Understanding Your Home's Heating and Cooling System

If you are reading this book, the odds are high that a room or area of your house makes you shiver all winter and swelter all summer. It just won't heat or cool well. No room in your house should be more than 2-3 degrees warmer or colder than any other room unless you want it to be. This chapter will help you understand how to heat and cool your house baby bear style – not too hot and not too cold. Plus you'll learn some things you probably never thought about.

It's important to state that the first part of fixing hot & cold rooms is almost always reducing air leakage and adding insulation, but those only get you part way, they only keep the heat and cool in.

How the heat and cool gets to the rooms of your house is the other part of the equation. Because it gets old both writing and reading it, I need to introduce an acronym: HVAC. It stands for heating, ventilation, and air conditioning. Basically, it's the furnace and air conditioner in your home, but there's more to it than that. I'll be using HVAC a lot through the rest of the book.

It's also time for a hard truth. With 99% certainty, I can say the HVAC system in your house sucks. Badly. It lacks a ton of features that really help make your home comfortable. (Comfort is far trickier than you might guess, see Home Comfort 102 for more.)

The good news is, you already own a state of the art HVAC system – in your car.

If I had all the capabilities your car has in your house, I would be a very happy camper, and so would you. Combined with a tighter house, a well executed HVAC system is likely a big part of the solution to the problem(s) you are reading this book for.

Let’s see how your home’s HVAC should work by comparing to your car’s HVAC

The HVAC system in most homes frankly sucks. My wife’s first car, a rusty $500 1992 Toyota Corolla, had a better HVAC system than 98% of US homes have today.

That simple little car had controls for the following:

Load Matching
The car could put out exactly as much heating or cooling as was needed for any situation. This is critical to comfort. It’s accomplished primarily with these two things:

Variable air temperatures
Heat or cool

Multiple fan speeds
Fast or slow, loud or quiet

Fresh air
Bring it in or not

Dehumidification
Availabile even in heating mode.

Flow Control
Blowing heating and cooling where we want it.

Almost no homes have all of these capabilities. If they did, it would be far easier to make homes more comfortable, healthy, long lasting, and efficient.

In our work, we help specify and design systems that provide these capabilities. You’ll want to be sure that any HVAC design you develop gives you a path towards them as well, even if you don’t install the complete system now.

“Little Whitey” in all of her state-of-the-art 1992 glory. Despite the old car smell, this and nearly every car has a far more sophisticated HVAC system than your home.

Learning HVAC from Our Cars

Our cars give us a really nice learning tool, because it’s something we use every day and understand. Let’s walk through the different parts of operating a car’s HVAC system.

An important thing to note is that we don’t typically let our houses freeze or roast outside like we do our cars. These examples assume that the inside of the car is already comfortable and is not freezing or roasting, unless noted.

Variable Temperatures

Cars have these wonderful dials that let us set whatever temperature we would like from very hot to very cold. The system can deliver lots of heat or cool quickly, when desired. More importantly, though, it can add just a little heat or just a little cold as needed.

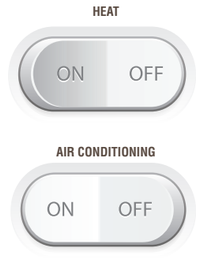
A trickle of heat or cool is far more important than a blast for comfort. Think about riding along in your car. After you’ve been in it for 10 minutes and it has become more comfortable, do you leave it cranked up to full hot or cold? Maybe on the hottest or coldest days, but what about most days? Of course not. It only takes a little to keep it comfortable. Otherwise you’ll sweat or freeze.

The same principle applies to your house. When it’s 40-50 degrees outside, it doesn’t take a whole lot of heat to keep the house warm - the weather is just not that cold. The trouble is, most heating and cooling systems are ‘single stage’ which means they are on or they are off. If it was a dial in your car, it would look like the knob to the right.

This makes it really hard to keep your house comfortable. Imagine if in your car you only had full hot or full cold - could you keep it comfortable easily? On a 50 degree day with the car’s heat on, how long do you want to have it blow full hot? Or if it’s 70 degrees out, how long for full cold? It would be hard to keep the car comfortable with the system running full blast.

It’s just too much heat or cold, you’ll have to turn it on and off a lot or keep opening and closing the windows to get comfortable; a never ending comfort battle.

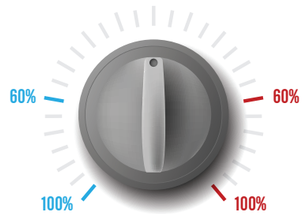
Your Car
As much or as little heat or cold as you need



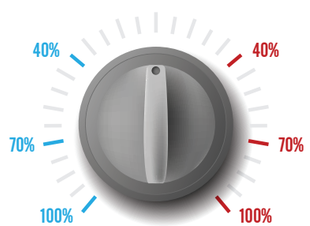
Your House

Imagine trying to fill a shot glass with a fire hose.

The same goes for your house. Single speed equipment generally stinks for this reason.



2 Stage

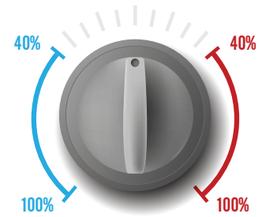


3 Stage

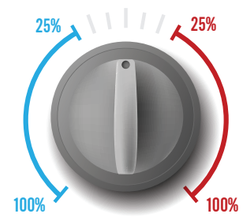
Better home heating and cooling systems have two stages, which make it a bit easier to control your home climate. Low stage is typically 50-70% of full capacity.

The best heating and cooling systems have three stages or many more. Many of them vary down to 40% of their full capacity; the best ones dial down to 25%, giving a very wide range.

These systems can minutely adjust their capacity between full blast and a trickle in many small, precise steps in order to match the system capacity with the building heating or cooling demand level. This type of HVAC equipment is known as a modulating capacity system.



Modulating



Best Modulating

Now imagine you are in your car on that 50 or 70 degree day. If you can turn down the heat or cool to what the car needs, won't it be easier to keep the car comfy?

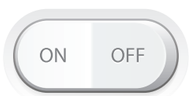
Hopefully it now makes sense that the better HVAC equipment allows for better comfort. In my experience, modulating equipment also uses surprisingly little energy, which is a nice side benefit.

Hopefully you can now see why we generally recommend higher end equipment. Or as we say, friends don't let friends buy single stage.

Big Caveat – If your house is still leaky, it will still be very difficult to control the climate inside of it, similar to a boat with a leaking hull. A leaky boat won't turn well or go fast. A bigger bilge pump or engine may mask the problem, but is not the root cause solution – fixing the leaks is. Some of our clients come to us with an awesome "bilge pump" (modulating HVAC equipment) already installed but they are still sinking in discomfort. Reducing air leakage (fixing the hull) and adding insulation still come first.

Fan Speeds

Your Car



Your House

Our cars also give us multiple fan speeds, where most home heating and cooling systems only have one fan speed. Multiple speeds are useful for a number of reasons:

Low speeds = Low noise When the fan is on high in your car, do you have to talk loudly to hear the other person? The same thing happens with single speed systems in your home - it's loud. On lower fan speeds in your car, it's so quiet you probably don't notice the fan. The same is true for heating and cooling equipment in your home that can offer lower blower speeds.

Mixing Air Is Good Air tends to be different temperatures between different rooms and levels of a house, and even between the floor and ceiling of the same room. Mixing it does the same thing as keeping the oil and vinegar of a vinaigrette mixed. Temperatures are more even. It also washes the air across surfaces, making their temperatures more in line with the air temperature and improving mean radiant temperature (MRT). See the Comfort chapter for more on MRT.

Filtration The fan always being on means air is constantly run through a filter, generally lowering pollutant levels like dust, allergens and more. See the indoor air quality section for more.

Move Different Amounts of Heat or Cool With only one fixed fan speed available, if you tried to put less heat into the air, it would come out of the supply vents fast and much colder, which doesn't feel good. See the comfort chapter for more. With variable speed equipment, this means that a lower fan speed can be matched with lower heating and cooling outputs, which more exactly match what the house needs at any given moment. This is more comfortable, and often uses less energy, too.

The good news is, better residential HVAC equipment with multiple stages of heat or cool almost always come with multiple fan speeds. The best equipment often features 3 or more fan speeds. Another bonus of better equipment is that the more advanced fan motors in them use substantially less energy, than less expensive motors do. You may not notice running the fan all month on your electric bill.

Is that rusty 1992 Corolla starting to sound better? It had all this! We're definitely not done yet, though.

Sending the Heat and Cool Where You Want It

Your car can send heat to your feet, face, or windshield. Believe it or not, so can your house! Well, sort of.

The Good News

Putting the heat where you need it is great. If you have a duct system in your house, you very likely have the ability to control how much air goes where when using dampers installed in the ducts.

Dampers are little valves in the room ducts, typically close to the main 'trunk' or 'plenum' duct. Most systems have one for every duct going to a room. That's the good news.

The Bad News

It Probably Won't Work Your oversized, single stage system likely doesn't run enough to send enough heat or cool to the rooms that need it most, even if you blast the house with heat or cool.

If It Does If you do manage to heat or cool troublesome rooms by forcing longer run times for your furnace or air conditioner, you'll likely use more energy and you'll probably see it in your bill. Zoning systems use this method.

Early HVAC Death By closing dampers, you'll likely drive the pressure inside the duct system up. This higher pressure translates to added resistance to airflow in the ducts, which means less air overall moves through the blower. For a furnace this can lead to overheating and damage to its heat exchanger, which can crack. A cracked heat exchanger is considered a carbon monoxide risk. For the air conditioner, it can lead to frozen cooling coils and damaged compressors. Please don't close dampers willy nilly!

Multi-Stage, Right Sized Equipment to the Rescue (Again.)

Multiple stage and fan speed equipment will run most of the time on a lower stage, which means adjusting the dampers is much more likely to work (but may not be necessary with this better equipment.) Lower stages usually mean lower pressures inside the duct system, along with the ability for the system to reduce its heating or cooling production. This makes for a happier fan.

Longer run times also mean fewer cycles. Most machines like to run at partial load without being turned on and off a lot. Think highway miles for your car. Single stage equipment gets all city miles like a New York cab.

Thanks to reduced pressures and longer cycles, early system failure is a much lower risk.

You're not off the hook yet, though. If a huge piece of equipment gets put in, early failure is still possible and you're unlikely to solve comfort problems. More on right sized equipment in the next section.

LEGAL NOTE: Do not simply close dampers in your ductwork, you may cause early failure of your HVAC system. Consult a qualified professional for static pressure testing before attempting. Pressures must be within equipment specifications.

AIR CONDITIONING AND DEHUMIDIFICATION

Ah, the magical A/C button on the dash. Jeez, I'd love to have this feature in every house I work on. It lets me remove humidity any time, whether the heat is on or the air conditioning is on. So many moisture and comfort problems can be substantially fixed. I'll just pause for a second now and dream. Ahhhhh.

Your Car

A/C

Your House

Cool
YES

Heat
NO

Dehumidify
NO

Humidity Issues

You may think humidity isn't a problem when the heat is on, but it can be. Think about getting in your car on a winter morning and the windshield fogs up as the car warms up. What do you do? Turn on the defrost. Do you know what that does? It almost always turns on the air conditioner, and clears the windshield so you can see. It does this because the a/c dries the air flowing across the glass, which in turn encourages the moisture on the glass to move into the drier air. In tighter homes moisture buildup is frequently a problem, so it would be good to have the ability to remove it, even during the heating seasons.

Air conditioners actually have two purposes

Removing heat

This is called removing 'sensible' heat.

Removing moisture

This is called removing 'latent' heat.

Depending on the season and where you live, removing moisture from the air, or dehumidification, is often the most important part from a comfort perspective. It also reduces the chances of mold, pests like dust mites, and many types of bacteria.

Let's walk through the four seasons to see why dehumidification is important, starting with the one for which air conditioning shines the brightest.

Summer

During the summer in wet climates (basically East of the Mississippi), it's muggy. this makes us want to reduce the humidity in the air. Air conditioners do this, although they only start dehumidifying about 2-5 minutes into the run cycle. Ironically, more efficient ACs stink at dehumidification because they are better at removing heat than humidity. An old school AC might remove 40% latent heat (moisture) and 60% sensible heat (heat in the air). Super efficient models may only be 15/85. If your AC is drastically oversized, or worse, drastically oversized and efficient, it likely does a crappy job with dehumidification.

Humid air feels hotter and stickier because it slows how fast you can cool yourself by sweating. I got a great example of this from a friend of mine who is an Eastern Orthodox monk. (Oddly enough, I spent a lot of time in 2014 insulating and soundproofing a monastery.) He wears a heavy cassock year round and noted to me that 70 degrees at 40% relative humidity feels great, but 70 degrees at 70% relative humidity is miserable. Removing moisture from the air is critical for comfort.

A battle of the sexes also sometimes rears its ugly head in summer around the set point on the thermostat. Often men prefer cooler temperatures, even if humidity levels are high. This can feel clammy. Many women don't like the cool temps or clamminess, and a thermostat war ensues. Even if the positions are reversed, high humidity levels frequently lead to discomfort and arguments.

Both parties are often happy if humidity levels can be held in the 40-50% range, often at temperatures in the 74-78 degree range. That's a 50-55 degree dew point. The system has to be carefully sized and designed to do this, though.

Dewpoint vs. Relative Humidity

Most measurement tools, such as your thermostat, rate moisture in the air by "relative humidity." It's relative to the temperature of the space that's being measured.

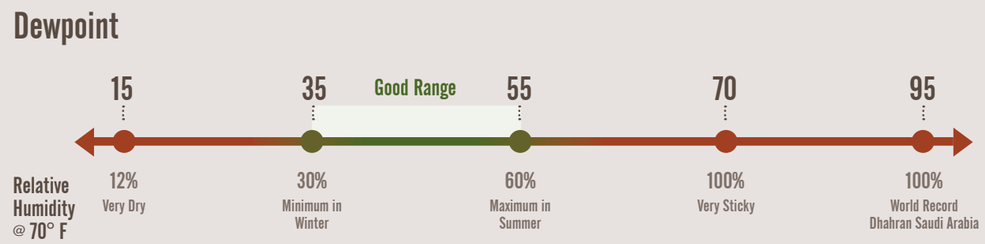
For example, if you take 50 degree air at 100% relative humidity and raise it to 70 degrees, the relative humidity of that same air at 70 degrees is 50%. Warmer air can hold a lot more moisture. Relative humidity is a somewhat limited measure, because you have to know the temperature as well as the percentage to understand how much moisture is in the air.

Dewpoint is a better way to understand moisture in the air. If you've noticed condensation (dew) on a glass with cold lemonade in it, or dew on the grass on a cool summer morning, you know what dewpoint is. You just didn't know it.

Dewpoint is the temperature at which air in a certain space can't hold any more moisture. The lemonade is probably close to freezing, or 32 degrees. If the dewpoint of the air around it is 32 degrees or above, condensation will form on the glass. That's likely on all but the coldest days of winter. The dewpoint of air in the summer is often in the 50-70 degree range, so most glasses with cold drinks will get condensation on them.

The 50 degree air at 100% humidity in the first example is at "dew point." The air is holding as much moisture as it possibly can. If that air touches a surface that is colder than 50, even 49, moisture drops will form on the surface.

If you ever see condensation on your windows during the winter, that's a dewpoint problem. The dewpoint of the air inside the house is too high, and it's likely that some spots you can't see inside the wall are getting wet, too. That can lead to mold and rot. Dew point is a very important thing to control. Here's a chart to help you wrap your head around it. If you want to dig deeper, Google "psychrometrics" or see the resources at the end.



With dewpoint, you only need one number to understand how much moisture is in the air. It's a common metric in the HVAC world. If it's too low dust, dry skin, flu viruses and more propagate. If it's too high mold, bacteria, dust mites, many creepy crawlies and more can be a problem. It's best to control the dewpoint of the air, hence my love of the AC button on the car because it can work anytime. See the moisture chapter for more.

Fall

Autumn is typically a very wet season for green grass climates (east of the Mississippi.) The ground is often wet from summer rains. Temperatures have been high and still can be warm, so the air holds a lot of moisture. The earth, house and basement have absorbed a lot of moisture in warm weather.

With dropping outside temperatures, the air conditioner won't run as much because the days are cooler. Dewpoints often skyrocket, particularly in basements. Since the AC runs less it can't take out as much moisture from the air, which then becomes muggy. Even if it does kick on, it's likely so oversized that it only runs for a few minutes before turning off.

Because of increased moisture, forgotten pet urine spots start to smell again. Mold often thrives. Asthma and allergies frequently flare up and may be moisture related. It's yucky.

This is where I would love to have that AC button like in your car. Reduce the humidity and moisture, improve Indoor Air Quality, make your house much more comfortable, reduce asthma flare ups, reduce colds spreading, stop dust mites from growing, and lots more. A car a/c can dehumidify while heating by blending warm and cool air streams so the cold, dehumidified air isn't so cold by the time you feel it blowing on you. Alas, I seldom have a tool like this for a house. See the Fresh Air chapter for potential solutions.

Winter

If your house is leaky, excess moisture in your home is likely not problematic in winter - it leaks out. If you get lots of dry skin or flu bugs spreading through your house like wildfire, a leaky house could be a root cause.

For tighter, more efficient homes, though, moisture often builds up in them, even in winter. As we shower, cook, and breathe, we put a lot of moisture into the house. If the house is tight, it doesn't escape quickly like it does in leakier homes.

Do you remember the "Sick Building Syndrome" of the 70s and 80s? A major root cause to this was moisture and fresh air not being managed well in tighter buildings. Damp buildings are still not well understood, except that they are consistently a bad thing. See below for more resources on damp buildings and the Healthy Home/Indoor Air Quality chapter for more on the subject.

As your home gets tighter, be sure you have a plan to manage excess moisture year round.

Spring

April showers bring May flowers, it's often a wet season. Like Autumn, it's not warm enough to turn on the air conditioner. The air in the house often gets stale during this time as well because the HVAC fan doesn't turn on much to mix the air. Having a plan to manage moisture and fresh air during spring and fall is key. A tight home makes this job far easier.

Getting Some Fresh Air

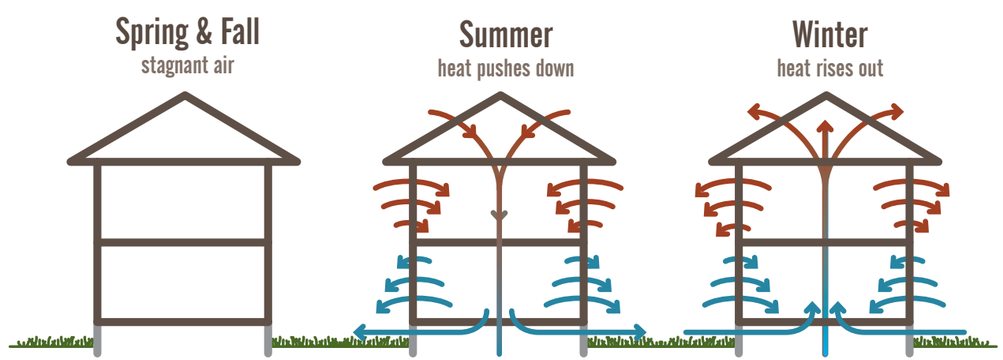
You may be feeling like getting some fresh air yourself at this point, but here is another thing that the 1992 clunker still has over your house – the ability to bring in fresh air. It brings it in from one known point – the cabin air intake.

Try flipping the switch in your car to recirculate for too long, you've probably notice two things. First, the windows fog up. Second, the car tends to stink more, especially if there are a lot of people in it.

The same thing happens in houses. Your car is actually very nearly air tight (it has to be to keep water out) so it has moisture problems like a tight house does – moisture builds up easily. Without fresh air being pulled into the house, odors tend to build up more easily as well.

In the spring and fall the house is damp, but doesn't have a lot of dehumidification or air mixing going on. Even a leaky house doesn't leak much because there is little stack effect pressure working on it. When indoor and outdoor temperatures are almost the same, there is little pressure to make it leak, similar to a boat with a leak at the waterline. The diagram below shows what how this looks.

Stack Effect



Because of the stagnant air that builds up, spring and fall are a good time to bring in fresh air. This is true for both leaky and tight homes. It's a good thing in summer and winter, too, although stack effect helps more in those seasons.

Bringing in fresh air can be done with several different devices, see the Fresh Air chapter for more.

Credit: Stefan Peter-Contesse of E3 Innovate in Nashville TN

One Known Point

Now that you know why you can't count on the leakiness of your house to bring in fresh air in spring and fall, it's important to note that if you are going to bring in fresh air, it's best done from one known point.

If you count on the leaks in your house to bring in air, they often will bring it in through 'healthy' places like your attic (mouse poop and/or mold), crawlspace (these are frequently revolting), basement (typically damp), or walls (mmm, fiberglass and dirt.) See the Air Sealing Guide for more on where leaks really come from.

Don't believe me? Here's a picture of a cold air return duct in a nasty crawlspace right next to a dead opossum. That homeowner was breathing dead animal. On top of damp, musty soil. Gross.

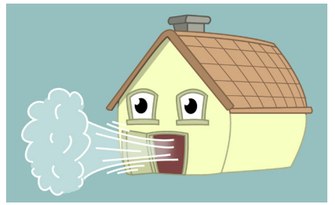
Better yet, get a blower door test and find out how connected the attic and basement are to the house. Houses are gross. Be sure that "fresh" air is really fresh – know where it comes from.

A house trying to 'breathe' through existing leaks likely brings in air from places with dirt, mold, dampness, animal excrement or even dead animals.

A House Has To Breathe

This is the time when that cursed line comes up. It's false. Houses don't need to breathe, people do. Furnaces do. Water heaters do. Gas stoves do. Dogs and cats do. As you get a house tighter and tighter, it's important to provide fresh air to the people and animals inside. The catch phrase for this is "build tight and ventilate right."

Hopefully by the end of this book you'll be convinced to get rid of anything that burns fuel inside the house, but if not make sure those appliances get outside air to burn too. A fresh air system solves the house breathing argument – you get plenty of fresh air! See the Fresh Air chapter for more.



MISCONCEPTION

Filtration

Most new cars have cabin air filters. These filter the air coming in from outside. Often these filters are quite good. Tesla has a Bio-Weapon defense mode, for example. They typically do not filter air inside the cabin, though. Most homes have a paltry 1" filter that is only good for filtering out large rocks and small children. These filters are meant to protect the equipment, not the occupants.

They filter the air inside the house, but not outside, at least not directly. We generally recommend a 4" media filter in a box for better effectiveness.

Humidification

Our odyssey to understand how your home's HVAC system works is nearly complete. The last item is something that cars do not have – a humidifier.

If you get dry skin in winter or the flu spreads quickly in your house, you may have a problem with low humidity. You can buy an air quality monitor to find out. If your home is consistently below 30-35% in winter, it's probably a problem.

Tightening a home usually increases humidity levels in a home, but sometimes a humidifier is needed.

If you add one, be sure it has an outdoor temperature sensor so that it dials down humidity levels as the temperature drops. If you ever see condensation on a window, turn your humidifier down. There is likely more condensation you can't see inside walls that could turn into moisture problems down the road.

A tight home may not need a humidifier, but it might, and they are fairly inexpensive if added to a new install.

WARNING: Humidifiers often cause mold, especially in attics, and especially in looser homes. Please strongly consider doing a good air sealing job on your home before adding a humidifier. Be sure your humidifier automatically reduces humidity levels as the outdoor temperature drops. Periodically inspect the roof deck from the attic to see if mold is forming.

Conclusion

Hopefully you now have a basic understanding of how your home's HVAC should work, thanks to your car. Coupled with a tighter, better insulated house, you can substantially fix almost any comfort problem. Here are the pieces to creating a very comfortable indoor climate in your home in rough order of importance:

1

Load Matching

Putting just the right amount of heat or cool into the house at all time using multi-stage and multi-fan speed equipment. Critical for comfort.

2

Filtration

Cleaning the air inside the house. Improves Indoor Air Quality (IAQ).

3

Dehumidification

Being able to remove moisture at any time is important for both comfort and health reasons.

4

Fresh Air

Keeping the air in your house healthy by bringing in outside air. Like a window open 24/7/365.

5

Right Place at the Right Time

Moving the right amount of heat or cool to different rooms for comfort and health reasons.

6

Humidification

Being able to add moisture to the house when needed.

A careful improvement design for your home can lay out the path to getting all of them. Get these factors right and a comfortable home is likely, with one glaring omission.

Right Sized HVAC

Just like engines in a car, HVAC systems come in different sizes, big and small. The importance of getting the right sized HVAC system almost can't be overstated when it comes to comfort. Oversized systems, even if they have all the capabilities I just listed, are very difficult or even impossible to optimize for comfort. That cold room will probably still be cold.

The next chapter will dig into what the different sizes of common HVAC equipment are, what it means, and how to determine what you need for your home both today and after improvements.
See the HVAC 102 chapter to learn more.

Resources

LEW HARRIMAN

IAQ Radio Interview

Lew is one of THE experts on damp buildings and controlling moisture. He talks at a layman's level and is very easy to understand. Check out his other interviews here too or any of his other work. This is one of my favorite podcasts.

JOE LSTIBUREK

Just Right and Air Tight

Dr. Joe is a wonderfully foul-mouthed, opinionated, and fun to read engineer. (An unusual combination.) He is also THE expert on Building Science, his company is actually called Building Science Corporation. He goes out there, sees what fails and tells people how to fix it (while getting paid a fortune.) He's not a lab rat, he's real world. (I like the lab guys too, though.) This article is a longer and more colorful version of my fresh air section in particular and much of the thesis of this book in general.

Dew Point Calculator

This is great to play with to understand the relationship between dewpoint and relative humidity. It shows how quickly mold is likely to grow, a useful gauge. It was built for protecting art, and it's worth bookmarking.

Weather Underground

US high dewpoints and a heat index chart. It also talks about records around the world including 95 in Saudi Arabia. Dewpoints are extremely important to control for comfort, health, and durability reasons.