night."

We also know that once you set the building up, someone may drill a hole to install cable or some other future modification, and now it's not working. An instrument can help you manage those changes. In my experience, once you give somebody an IAQ monitor on their phone, they quickly become knowledgeable about it.

ML: We want to have both the system running at a baseline and homeowner engagement. You can't smell most of the harmful contaminants—an odor-based standard is not going to provide good health. So we have to count on something to tell me that my particulate count is too high. If you look at cooking, for example, you will go from a count of zero to 100 in a matter of 20 minutes. The average consumer probably has no idea that turning on the stove had that big of an impact. But if they watch a gauge all of a sudden go into the red zone, then they're going to turn the hood on.

I remember when Whirlpool did a study where it installed a wall control that showed energy consumption in real time. When people would walk out the door, they would look at it and ask, "Why is it in the red?" And they'd run downstairs and find all the lights were on, that sort of thing. The wall control was a way to activate awareness.

For us to become activated around ventilation, we need to pay attention to several practical things about an ERV system: proper equipment selection; proper sizing; envelope performance (insulation, air-sealing, windows with a low U-value); system controls that maintain a health-based ventilation rate; and education that allows occupants to rationally engage with that system. But none of this is Fifth Element stuff. This is right now. And we can do it affordably.

A good example is what Gord Cooke is doing with 16 builders in the Toronto greater metro area, all building to net zero. Gord has been able to demonstrate that the increased cost, including ventilation and energy recovery in every house, has been between 5% and 10% at the most, and in some cases finding neutral cost. This group is working to specific outcomes—net zero—and so they are able to work with clients to say "take this out and add this here" to arrive at the outcome. When a builder can do that over and over, always aiming at their modeled benchmark, who would make a choice to go back to the other way? No one; otherwise, they lose the edge of what allows them to demonstrate to customers what makes them different and better.

Gord's example aims at an energy outcome. It includes ventilation because that is critical to building performance. But I think the work you are doing, Bill, comes at it from health, and as you say, that creates urgency that is going to move the industry faster toward a higher building standard. We need a solid health-based outcome.

A HEALTH-BASED VENTILATION STANDARD

BH: The advantage of coming from the perspective of personal health is that we're much more engaged with it than we are with energy. We naturally tend to be more concerned about health than energy because the impacts seem so much more serious for ourselves, and for children. The trigger event of 2020 began to draw a bright line around health and home. If home is our safe haven, it better be safe. Is it? Maybe not, if our ventilation standards are based on comfort and energy control instead of health factors.

Jillian Pritchard Cooke, of Wellness Within Your Walls, brings the dichotomy into sharp focus: In a recent workshop, she compared the annual savings generated by EnergyStar—about $17 billion per year on average—to the estimated cost of environmental diseases in children, which was in excess of $76 billion in 2008. The vast difference in social cost between $17 billion and $76 billion is an impact that should help reframe priorities around a ventilation standard.

For me, the current standards are not high enough if we are to address health as a primary concern. I run my home at about 30 cfm per person. That's around what old health-based codes called for, but I do it because I'm reading the instruments and want to keep the air in my home below the World Health Organization's maximum, which is 500 TVOC [total volatile organic compounds] parts per billion. The ventilation rate in my home is a lot higher than the baseline of ASHRAE 62.2-2013, but it's not as high as the recommendations in a Harvard University cognition study that found that people think clearer, sleep better, and have higher workplace productivity rates when the ventilation rate is closer to 40 cfm per person in office buildings. For homes, the correct number is between 20 to 30 cfm per person. Really, once you have a tight, well-insulated shell and a stand-alone continuous system with energy recovery, you can set it at any level that is appropriate to the customers' needs. We can do this with dedicated ERVs without having an outsized effect on energy use in the home. The energy impact has been driving ventilation rates down for the last 48 years. But that is no longer relevant with the efficiency of today's ERVs. We are ready for a complete shift in how we ventilate homes.

Health does create urgency. Everyone wants to be healthier, live longer, spend less money on health care, and be free to make life decisions that aren't encumbered by health restrictions. This is something builders can sell, not just to make money but to do the right thing. If you make homes healthy, you make them energy efficient as well because you can't control the air inside until you control the envelope. Usually the line for the last 20 years among energy-conscious builders has been the opposite: "If you make it energy efficient, you will see all these other benefits like better indoor air." But building owners don't care enough about energy to spend the money needed. If we come at it from the direction of health, we create an urgency to make that investment. And then your company is in the business of making people healthier and happy, even improving conditions for everyone on the planet by driving a lower impact on resources and energy, and driving a market for less toxic materials, less industrial pollution. The impacts go out like ripples in a pond from the simple act of making better homes.

VENTILATION CODE SIMPLIFIED

For installing a stand-alone, continuous whole-house ventilation system, the International Residential Code (IRC) follows ASHRAE Standard 62.2-2010 and offers two methods to determine the required airflow in cubic feet per minute (cfm). Note that the IRC does allow whole-house ventilation systems to operate intermittently according to rate factors defined in Table M1507.3.3(2), but if you are following the arguments put forward in this article, continuous ventilation offers the best performance for both the building and the health of the occupants.

Formula. The required flow rate for whole-building ventilation can be calculated as follows:

Ventilation rate in cfm =
floor area / 100 + (number of bedrooms + 1) x 7.5

Prescriptive table. Another way to determine the baseline airflow rate is to use the prescriptive table (right).

Minimum Continuous Whole-House Ventilation (cfm)

Floor Area (sq ft)	Number of Bedrooms				
	0 to 1	2 to 3	4 to 5	6 to 7	> 7
< 1,500	30	45	60	75	90
1,501 to 3,000	45	60	75	90	105
3,001 to 4,500	60	75	90	105	120
4,501 to 6,000	75	90	105	120	135
6,001 to 7,500	90	105	120	135	150
> 7,500	105	120	135	150	165

Table M1507.3.3(1) of the International Mechanical Code is referenced in Chapter 15-Exhaust Systems of the International Residential Code.