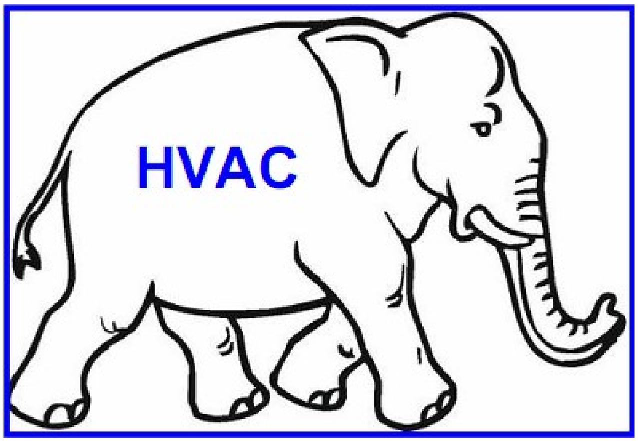
The Elephant in the Room
HVAC for High Performance Homes



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The Elephant In The Room – HVAC for High Performance Homes

At a recent workshop on high performance homes, one speaker defined a code-built house as "The worst house allowed by law!"

Homes that simply 'meet code' are no longer acceptable for a growing number of homebuyers. Purpose-built high performance homes, once a niche market, have moved into the mainstream. By all accounts, builders who participate in Energy Star and other recognized efficiency programs are experiencing stronger sales than their competitors in these difficult economic times. Further increases to energy costs will no doubt accelerate demand, as happened in the automotive industry when gasoline prices spiked in 2008.

Just what is a high performance home? It's a home designed and built to substantially exceed building codes in terms of energy use, comfort, air quality and durability, using proven methods, materials and field verification procedures. Green building programs go further by considering the impact of a home on the environment – including water use, carbon footprint and embodied energy, sustainability of materials, and building site impacts.

The role of the home performance professional is to provide guidance throughout the design and construction process, helping the builder and design team evaluate and implement an appropriate mix of performance improvements. Because of the interactions and potential conflicts between various performance improvements, it's important to approach the house as a system. The home performance professional is best equipped to provide this perspective.

A Historical Perspective – Overcoming Inertia

Today's home performance industry grew out of the 1970's energy crisis. At the time, household energy usage had been on the upswing for more than a decade, primarily due to the widespread adoption of central air conditioning and increasingly larger homes. Against this backdrop, the shock caused by the energy crisis spawned numerous utility and government sponsored weatherization programs and a new emphasis on energy efficient design. However, receding oil prices and a strong economy over most of the next two decades shifted the spotlight away from energy conservation.

But a more fundamental reason helped prevent the conservation movement from gaining traction: home builders don't like change – *If it ain't broke, don't fix it!* This isn't necessarily a bad thing. Many tried-and-true construction methods developed in the first half of the last century remain relevant today. Unfortunately, the craftsmen from that era along with the knowledge they possessed have all but disappeared.

Today's builders and tradesmen honed their skills during an era when production was paramount. Indeed, the pursuit of production efficiency has driven most of the change seen in the home building industry in recent years. Unfortunately, an efficiently built home isn't necessarily an efficient home.

High-Performance Homes No Longer an Oddity

More than three decades after the first energy crisis, market transformation is finally taking place. Within the span of just a few years, energy efficiency has become the primary driver of change in the home building industry. The home performance industry has become the vehicle for change.

Why the sudden interest in energy efficiency among home builders and home buyers, and why now? No single factor could explain this amazing metamorphosis. It took what amounts to a 'perfect storm' born out of the confluence of many factors:

- More stringent building codes and appliance efficiency standards
- The 'green' building movement, spawned by widespread concern over the environment
- A shift in homebuyer priorities (hot tubs no longer out-rank energy efficiency)
- The maturation of the home performance industry and building science in general

- Broad acceptance of HERS[1] as an objective yardstick for evaluating home energy efficiency
- The widespread success of Energy Star and other independent verification and certification programs
- Higher energy costs and the expectation of even larger increases ahead

Here's the most compelling evidence that home performance is no longer a cottage industry: The number of Energy Star homes has passed the one-million mark through its network of over 5,000 participating builders! Indeed, entire communities of high performance homes are being built in large and small markets across the country. Moreover, serious inroads are being made toward achieving 'net-zero energy' communities at reasonable price points.

Trust But Verify

Although it took all of the above factors to get us where we are today, none is more critical moving forward than verification and certification. Without an independent set of eyes on a project, home buyers have no idea what level of performance they're getting.

Virtually all builders and real estate professionals understand that 'green' and 'energy efficient' are desirable attributes in today's market. Many builders jump on the 'green' bandwagon for competitive reasons, often without professional guidance. This can and often does lead to unwise choices when it comes to energy efficiency. More often than not, builders rely on recommendations from suppliers, trade magazines, and worst of all, hearsay where unsubstantiated claims are rampant, especially involving energy efficiency and potential energy savings. The basics often get overlooked in favor of sexier (but often inappropriate) efficiency upgrades.

Homebuyers are even less qualified to separate the wheat from the chaff. And those who make a serious effort to self-educate often make poor choices because much of the available information is over-generalized, misguided or taken out of context. When it comes to home energy efficiency, myths abound and conventional wisdom often lets us down.

Most folks don't realize that achieving energy efficiency is more about quality assurance and construction techniques than choosing the right components. Indeed, much of what helps a home achieve true energy efficiency is invisible, hidden behind the walls. For this reason, an effective home performance program must include on-site inspections as well as diagnostic testing.

Verification and certification (V&C) represents the lowest of the low-hanging fruit. It not only ensures the basics have been met, but offers an objective yardstick for evaluating the cumulative impacts of potential improvements. Trying to build an efficient home without V&C is like trying to treat a serious disease without a medical exam. Either way, the odds are against a positive outcome.

The Energy Star Qualified Homes program deserves much of the credit for bringing high performance to the mass market. Aside from a widely recognized and respected brand, Energy Star accomplished that which previously eluded industry pioneers: it created a uniform verification and certification procedure that could be replicated on a mass scale at a reasonable cost.

Other certification programs are also enjoying success. California, Oregon and Washington have developed regional variations of Energy Star. Masco's Environments For Living program offers both energy and comfort guarantees through its network of home builders. To date, over 100,000 EFL homes have been built. A number of regional energy efficiency and green building programs have been adopted by counties, municipalities and non-governmental organizations.

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[1] Standardized home energy ratings date from 1981 when the mortgage industry collaborated to develop a way to consider energy efficiency in the underwriting process. In 1993, the Home Energy Rating System (HERS) Council formed to create guidelines for home energy rating systems nationwide. In 1995, RESNET (Residential Energy Services Network) formed to develop a market for home energy rating systems. That same year, Energy Star rolled out its new homes program and adopted HERS as the basis for certification. RESNET continues to further develop and maintain the HERS standard and is responsible for credentialing HERS raters.

The Elephant in the Room

Progress on this scale couldn't happen without collaboration between builders and home performance professionals. By participating in a verification and certification program, the builder gains a knowledgeable partner – an expert who can assist with design and construction details, and work on the front lines to help retrain key trades – especially framers, insulators and HVAC contractors.

However, for all the training and experience in envelope design, advanced framing and whole-house diagnostics, the home performance industry is largely unprepared to provide HVAC guidance. This is incredibly ironic considering that HVAC is by far the largest energy user in the home. When it comes to high performance homes, HVAC is the 'elephant in the room.'

To understand how this happened, one need only consider the origins of the energy conservation movement. Many industry pioneers came out of the utility and government funded weatherization programs of the late 1970's and early 1980's. Others cut their teeth on solar water heaters, energized by the 1978 federal tax credit. And then there were the generalists, deeply rooted in self sufficiency and ecology. For the most part, HVAC expertise was nowhere to be found.

Early conservation efforts targeted windows and insulation. Rightly so. At the time, many homes still had leaky single-pane windows and little or no insulation. Although heating and cooling energy use benefited from shell improvements, little attention was given to the HVAC system itself.

That changed in 1992 with the introduction of federal efficiency standards for furnaces, boilers, and air conditioners. This emphasis on source equipment ('box') efficiency ignores the even larger impact of poor design and installation practice. Indeed, as the building envelope and source equipment have become more efficient, HVAC design and installation quality remains mired in mediocrity, now becoming the Achilles Heel of home performance.

Field studies have consistently shown that design and installation issues have a far greater impact on overall system efficiency than source equipment ratings. SEER, AFUE and HSPF are theoretical ratings based on standard operating conditions. The efficiencies signified by these ratings can only be approached when equipment is sized correctly and delivery system losses are ignored.

In the real world, poor HVAC design and installation practice accounts for more energy waste in new homes than any other single factor. Unfortunately, in the real world it's easier to sell high efficiency boxes than high efficiency *systems*, a distinction invariably lost in a competitive marketplace. As a result, HVAC remains the weakest link in most high performance homes.[2]

The HVAC trade has struggled with this issue for years. Market pressures tend to drive down technician skill levels to the lowest common denominator, and penalize contractors who aspire to do things right. There's little incentive to do better when the market doesn't place value on careful design and quality workmanship. And building inspectors have their hands full holding up the rear.

The solution must begin with an educated builder. Through this strategy, home performance professionals are beginning to transform other key trades such as framing and insulation. But with virtually no training in duct design or equipment sizing and selection, most home performance practitioners are ill-prepared to take on HVAC, the most technically demanding of all trades.

Today, the home performance industry is beginning to pay more attention to the HVAC system. Energy Star took a step forward by requiring duct tests. But with leakage limits based on floor area (as opposed to nominal fan flow), the test becomes meaningless when applied to high performance homes with very small HVAC systems (see footnote 3, later). Moreover, sealing leaky ducts can and does lead to serious refrigeration problems if the ducts are undersized to begin with. Very little in building science operates in isolation. The systems approach is always the best approach.

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[2] In California, utility stakeholders recently identified the lack of adequately trained energy professionals and HVAC contractors as a serious impediment to achieving the state's energy efficiency goals (Californian Energy Commission Decision 07-10-032, Section 5.2).

Bigger Is Definitely Not Better

As homes have become more efficient, oversized HVAC equipment has emerged as one of the more serious problems in building science. Although there's general awareness of this issue among industry practitioners, few understand the full extent of the problem or its consequences.

Economics: Most people understand that oversized equipment has a higher first-cost. However, oversized equipment also costs more to operate due to increased cycling losses. Short run-times are like stop-and-go driving: system efficiency drops off as cycles become shorter. Also like automobiles, excess cycling is hard on equipment, especially the compressor. On average, oversized compressors have shorter life spans than undersized or correctly sized compressors.

The high efficiency trap: The highest efficiency ratings go to multi-stage equipment. Multi-stage air conditioners and furnaces are designed to operate at reduced output (first stage) most of the time. This allows longer run-times. However, the oversizing penalty is greater for multi-stage since its high efficiency rating is derived from the presumption of reduced cycle losses. When a multi-stage system is oversized, the efficiency gain diminishes or disappears entirely.

Many HVAC contractors intentionally size multi-stage equipment based on the first stage capacity and consider the high stage as reserve capacity for extreme weather conditions or a big party. By taking this approach, contractors unknowingly cheat homeowners out of the efficiency they paid for. Even when sized properly, payback for multi-stage usually exceeds the life of the equipment.

Comfort: Oversized equipment leads to wider temperature swings, especially in perimeter areas and remote zones. Consider what happens if on the coldest day, a furnace only operates 20 minutes an hour. As soon as the furnace cycles off, the house begins to cool from the outside in. The thermostat is purposely located away from exterior walls and windows, often in a hallway. While the furnace is off, air doesn't circulate. By the time the thermostat senses the lower temperature, perimeter areas may have dropped by several degrees. During mild weather when loads are tiny, minimum runtime logic assures significant overshoot. Either scenario causes discomfort; the greater the oversizing, the larger the temperature swings. The same occurs in cooling mode.

Indoor relative humidity plays an important role in comfort. In cooling mode, increased moisture will heighten the body's sensation of heat, often leading the occupant to compensate by lowering the thermostat setting. Oversizing compromises an air conditioner's ability to remove moisture (see Moisture Control, below), resulting in discomfort and increased energy consumption.

Ergonomics: An oversized system produces more noise than a system that is properly sized. Not only is the source equipment noisier but diffuser noise can be annoying if proper design procedures aren't followed. With proper design, a correctly sized system in a high performance home can be virtually silent. Note: Radiant heat eliminates noise during heating mode but it's rarely cost effective in moderate or mild climates, and can cause overshoot under part-load conditions.

Indoor air quality: Because an oversized system has shorter run-times, air filtration is reduced. During winter months, heat pumps provide the best filtration since they run nearly continuously during cold weather. Grossly oversized air conditioners can also lead to dust mites, mildew, and even mold in extreme cases, as a result of inadequate moisture removal.

Moisture control: An air conditioner's ability to remove moisture (latent capacity) is a function of the indoor coil temperature. Each time the air conditioner starts up, it takes at least 10 to 15 minutes for the coil to get cold enough to condense water vapor. Because an oversized system has shorter run-times, it spends a higher percentage of the time operating in this initial 'dry coil' phase.

Peak moisture loads tend to occur under part-load conditions, especially during the spring and fall. In this situation, an oversized air conditioner may not run long enough to condense *any* moisture, thus permitting indoor relative humidity to rise. A major selling point of multistage air conditioners is improved moisture control during part-load conditions. At best, this is an expensive solution to the part-load problem, but when a multi-stage system is oversized, it's no solution at all.

Structural durability: In many areas of the country, air conditioning is necessary to manage moisture loads. Perhaps the most insidious consequence of oversizing is its impact on moisture removal. An oversized air conditioner removes less moisture than an air conditioner that's properly sized. Depending on the climate and the degree of oversizing, the consequences of excess moisture range from discomfort to serious health issues, and from minor damage to structural failure.

High relative humidity provides an ideal environment for destructive fungi to thrive. Aside from the obvious health concerns, mildew left unchecked will eventually damage the host material. Paint, drywall paper and wood products are all at risk. Atmospheric moisture also affects the dimensional integrity of wood. Solid wood products such flooring and wainscoting expand as their moisture content rises. This can lead to cupping or bowing if the relative humidity gets too high.

And now the bad news: Oversizing, endemic in code-built homes, is potentially an epidemic in high performance homes. Even though most HVAC contractors have been taught the virtues of right-sizing, they can't seem to break free of their 'bigger is better' bias. As a result, high performance homes often end up with grossly oversized equipment. This not only undercuts potential energy savings, but makes these homes especially vulnerable to comfort and moisture problems.

Why Oversizing Persists

In order to address the oversizing problem, it's important to understand why the practice continues, despite the overwhelming rationale against doing so.

Fear of undersizing: How many homeowners ever complain that their HVAC system is too large? On the other hand, they're quick to complain if they believe their system is too small.

That's how I've always done it: Many HVAC contractors still size by 'rules of thumb' developed decades ago when homes were far less efficient (and forgiving). And many who use software-based load calculation tools don't completely trust the results, rounding up at every chance to protect against undersizing.

Can't afford to do it right: Equipment is typically sized during the estimating process, before the job is secured. At this point, it's hard to justify the time required to accurately model the home. Rather than tracking down detailed window, orientation and other construction details, most HVAC estimators use worst-case assumptions, resulting in larger equipment than necessary. Once a job is secured, it's rare that the contractor will go back to fine tune the load analysis.

Substituting size for quality: Comfort complaints account for more callbacks than any other issue in new construction. Contrary to popular belief, undersized equipment is rarely the problem. The major culprit is usually poorly designed and constructed ducts. Whether consciously or not, HVAC contractors tend to compensate for substandard workmanship by upsizing the source equipment.

The builder dilemma: Few builders understand the importance of proper sizing. And those who are aware that oversizing is a problem are hesitant to push too hard. The last thing a builder wants is an HVAC contractor who abdicates all responsibility for customer satisfaction.

Quality isn't free: Consider the HVAC contractor who hires top notch labor and follows best practices. In all likelihood, his bids will be higher and his systems smaller than the competition. Despite all efforts to convey his value proposition, this contractor routinely loses jobs to installers who do only what's required to meet code, a low hurdle indeed. It's difficult for builders to accept paying more for less. In this scenario, the builder may ask the low bidder to downsize his equipment, and his bid. Rather than back down on sizing, the standard response is to put doubts in the builder's mind as to whether a smaller system can handle the job. In the end, the builder usually opts for the low bidder and a larger system 'just to be safe' (see Fear of undersizing, above).

Managing expectations: Homeowners expect their air conditioners to keep their homes cool even under the most extreme conditions. And why shouldn't they? Most folks have no clue when it comes to the consequences and trade-offs associated with excess capacity. With a bit of education, most people can understand the right-sizing rationale and will adjust their expectations accordingly.

No help from code officials: Although many state and municipal building codes require load calculations to be performed, enforcement is almost non-existent. Even in jurisdictions that require loads to be submitted during permitting, inspectors aren't in a position to question or verify their accuracy. This is also a problem for energy raters, as discussed in the next section.

Financial disincentive: With no accountability, there's little incentive for an HVAC contractor to take the necessary time to perform accurate load calculations. If anything, he has the least incentive to sharpen his pencil and do it right. After all, bigger systems mean bigger contracts and bigger profits. On supersized homes with multiple systems, the status quo approach can add tens of thousands of dollars to a contract. No one seems to complain.

Outdated training: As with other building trades, the HVAC industry has been slow to embrace change. For the most part, training programs rely on curriculum materials developed decades ago. Trainers as well as those who train the trainers tend to be retired technicians who are largely unfamiliar with the unique challenges and nuances of high performance homes.

Nothing in a contractor's training or experience prepares him for homes that size out to 1,000 square feet per cooling ton, and sometimes much higher. A seasoned contractor was dumbfounded when confronted with this author's 3,200 square foot home with a design cooling load of two tons. He retorted, "That'll never work… 800 CFM ain't enough air to blow out a candle!"[3]

Verifying Proper Sizing – Easier Said Than Done

Energy Star recognized the importance of equipment sizing, at least in the case of air conditioners. When the program requirements were updated in 2006 (Energy Star 2), raters for the first time were required to verify proper sizing. In particular, raters must:

- confirm that cooling equipment is sized according to the latest edition of the ACCA or ASHRAE load calculation and sizing procedures within a specified tolerance
- confirm that the load calculations are based on a prescribed set of operating conditions (e.g., outdoor design, indoor design, and infiltration assumptions)
- confirm that indoor and outdoor coils are ARI-matched

On the surface, this policy is a positive first step. But as well-intentioned as it may be, there have been serious impediments to its implementation.

First and foremost, Energy Star raters are not specifically trained to interpret load reports, evaluate equipment sizing or verify coil match-ups. Although some rating providers have HVAC expertise on staff, this is the exception. Equipment selection is a non-trivial step in the design process. In fact, the procedure for matching equipment to load is the subject of an entire design manual.[4]

One year after raters were first required to verify correct sizing, this author contacted several HERS training programs to find out what they were doing to prepare raters for this new requirement. The answer: not much. The technical director for one program acknowledged that load calculation training was limited to a single bullet on one slide. Likewise, the RESNET National Rater Test currently includes only one question on heating and cooling design.

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[3] This home illustrates how Energy Star's 6% duct leakage requirement is meaningless when applied to a moderately high performance home. A Duct Blaster reading of 192 CFM(25) would pass muster, even though the air handler's nominal fan flow is only 800 CFM!

[4] One cannot simply compare the load with nameplate or ARI capacity to confirm an air conditioner is sized correctly. The procedure for equipment sizing and selection is documented in Manual S, Residential Equipment Selection, published by the Air Conditioning Contractors of America (ACCA).

Second, oversizing is unlikely to be caught prior to final inspection. At that point, replacing a non-complying air conditioner can be expensive. And often it's not just the outdoor unit that must be replaced. In many cases, the indoor coil and even the air handler or furnace must be replaced along with diffusers and boots. This puts the builder in a difficult position. Many Energy Star raters are opting not to enforce the sizing requirement rather than risk having builders pull out of the program.

Third, there's no way an independent reviewer can verify if a load was done correctly without doing it over again. Energy Star only requires raters to check the load for correct design conditions. At a minimum, raters should verify correct solar orientation and window specifications.

Forth, there's lots of pushback from HVAC contractors who aren't keen to having someone looking over their shoulder, especially if they don't believe the person is qualified. Moreover, many take issue with the Energy Star prescribed operating conditions, especially the 75º F indoor design temperature. Contractors are quick to point out who gets the call if the homeowner isn't happy with the air conditioner, and whose license is on the line if the system doesn't work.

Another area of contention is the requirement that the designer use the latest edition of the load calculation procedure, which in most cases is ACCA Manual J. Many HVAC contractors still use the Seventh Edition, published in 1986. This procedure is woefully outdated and totally inadequate for modeling high performance homes. For example, it predates NFRC ratings so there's no way to account for window u-values and solar heat gain coefficients. Moreover, it uses simplistic methods to estimate duct losses and peak window loads, and doesn't support high efficiency wall systems, cool roofs and other advanced construction methods. Even for homes built the old fashion way, the Seventh Edition is known to overestimate cooling loads by 20% or more.

Manual J Eighth Edition, known as MJ8, was first published in 2004 and has since undergone two major revisions. It represents a giant leap forward in residential load calculation procedures. However, many HVAC contractors don't trust MJ8 because it results in smaller loads (even though research has shown it has at least a 10% buffer). At least one major Manual J software program still allows users to select the Seventh Edition procedure, something ACCA should put a stop to.

And finally, liability is a real concern and should be addressed in advance by all parties. Each participant must assume liability for his/her own work. For example, if a rating company performs a load calculation, it must accept liability for the load. On the other hand, an HVAC contractor cannot arbitrarily shift liability for customer satisfaction (if there is such a thing) to the rater simply because he doesn't agree with the load. There are many issues beyond equipment sizing that impact comfort, and ultimately homeowner satisfaction.

Energy Star did back down on the prescribed outdoor design temperature. Although the ASHRAE method[5] is recognized by all load calculation procedures, HVAC contractors routinely design to higher outdoor temperatures. A number of contractors complained, arguing Energy Star doesn't have authority to dictate design conditions. Energy Star agreed to accept a higher outdoor design temperature if it represents prevailing local practice and does not exceed historical climate data. However, Energy Star refused to budge on the prescribed 75º F indoor design temperature.

Energy Star 3, currently in development, aspires to raise the HVAC bar even higher by emphasizing best-practice installation. This is absolutely where the home performance industry needs to go. But without a serious commitment to train, test and certify raters on HVAC competency, these new requirements are destined to become another 'unfunded mandate.'

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[5] The ASHRAE Handbook on Fundamentals includes historical climate data for more than 4,400 locations worldwide. The 1%* design temperature for a given location corresponds to the first percentile in terms of frequency of occurrence. In other words, it represents the temperature that was exceeded by 1% of the hours on average during the period of record (1972 to 2001 for the United States).

***** The Energy Star specification erroneously refers to the ASHRAE 99% design temperature, which is for heating loads.

Moving Forward – Practical Tips for Better HVAC Systems

The motivated home performance professional who endeavors to learn essential HVAC skills can make a real difference in both comfort and energy efficiency. And while it's not necessary to become a proficient HVAC designer or refrigeration technician, the successful practitioner must understand the concepts and pitfalls so he can help builders get better value for their HVAC dollars. Familiarity with the procedures outlined in ACCA Manuals J, D, S and RS would be a good start.

The following primer covers some of the most common problems and misconceptions found in residential HVAC:

More on Load Calculations and Equipment Sizing

Myth: (Builder) A mechanical engineer did the loads, therefore they must be correct.

Reality: Engineers are specialists. Mechanical engineers who specialize in HVAC design are most familiar with commercial or industrial systems and design guidelines. Although the theory is the same, design guidelines and other practical considerations don't translate well to single family homes, which are dominated by envelope loads. Moreover, designing HVAC for high performance homes is a highly specialized field. Few engineers specialize in this area.

Myth: (Builder) My HVAC contractor uses a computer-based load calculation tool; therefore the equipment will be sized correctly.

Reality: For all the reasons cited previously, the contractor has little incentive to be precise. And because software tools do a good job at hiding some of the complexities, the average user doesn't understand the underlying procedures, blindly using the tools without regard to correctness. Moreover, the builder has no way of verifying that the installed equipment matches the load. Having an independent specialist perform the load calculations avoids these problems.

Myth: The Seventh Edition of Manual J has worked for years. There's no reason to change.

Reality: Sizing equipment according to the Seventh Edition virtually guarantees oversizing. Just because homeowners don't complain doesn't make oversizing good practice.

Myth: When performing a load calculation, a block load is good enough to size equipment.

Reality: A block load analysis may yield a reasonable total load, but a careful room-by-room analysis is required in order to do proper duct design. Moreover, MJ8 includes a new software procedure that calculates the hourly window loads to determine if the zone has adequate exposure diversity (AED). The procedure adds an 'excursion' load to each room that doesn't have AED.

Myth: It's OK to oversize a furnace.

Reality: Oversized furnaces result in most of the same problems associated with oversized air conditioners. In fact, oversized furnaces have become a source for comfort complaints in high performance homes due to excessive temperature swings. As it turns out, tightening a house has a much larger impact on the heat load than the cooling load. This exacerbates what was already a problem with oversized furnaces in conventional construction in the southern half of the country. Unfortunately, manufacturers have not adjusted their product lines accordingly. In many climate zones, a heat pump is a better choice for a high performance home. Otherwise, the smallest possible capacity furnace should be selected and the duct system sized to achieve the design cooling airflow.

Myth: Equipment should be sized according to ARI capacity, using a 75% sensible heat ratio.

Reality: ARI rated capacity should never be used for sizing. ARI ratings are based on 80º F indoor temperature, 67º F entering wet bulb and 95º F outdoor temperature. Equipment should be sized based on *actual* design conditions for the project, referencing manufacturer expanded engineering data. Moreover, ARI ratings don't provide sensible or latent capacity. Using a generic sensible ratio isn't appropriate since it varies significantly from one system to another and depends heavily on the design conditions. Equipment selection and sizing procedures are outlined in ACCA Manual S.

Duct Losses and Airflow

Myth: Increasing attic duct insulation to R-8 reduces duct losses to an acceptable level.

Reality: In recently built homes, equipment and ducts located in vented attics account for more energy waste than any other single factor. When 55º F air moves past 140º F air, a little extra insulation isn't going to do much to reduce heat transfer. The worst-case scenario is an upflow unit with an 'octopus' duct system hung from the rafters. When a home is specifically designed to accommodate the HVAC system inside the envelope, the extra cost is small compared to the benefits. HVAC contractors don't push hard on this because it's easier to put everything in the attic.

Myth: Using mastic and UL tape, a good crew can install tight ducts without a leakage test.

Reality: Even the best crews make mistakes. After all, air leakage is invisible. Every HVAC company should own a Duct Blaster® or equivalent in order to perform QA on their own work. Without a way to detect leakage, no HVAC contractor should claim tight duct systems. Even with Energy Star's relatively lax requirements, duct leakage is a leading cause of failed final inspections.

Myth: Air balancing is too expensive and is unnecessary for the residential market.

Reality: It's true that air balancing is almost unheard of in the residential market. In conventional construction, even the best duct designs won't necessarily deliver the correct airflow to each room without adjustment. Without air balancing, significant room-to-room temperature differentials have become a fact of life. In high performance homes, homeowner expectations tend to be higher. But with much less air to work with, it's impossible to achieve balance by varying duct diameter alone.

Myth: A clean filter will not create a significant restriction on airflow.

Reality: This may be true for fiberglass filters, but then these filters don't do much filtering. That's why they're called bird catchers. The 5-inch pleated media filter does an excellent job cleaning the air but it can starve the blower of air, reducing system performance and efficiency and possibly cause the coil to freeze up. When selecting a filter, ignore the CFM rating and check the pressure drop (PD) specification. Even among name brand filters, the MERV-to-PD ratio is all over the map. Also, a media filter should never be installed adjacent to the return opening on the blower. Many newer furnaces and air handlers have less powerful blowers, making it necessary to flare out to a larger cross-section (e.g., side-by-side filters). Very few HVAC contractors follow this practice.

Myth: One or two returns per floor are usually sufficient, depending on the home's size and layout.

Reality: When supply air doesn't have a return path, air distribution is compromised. The return path may be a ducted return vent, transfer grill, or jumper duct. Undercut doors are insufficient except for the smallest rooms. (Return vents should never be installed in a bath, laundry, garage, crawl space, or near a cooking area.) Jumper ducts are a good solution for isolated kitchens. A pressure test should be used to identify problem rooms. Drops exceeding 3 Pascals across a closed door will impede supply air.

Myth: Flex duct is a superior product when installed correctly.

Reality: Good luck finding crews that install flex duct properly. It may be the most abused product in the HVAC industry. Flex should be limited to short run-outs from a trunk or an extended plenum.

Myth: System airflow will be adequate if the ducts are designed according to Manual D procedures.

Reality: More often than not, the as-built duct system is very different from the design, especially when flex duct is involved. Duct runs end up being longer and the friction rate (resistance) higher due to sag, compression and kinks. This restricts airflow, which slows down the blower. Inadequate airflow is the primary symptom of poor duct design. If airflow is lower than design, both total and sensible capacity will drop and overall efficiency will take a hit. One way to check for this problem is to take static pressure measurements at the return and supply plenums. Energy raters already have the necessary tools and can easily learn how to do this quick diagnostic.

Myth: Central air conditioning systems need to operate at no less than (fill in the number) air changes per hour in order to properly cool the house.

Reality: Rules of thumb never were a good way to design HVAC systems, but the low design airflow in a super insulated home stops most contractors cold. Nothing in their training or experience prepares contractors for systems delivering only 20 or 30 CFM per 100 square feet (less than 2 changes per hour). In particular, minimum velocity guidelines in Manuals D and T may not be attainable using conventional duct components. However, in the words of Hank Rutkowski, author of ACCA's residential design manuals, low velocity in an airway is among the least important things a designer should worry about.[6] Short throw patterns due to low terminal velocity can be an issue, but can be mitigated by using small high-quality engineered fully adjustable diffusers. In this author's experience, throw patterns are irrelevant in a high performance home.

Myth: Walk-in closets should always have a supply vent.

Reality: Whether or not a supply vent is needed in a closet depends on the load. Some customers demand supply vents in all large closets because of a bad experience in a previous home. However, if the closet doesn't have an exterior wall, the load may be too small to warrant a supply vent, depending on floor and ceiling exposure. Installing a supply vent in a room with little or no load will increase relative humidity in the closet (not good) and will reduce the amount of air delivered to other rooms. This is especially important to avoid in a high performance home where there's less airflow to work with. It's a good idea to install a small return vent in a low or no-load closet to ensure air circulation and humidity control. Louvered doors work well for smaller closets.

Myth: A commercial gas cooktop requires a high velocity commercial range hood.

Reality: High volume exhaust is necessary in a commercial kitchen due to heavy, continuous usage and to meet OSHA requirements. However, a range hood that exhausts up to 1,200 CFM will play havoc in a tight home. At a minimum, a nearby relief vent is required. This not only wastes energy but can create comfort issues in cold weather. In a home setting, a standard range hood operating at 250 to 300 CFM is more than adequate for even the largest cooktops. Downdraft exhaust fans should be avoided, as they require a higher flow rate to offset the impact of thermal convection.

Homeowner Complaints

Myth: Reducing air conditioner tonnage will only lead to more homeowner complaints.

Reality: Numerous field studies have shown that undersizing is rarely the cause for comfort complaints. NOTE: Proper sizing will not eliminate complaints. The system must still be designed and installed properly!

Myth: Some homeowners have unrealistic expectations when it comes to HVAC and comfort.

Reality: If homeowners have high expectations, it's only because HVAC marketing campaigns emphasize comfort without qualification. The fact is most HVAC systems do not perform anywhere close to their potential due to poor design and workmanship. Production builders report that HVAC issues generate more call-backs than anything else. Ironically, high volume HVAC contractors who are able to hang onto their production contracts may simply be the most skilled at convincing irate homeowners to accept second-rate work.

HVAC Equipment Efficiency and Operating Costs

Myth: A high performance home by definition should have a high efficiency HVAC system.

Reality: If the budget is unlimited, there are plenty of products available that will save energy. But most people have a limited budget, or at least expect a reasonable payback. The problem with most marketing hype is this: There's always the presumption that the product being promoted is the only

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[6] ACCA Manual D, Third Edition (2009), Appendix 15, Section A15-5.

energy savings measure being applied. In reality, each incremental improvement must be evaluated against a diminishing energy bill. As a cost-effective strategy, high efficiency (multistage) HVAC equipment usually isn't even close. Multistaging offers certain comfort benefits when properly applied (a big if), but those same benefits can often be achieved in other ways for less money.

Myth: Ground-source heat pumps will eventually pay for themselves in energy savings.

Reality: See previous Myth. The economic viability of a geothermal heat pump depends on many factors: soil characteristics, fuel costs and availability, heating and cooling degree days, lot size, design loads, and local labor costs (especially if wells must be drilled). In general, geothermal heat pumps are almost never cost-effective in moderate or cooling dominated climates, and especially in high performance homes with relatively small heating loads. The newly expanded tax credit for ground source heat pumps could flip this the other way in some cases. The important thing to keep in mind when evaluating high SEER equipment in high performance homes is that you're starting from an already low baseline.

Myth: Since there's no blower fan, radiant heat is more efficient than forced air heat.

Reality: The overall efficiency of a radiant heat system depends on the efficiency of the primary heat source, factoring in the additional ground heat loss in the case of a radiant slab. When homeowners ask about efficiency, what they're usually concerned with is the operating costs. But it's also important to consider installation and maintenance costs. In a moderate or mild climate with average electric rates, a heat pump typically costs less to operate than radiant or gas heat. In cold climates, radiant floors are considered to be more comfortable than forced air heat, but high-mass radiant slabs can cause overshoot during the spring and fall when outside temperatures can quickly swing from cold to warm and back. This is not just a problem in milder climates. For this reason, a heat pump combined with radiant heat offers the best of both worlds in cold climates.

Myth: Dual-fuel heat pumps (also known as hybrid heat) cost less to operate than either a heat pump or furnace because they apply the most efficient heat depending on outside temperature.

Reality: Debunking this myth requires a basic understanding of the way heat pump work. Because heat pumps extract heat from the outside air, capacity drops with temperature. Conversely, a home's heat load increases as the outside temperature drops. The temperature at which heating capacity equals the load is referred to as the balance point. Depending on the size of the heat pump relative to the design load, the balance point typically occurs between 25º and 35º F. The need for supplemental or auxiliary heat increases gradually as the temperature drops below this point.

Conventional heat pumps rely on a small electric furnace for supplemental heat, referred to as heat strips. The thermostat energizes the strips on demand. Since the heat strips operate simultaneously with the heat pump, they only run long enough to make up the difference. At 20º F, the heat pump may still be providing most of the heat. Most folks don't realize that even at 0º F, a 14 SEER heat pump has a COP (coefficient of performance) of about 2.0! The issue capacity, not efficiency.

Dual-fuel heat pumps instead rely on a gas furnace for auxiliary heat. Although a gas furnace costs much less to operate than electric strip heat, this strategy doesn't necessarily yield lower overall energy costs, especially in a moderate climate. Here's why: Because of the way gas furnaces are designed, the heat pump and furnace cannot operate at the same time.[7] This means the heat pump, while still capable of producing most of the heat, must be shut down when the gas furnace is activated. Thus, the savings from using gas heat may be more than offset by having to rely solely on gas below the balance point. The little detail gets lost in the marketing hype. On the other hand, dual-fuel heat pumps may be a good choice in cold climates where natural gas is available.

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[7] With a gas furnace, the coil must be on the downstream (supply) side of the burner to prevent condensation damage to the furnace components during cooling operation. In this configuration, the heat added by the furnace would interfere with the refrigeration cycle if the furnace and heat pump were allowed to operate simultaneously.

Taming the Elephant – Education is the Key

For the vast majority of new homes, the builder is ultimately responsible for making the decisions that determine a home's energy performance. As a result of Energy Star and other verified energy efficiency programs, builders are increasingly looking to home performance professionals for guidance. We must continue to educate ourselves so that we can meet the challenge.

Heating and air conditioning account for the lion's share of home energy use, so it stands to reason that a major part of our efforts should be directed toward helping builders make better decisions when it comes to spending their HVAC dollars. Given the history of the home performance industry and the complexities of the HVAC trade, this has proven to be exceptionally difficult to achieve.

Further exacerbating the problem is the current state of the HVAC industry, especially the new construction end of the business. It's no overstatement to say that the residential HVAC industry is broken. Moreover, the industry has failed to address the unique design challenges associated with high performance homes, leaving tradesmen mostly to their own accords. On the other hand, the home performance industry offers little more than a duct leakage test, lip service for right-sizing, and a prescription for high efficiency equipment. Good design practice is usually taken for granted.

Individually, each of us must take responsibility to become familiar with the HVAC design process from start to finish, especially the nuances of high performance homes. We must gain the respect of HVAC contractors by demonstrating our ability to deal with them on their level. This takes knowledge, experience, confidence, and above all, a spirit of teamwork. Nothing positive comes out of an adversarial relationship.

Energy Star 3, with increased emphasis on best-practice HVAC installation, will soon put an exclamation point on the need for more rigorous HVAC training for raters. As more practitioners take the initiative to excel in this area, the industry at large is sure to follow. It's time for RESNET to give serious consideration to advanced certification for HVAC competency.

HVAC-savvy home performance professionals can provide builders with ammunition to hold HVAC contractors to higher standards. The conscientious HVAC contractor with strong design skills and well-trained crews will appreciate having an advocate for high quality design and installation practice. He may be less thrilled when his new friend recommends against his most profitable high-end equipment. Be prepared to defend your recommendations with sound analysis.

Computer modeling tools such as Rem/Rate have become increasingly versatile and accurate, allowing the skilled user to quickly evaluate competing efficiency improvements. But the most egregious misapplications of resources in terms of payback can be evaluated on the back of a napkin. All that's required is a good sense of the relative contributions to the energy pie, a handle on local energy costs, and the formula to convert between kilowatt-hours and Btu's.

Payback analysis is only one dimension of the building science puzzle. Design decisions must also be evaluated against sometimes competing objectives of comfort, structural durability and safety. Moreover, home performance practitioners are increasingly being asked to consider environmental impacts. Fortunately, a properly designed and installed HVAC system will simultaneously excel in all of these areas. On the other hand, a poorly done system can drain a bank account, cause chronic discomfort, rot a home's structure, kill the occupants, and contribute to global warming!

Finally, education does not end with the builder. Home performance professionals must help builders and HVAC contractors educate the homeowner. We must provide builders with written materials to this end. For example, if homeowners were to understand the many downsides of oversized HVAC equipment, they would be more willing to tolerate an air conditioner that falls a little short on an exceptionally hot day.

About the author: David Butler, President of Optimal Building Systems, has practiced as a building systems engineer for more than two decades. During this time he has consulted with multinational manufacturers, energy utilities and land developers on a variety of research and development projects related to energy efficiency.

During the 1990's, Butler produced the syndicated column, *At Home With Technology*, which appeared in newspapers nationwide. In 2001, Butler joined Enalasys Corporation as Senior Building Systems Engineer, where he led the software team for eScan, the company's flagship product. eScan is a comprehensive whole-house diagnostic tool for HVAC contractors. While at Enalasys, Butler wrote the winning proposal for an SBIR grant from the Department of Energy to develop a low-cost continuous commissioning system for residential HVAC systems, partnering with the Buildings Technology Center at Oak Ridge National Laboratory. From 2005 until 2008, Butler was affiliated with Charlotte-based Environmental Building Solutions, a winner of the 2008 Energy Star Partner of the Year award.

Butler currently resides in the high desert in southeast Arizona where he spends most of his time designing HVAC systems for high performance homes, and riding herd on his net-zero-energy home. Butler holds a MS in Engineering and a BS in Business. He is an associate member of ASHRAE and an avid amateur astronomer.