Sizing & Selecting Equipment for Proper Humidity Control

Guidelines for sizing and selecting equipment to avoid humidity and moisture problems.

By Glenn C. Hourahan, P.E.

The leading causes for moisture/mold problems in buildings are related to envelope problems (e.g., leaks through roofs, walls, foundations, windows, and doors), minor and catastrophic piping failures (plumbing and appliance leaks), sewer backups, and floods. Sound maintenance and due diligence are required by building owners/operators to ensure that structural components have not deteriorated and that minor concerns do not become major problems. Of lesser notice, however, are the humidity and moisture problems that result from incorrectly applied and/or improperly sized air conditioning systems.

Given all that is known about the negative impacts of oversized mechanical equipment (see chart below), it is surprising that equipment oversizing is common in U.S. homes and buildings. Yet, surprising or not, equipment is still routinely installed with total capacities that are 50% to 100% to 200% greater than needed. Even though recognized industry procedures for calculating loads are in place, latent loads (caused by the infiltration of warm moist air, internal latent sources, etc.) are often inappropriately considered. This article briefly explains why oversizing occurs and outlines steps for properly selecting HVAC equipment for building applications.

Oversizing Impacts	
Comfort	**Equipment**
Marginal part load temperature control Large temperature differences between rooms Degraded humidity control Drafts and noise Occupant discomfort/dissatisfaction	Larger ducts installed Increased electrical circuit sizing Excessive part-load operation - Frequent cycling (loading/unloading) - Shorter equipment life Nuisance service calls
Economic	**Health**
Higher installed costs Increased operating expense Increased installed load on the public utility system	Potential to contribute to mold growth Potential to contribute to asthma and other respiratory conditions

Reasons for Oversizing Equipment

There are a number of explanations as to why designers and contractors specify equipment that is too large for the application. The reasons range from load calculations not being undertaken, to incorrect observance of procedures, to reliance on inappropriate rules of thumb.

- **No load calculations**

  Prior experience is used. A contractor, relying on his years of experience, is comfortable quantifying cooling and heating loads by comparing one building against similar buildings completed in the past. Yet, this guess ignores new construction materials and methods that have resulted in tighter, more energy-efficient structures. Additionally, it minimizes the increased expectations that today's occupants have for comfort and healthy environments.

  Simple replacement of "like" for "like." When replacing existing equipment, some designers simply size the replacement equipment at the same tonnage as the existing unit. However, this assumes that the original equipment was properly sized. Additionally, this approach doesn't consider whether:

  —Building functions have changed (activity type, occupancy level, intensity of appliance and equipment load, increased electronics)

  —Substantial upgrades have been made to the building (e.g., improvements in lighting, insulation, more efficient appliances, better windows)

  —Latent loads have changed substantially since the building was constructed (e.g., more plants, fountains, Jacuzzis, an indoor pool).

- **Incorrect observance of procedures**
  Mistakes in the load calculation. Even if the designer uses industry-recognized load-calculation procedures, simple computational errors, input errors (when utilizing computer programs), or incorrect building detail assumptions may result in erroneous loads.
  Use of safety factors. Many designers and contractors routinely add a safety factor—as a “just-in-case” insurance—when they complete a load calculation; perhaps they think this is a correct approach since they’ve been doing it for years and have had relatively few “non-cooling” callbacks. However, it cannot be reiterated enough—once a correct load calculation has been performed, there is no reason to add safety factors. Doing so leads to oversized equipment.

- **Use of obsolete and inadequate “rules of thumb”**
  Estimating shortcuts. Over the years, numerous rules of thumb and other load estimating shortcuts have been devised to determine equipment selection. These include:
  —Floor area per ton of cooling (such as 500 to 600 sq.ft./ton)
  —Airflow-to-ton relationships (such as 350 to 450 cfm/ton)
  —Relationship of latent load to full load (such as latent load = 30% of total capacity).
  However, “rule-of-thumb” shortcuts generally result in greatly mis-sized HVAC equipment in various building applications.

Steps for Sizing Equipment Correctly

Rigorous heat-gain/heat-loss procedures

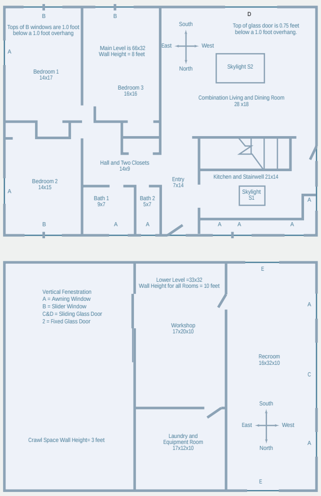
Comparative Example of Inappropriate Rule of Thumb

Using the 600 sq.ft./ton rule, a 2,800-sq.ft. home would “require” an air-conditioning system that was sized at 4.7 tons. Yet this same home, when placed in various geographic locations—with markedly dissimilar cooling needs—results in a unit selection that is 65% oversized in Tempe, AZ; 85% oversized in Tallahassee, FL; and 125% oversized in Augusta, ME. Since equipment is sized for full-load, peak-condition operation (which, for the 1% cooling design temperature, occurs for relatively few hours each year), the equipment is greatly oversized during less-hot days.

Some designers/contractors respond that this is not a concern as they use a square-foot-per-ton relationship that is appropriate for their location. However, even if a revised metric is used, it doesn’t take into account important building factors that result in significant tonnage variations between similar-sized homes in the same neighborhood, including:

- Compass orientation of the home
- Tightness of envelope
- Design (insulation, etc.)
- Tightness and location of ductwork
- Color of roofing
- Construction materials used
- Extent of glass.

Comparative Example



Log and block home: 2800 ft^2, 3 BRs, 2 BAs, NFRC glass, partial below grade, crawl space.

location / thumb	Augusta, MA	Tallahassee, FL	Tempe, AZ
600 ft^2/ton	4.7 tons (125%)	4.7 tons (85%)	4.7 tons (65%)
MJ8 Calc.	2.1 tons ---	2.5 tons ---	2.8 tons ---

are necessary to ensure that equipment is properly sized for varied applications. The proper steps for sizing and selecting HVAC equipment are:

1. Establish building design and criteria requirements.
2. Determine the design loads.
3. Do not arbitrarily increase load (safety factor).
4. Verify system capacities.
5. Evaluate latent requirements.

Wringing Moisture Out of the Space...Reduce the Airflow

The greater the difference between the indoor evaporator coil temperature and the return air wet bulb temperature, the greater the ability the coil has to remove excess moisture. How the equipment is designed, maintained, and controlled governs the coil temperature. Step 5 of this article (Considerations if Selected Equipment Cannot Satisfy Latent Requirements) outlines several strategies that manufacturers employ to reduce evaporator temperatures. An approach designers and contractors use to reduce coil temperatures is to reduce the airflow across the coil.

Reducing the airflow from a nominal 400 cfm/ton to 300 cfm/ton for a 10-ton rooftop unit, for example, results in an improved sensible heat ratio and, with only a 4% reduction in total capacity, improves the latent capability by approximately 20% (see chart below). As a more extreme example, reducing airflow from 500 cfm/ton to 300 cfm/ton improves the latent capacity by 58% at a degradation of only 6% in total capacity. Hence, lower airflow can provide an extra margin of latent capacity at a very nominal capacity reduction. Additionally, other benefits of lower airflows are reduced system noise, increased filter performance, and slightly lower energy consumption.

Impact of Airflow on the Cooling Capacity of a 10-Ton Rooftop Unit

CFM	CFM/Ton (nom)	Total Capacity (BTU/h)	Sensible Capacity (BTU/h)	Latent Capacity (BTU/h)	SHR	% Latent change (compared to 400 CFM/ton)	% Total change (compared to 400 CFM/ton)
3,000	300	120,700	79,600	41,100	.66	19.8%	-4.1%
4,000	400	125,800	91,500	34,300	.73	–	–
5,000	500	128,500	102,500	26,000	.80	-24.2%	2.1%

Equipment: 10-Ton, 11.0/11.4 EER/IPLV rooftop unit, dual-scroll compressors, HCFC-22, vertical discharge. Catalog conditions of 95F OAT, 80F/67F indoor return air, indoor fan motor heat not subtracted.

Step 1: Establish Building Design and Criteria Requirements

Before undertaking a load calculation, it is important to ascertain the type of HVAC systems that are compatible for a building and its use. This includes determining special space requirements or occupant needs or expectations:

- Duct location and level of sealing and insulation?
- Ventilation or filtration needs for asthmatics?
- Special occupant comfort and health needs?

Appearance issues, architectural design concerns, and building constraints also have an impact on the type of system that should be specified and on how the mechanical equipment can respond to the design and building requirements. In older buildings without central air-conditioning, finding space for ductwork can be challenging. As such, ductless mini-splits, high-velocity/small-duct systems, or chilled-water systems might be considered.

The overall building budget and system budget also affect the type of system, zoning, and capabilities of the equipment that will be selected. The fuel types available to the site, and relative costs, will also have an impact.

Step 2: Determine the Design Loads

A. Building Construction Parameters

With an understanding of the building requirements and the type of system to be used (e.g., central ducts, non-ducted, heat pump, air conditioning with gas heat, chilled water, etc.), the next step is to perform a rigorous load calculation using tools such as ACCA's Manual J® for residential buildings and Manual N® for commercial buildings. It is critical that the designer carefully evaluates building construction parameters and verifies assumptions about the related building details. Examples of such deliberations include:

Building envelope: How tight is the building envelope? Were sound construction practices observed? Were high-quality materials with good insulation values used in the wall, ceiling, window, and door components?

Solar orientation: The direction the building faces has a large impact on the loads experienced by various rooms. Buildings with large amounts of glazing (windows, skylights, etc.)—especially when concentrated in the South or West exposures—may have profoundly different loads than equivalent buildings oriented North or East.

Glass type and shading: When using "rated" glass, the window values from the National Fenestration Rating Council (NFRC) should be used, and not the values for generic glass. The NFRC ratings will yield a closer approximation of the actual loads. Additionally, the use of internal and external shading must be considered.

Insulation type/level: The effectiveness of the insulation in the walls, around the windows, in the ceiling, and in the basement/slab areas affects the amount of heat gain/loss within a building. A sound estimate of "R-value" for existing buildings, or judicious use of information provided on the drawings of new structures, needs to be made to ensure proper load determination. Correct determinations of the degree of effectiveness of wall sections, doors, windows, insulation, etc., will yield a more accurate load. Wrongly assuming that a building is of average construction when it is of much better construction will result in oversized equipment.

Duct tightness/location: The location of the ductwork, and its level of insulation, has a great impact on the building load. As an example, a leaky, poorly insulated duct located in an unconditioned attic can result in a need to double the equipment size to satisfy the occupied space conditions. However, observing sound duct procedures, which minimize the introduction of warm, moist air to the system, will result in a marginal impact on the load requirements. Even better is placing the ducts within the conditioned space as this minimizes the effect of any duct leaks. Leaky ducts in the conditioned space can increase room-to-room temperature gradients. However, they have less impact on energy use and latent loading.

B. Design Conditions

Observing design conditions is an important step. Outdoor design conditions should be the 1% cooling dry-bulb design point for the specific geographic location where the building is located. The indoor design conditions should be based on customer needs and requirements. As a default, designers should observe the following nominal indoor design conditions:

- Winter heating design point: 70F (21C) at 30% relative humidity
- Summer cooling design point: 75F (24C) at 50% relative humidity

The key point here is establishing the temperature differentials for use in the cooling and heating load calculations.

C. Full Load Versus Part Load

Once the load has been determined, it is important to pay attention to the sensible and latent loads resulting from the calculation. The load calculation is based on peak load conditions (the 1% design day). For summer cooling, this generally occurs on a sunny, hot day, and the peak sensible condition results from the peak dry bulb observed. However, what happens during the evening when the sun sets? What if it is raining? It is quite reasonable to expect a number of summer evenings where the outdoor condition may be in the low 80Fs with a relative humidity of 100% (it's raining!).

"Many practices, procedures, and approaches used in the past are inadequate for providing adequate moisture control."

Since the design methodology results in equipment sized for peak dry bulb temperature (the hot, sunny afternoon), the equipment is quite oversized when operating at non-peak, part-load duty (the other 99% of the time). Hence, just when latent removal capability may be needed most, it is least available. Fixed-capacity equipment, in being oversized for a part-load condition, easily satisfies the thermostat and cycles off long before moisture removal can be effected. The issue here is whether it is preferable to be a little warm on the very hottest day or have poor humidity control from excessive cycling almost all of the rest of the time.

One solution is for designers to rerun the load calculation for a reasonable nighttime, high-humidity condition (say, 83F and 95% relative humidity). Since all the building parameters (i.e., measurements, orientations, and construction factors) have already been entered into the computerized calculation method, rerunning with a revised outdoor condition is relatively quick. This new run will result in a lower total tonnage capacity, but is likely to indicate a much higher latent load (i.e., the peak latent load occurs with the peak dew point conditions). The peak dry bulb condition should be used to size the needed capacity of the equipment. However, the second run allows the ability to assess that the selected equipment can also handle the peak dew point latent load.

"Rule-of-thumb shortcuts generally result in greatly mis-sized HVAC equipment in various building applications."

Step 3: Safety Factor—NOT!

Once a load calculation has been determined and the sensible and latent loads established, there is no need to "ruin the good work" by arbitrarily adding safety factors. Routinely adding "just-in-case" safety factors of 25% to 50% to 100% is not an acceptable alternative for undertaking a proper load calculation. Other ways to ruin an otherwise good load determination include:

- *Overly conservative assumptions about the building construction details.* Purposely using "loose" or "conservative" design criteria to increase the calculated cooling requirement is unnecessary and counterproductive for obtaining the proper loads.
- *Failure to observe room and building diversity factors.* The required capacity is not necessarily the sum of the peak individual room loads. Buildings with large levels of solar glass load—especially if these windows are predominantly on one side of the structure—will have rooms with large loads that peak at different times than other rooms.
- *Upsizing equipment in the belief that bigger is better.* This is also a problem with customers who think getting a bigger unit for nearly the same money is good value. Contractors need to carefully explain the benefits of using properly sized equipment. Why should customers buy oversized air conditioners when they would not walk in oversized shoes?

Care must be observed when selecting equipment to satisfy the load requirements. For example, if the load comes out to be a 31,500 BTU/h requirement, nearly all contractors select a 3-ton (or greater) unit rather than a 2.5-ton unit. However, when moisture control is an issue, it is better to be 10% undersized than 10% oversized. As a guide, for air conditioners and heat pumps in warm climates, select equipment that is within 15% of the calculated loads. For heat pumps in cold climates, select equipment that is within 25% of the calculated loads.

NOTE: The sizing of heat pumps in very cold climates is currently being hotly debated. If the units are greatly oversized, they have poor humidity control in the summer. But if undersized, it leads to enormous strip heating requirements during the winter.

Step 4: Verify System Capacities

In verifying capacities and making the final equipment selection, all manufacturers' sizing, selection, and application guidelines must be observed. Additionally, as noted previously, the equipment must be able to meet the sensible and latent cooling requirements without being oversized. However, for controlling moisture within the building, it is crucial that the selected equipment has the capacity to handle the latent load—at full-load operation (peak dry bulb conditions) and part-load operation (peak dew point conditions).

When discussing moisture control, it is

common to refer to the sensible heat ratio (SHR), defined as the ratio of the sensible load to the total load, where the total load is the sum of the sensible and latent loads. However, there is a difference between equipment SHR (occurs at the evaporator coil) and application SHR (occurs in the conditioned space). Given that the building heat gains/heat losses are properly determined and the equipment is properly selected and sized, equipment SHR is largely a function of the coil apparatus dew point. Application SHR, on the other hand, is largely dependent on how the equipment is operated/controlled and on the latent loads generated within the building, infiltrated through the envelope, or introduced as ventilation requirements.

As the heat gain decreases, the space-sensible load decreases while the space-latent load generally remains the same. This results in a decreasing space SHR requirement (say, 0.75 going to 0.65, or lower). This means that the latent removal requirement is a higher percentage of the total load. Yet as the total load decreases, the latent capabilities of most air conditioners are unable to track the changing SHR requirements of the space.

The likelihood of a mismatch between equipment SHR and space SHR illustrates the need for appropriate design analyses to ensure that the HVAC system meets both sensible and latent loads at full and part-load conditions. This is absolutely critical when outdoor air ventilation (generally, warm and moist air) is required and/or if the HVAC system operates with continuous fan while the compressor cycles.

For example: Many commercial HVAC systems operate with continuous fan, allowing the compressor to cycle on and off based on thermostat set points (sensible control). Hence, under part-load conditions, continuous fan operation with an “off” compressor increases the evaporator temperature and could allow moisture on the coil to evaporate and be reintroduced into the building, raising the humidity level in the conditioned space.

Other factors also exist that could contribute to excessive humidity levels and a mismatch of equipment and room SHRs. These include:

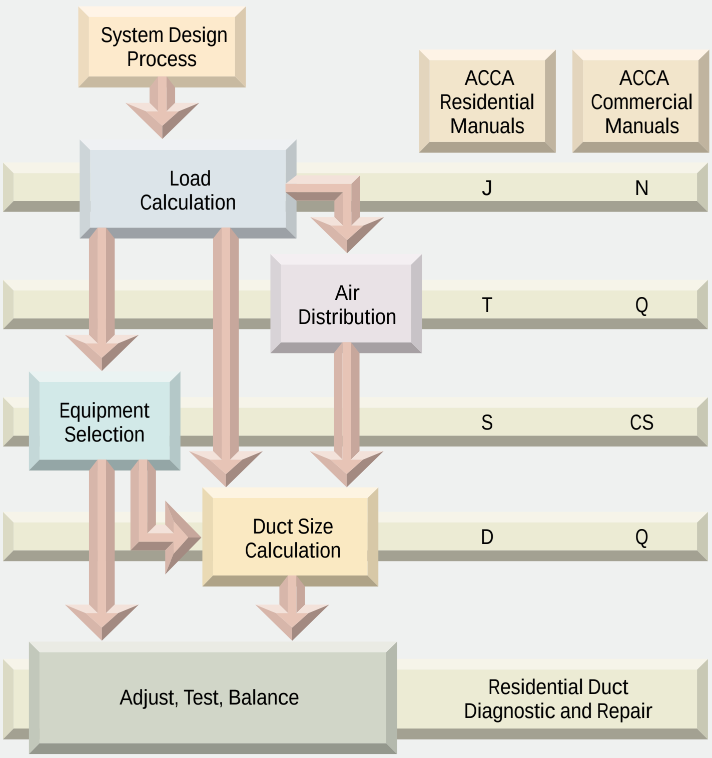
- Improper space pressurization (increases infiltration of moist outdoor air)
- High thermostat set points during unoccupied periods
- Improper system operation.

These factors need to be considered and addressed to ensure that the latent removal capability of the equipment is not overwhelmed.

Consideration of latent load requirements separate from sensible cooling load require-

Moisture Control Requires Good Overall System Design

Sizing the load correctly is only an initial step in providing proper indoor conditions. To ensure that air conditioning systems are correctly applied for occupant comfort, health, and safety, a number of industry-recognized practices should be observed. Each element in the design process is interrelated, and successful execution of one is dependent on proper completion of earlier elements. A systems approach results in better application control and customer satisfaction.



ments is not all that far-fetched. In many parts of the U.S., it is relatively common for slow-moving, low-pressure weather patterns to move in, and 70F-75F with 100% relative humidity conditions are experienced for extended periods. Therefore, with no sensible load and no call for cooling, most air conditioners provide limited moisture reduction.

Step 5: Considerations if Selected Equipment Cannot Satisfy Latent Requirements

There are a number of options to consider if a "standard" equipment selection is unable to satisfy the full-load and/or part-load latent requirements. Equipment manufacturers offer innovative options and approaches for modulating moisture:

- *Modified control strategies* that engage the cooling equipment based on humidistat demand. This could lead to a requirement for reheat to prevent overcooling in the conditioned space. Other control sequences can permit the evaporator to operate at a lower temperature.
- *Optimized equipment* that utilizes multi-speed/variable-speed indoor fan units and compressors to enable longer system runtimes. Additionally, some permanent magnet fan motors allow the contractor to set an explicit airflow. Longer operation periods provide for increased opportunities to remove moisture from the air stream.
- *Hybrid equipment* that uses wraparound heat pipes, desiccant materials, or enthalpy control. The intent is to wring out as much moisture as possible before the air reaches the primary cooling coil.
- *Optimized evaporator coils* with split-face capability or increased number of coil rows to better remove moisture. Coils with wider fin spacing allow the condensed water to drain off more quickly.

For humid applications, or where a high level of humidity control assurance is needed, designers and contractors also should consider independently controlling temperature and humidity:

- *Whole-building dehumidification equipment* (perhaps interconnected to the primary fan and using the same duct system as the air conditioning system) can independently control building moisture loads.
  (An economical dehumidification strategy for homes may be to just set up a modest-capacity dehumidifier. Yes, it rejects heat into the occupied space, but it is optimized for latent heat and runs without any additional control on the central system. The special caution here is that without a properly maintained drain line, it's up to the homeowner to keep the drain pan empty and clean.)
- *Dedicated outdoor air systems* can reduce the moisture loads that arise due to the introduction of warm, moist air for ventilation requirements. This permits outdoor air to be separated from indoor return air.

Both approaches knock out a major part of the moisture load and allow the primary coil to do a better job of sensible cooling.

Conclusion

The correct application of equipment and operational strategies can handle challenging comfort conditioning requirements and provide for proper moisture control. However, many practices, procedures, and approaches used in the past are inadequate for providing adequate moisture control in geographic areas of moderate-to-high outdoor relative humidity.

The proper sizing and selection of HVAC equipment are key to controlling humidity levels. This requires that the HVAC system meet both sensible and latent loads, not only at the design conditions (full-load), but also over a broad range of off-design conditions (part-load). Additionally, buildings with large internal latent loads need special considerations. Truly controlling moisture—as opposed to merely moderating it as a byproduct of the air-tempering process—requires dedicated equipment and controls. ■

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