
White Paper

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Introduction and Purpose

The Consortium for Energy Efficiency (CEE) has developed the Specification of Energy-Efficient Installation and Maintenance Practices for Residential HVAC Systems. The primary purpose of this Specification is to guide contractors and technicians in the installation practices that impact the energy use of HVAC systems. A secondary mission is to improve system durability and life span to conserve the energy embodied in the system’s components. This project has two final products: The illustrated Specification and this White Paper.

The purpose of this White Paper is to 1) explain process used to derive the Specification, 2) explain and defend certain elements of the Specification, 3) discuss obstacles to industry adoption of best-practice HVAC installation, and 4) recommend HVAC industry changes that will enhance market transformation.

This White Paper includes most of the sections of the Specification. The acknowledgements; foreword; table of contents; abbreviations, acronyms and definitions; and quick reference tables are not reproduced in this document. The Specification as it appears in this document is annotated with comments regarding sources, justification, and discussion of the Specification’s elements.

The Specification Development Process

Project Scope

Over the last decade building scientists have discovered that a highly efficient HVAC heating and/or cooling unit can be rendered inefficient as a result of poor installation or a faulty distribution system. Researchers have discovered that it is important to judge HVAC installations not only by the equipment installed but also by the manner by which it is installed. For example, a high-efficiency condensing furnace unit with a high degree of duct leakage to the outdoors results in an inefficient heating system that wastes the homeowner’s and nation’s energy.

Government standards, such as the National Appliance Energy Conservation Act (NAECA), have dictated space heating and cooling unit efficiency ratings for years, but researchers have found the overall efficiency of space cooling systems can be degraded by as much as 35 percent (as much as 16 percent for heating systems) because of poor installation practices. In other words, the weak link in the HVAC system chain is often not the HVAC unit; it is the faulty installation. The Specification is an attempt to upgrade poor HVAC installation practices in the residential sector.

The details and the scope were well defined during the first month of the project and refined as the project progressed. The Specification would 1) address the residential market sector only; 2) address the topics of central cooling equipment, central gas-fired heating equipment, and ducted distribution systems; and 3) only cover practices that impact energy use in the short- or long-term. It was decided to exclude topics that were already addressed by other existing documents, including health and safety, venting appliances, and electrical wiring.
Overall Project Process

The development of the Specification of Energy-Efficient Installation and Maintenance Practices for Residential HVAC Systems involved dozens of people and required many months of work. The project manager at CEE was Denise Rouleau, the primary project contractor was Rick Karg of R.J. Karg Associates (Topsham, Maine) and the subcontractor was John Krigger of Saturn Resource Management (Helena, Montana).

Early efforts were made to include important national experts, organizations, and manufacturers of residential HVAC equipment.

Near the beginning of the project, we attempted to identify potentially contentious Specification practices and elements and prepare strategies for integrating these elements into the Specification. These elements included load calculation and equipment sizing, the use of duct board and liner, methods for checking refrigerant charge, and methods for checking indoor coil airflow. The strategies were formulated with the primary objective of reaching a consensus about these difficult issues.

Two drafts of the Specification where distributed before the final Specification was completed. Before the first draft was released for review, a “matrix” of the Specification elements was circulated for comments from the three reviewing groups. This matrix, or table of the practices and elements, listed each element along with potential savings from the element, required verification test method, maintenance required, and issues/comments. The matrix reduced the Specification to five pages, providing a fast, but thorough way for reviewers to critique the work in process.

After the matrix, the first and second drafts of the Specification were distributed for review. The three groups of reviewers responded by e-mail, mail, telephone, and fax. In a number of cases, the members of the CEE Residential HVAC Quality Installation Specification Subcommittee responded by telephone conference call.

Reviewers and Consultants

CEE Residential HVAC Quality Installation Specification Subcommittee

Many of these individuals represented member organizations of the Consortium for Energy Efficiency. This group fulfilled many important needs for this project:

1) They advised the project manager, Denise Rouleau, regarding the direction and scope of the project,
2) They reviewed the many draft and final project documents,
3) They supplied the project contractors with research documents and expert consultation, and
4) They helped advise the project contractors during the project.

The active members of the subcommittee were:
Andrew Fisk, New York State Energy Research and Development Authority
Marshall Hunt, Pacific Gas and Electric
Consultants and Experts

Rick Karg and John Krigger, the authors of this document, selected this group of consultants and experts. We contacted experts on an as-needed basis as the project progressed. Most of the consultation was done over the telephone. These individuals 1) helped determine what elements should be included in the Specification, 2) provided content for the Specification’s elements, and 3) reviewed various draft editions of the Specification. The consultants and experts were:

Michael Blasnik, consultant, MA
Bob Davis, Ecotope, WA
Tom Downey, Proctor Engineering, CA
Rob Falke, contractor/trainer, CA
Doug Garrett, Building Performance and Comfort, TX
Bruce Manclark, Delta-T, Inc., OR
Gary Mazade, Energetechs, MT
Leon Neal, Advanced Energy Corporation, NC
Gary Nelson, The Energy Conservatory, MN
Jack Orum, contractor/trainer, NC
Danny Parker, Florida Solar Energy Center, FL
John Proctor, Proctor Engineering, CA
Ron Rothman, The Energy Conservatory, MN
John Tooley, Advanced Energy Corporation, NC

Industry Advisors

The CEE Residential HVAC Quality Installation Specification Subcommittee and Denise Rouleau, the project manager, selected the industry advisors. The members of this group were used to review the various drafts of the Specification. In a few cases, the project contractors telephoned members of this group to ask specific questions. The panel of industry/organization experts were:

Terry Chapp, Modine Manufacturing Company, VA
Bill McCoullough, Lennox Industries, TX
Eli P. Howard III, SMACNA, VA
Jeff Johnson, The New Buildings Institute, WA
Tom Johnson, Lennox Industries, TX  
Joel Kinsch, North American Technician Excellence, Inc. (NATE), OK  
Dave Lewis, Lennox Industries, TX  
Bill Pennington, California Energy Commission, CA  
Hank Rutkowski, Air Conditioning Contractors of America, OH  
Dick Shaw, Consultant for Air Conditioning Contractors of America, MI  
Jeff Warther, Carrier Corporation, NY  
Craig Wray, Lawrence Berkeley National Laboratories, CA

**Project Process**

The process for the writing of the *Specification of Energy-Efficient Installation and Maintenance Practices for Residential HVAC Systems* included dialogue among many people and the review of many draft documents. Most of the people who were involved are listed above. The schedule of documents is listed below.

There was an effort to work in association with other organizations during this project and incorporate their objectives, as much as possible, into this *Specification*. One of these organizations was the North American Technician Excellence, Inc. (NATE), and Air Conditioning Excellence HVAC certification program. The only section of the *Specification* that is not included in the current NATE certification guidelines is duct blowers and their use. As a result of this *Specification*, NATE is attempting to include duct blowers in their future guidelines.

The contractors of this project also worked closely with Mia South of the EPA ENERGY STAR program. Ms. South was project manager for the ENERGY STAR *Specification for Existing Ductwork* during the period the CEE *Specification* was written. Throughout there was a free exchange of information. Each project had impacts on the other. One of the project contractors, Rick Karg, and Ms. South co-presented a workshop at the Affordable Comfort Conference in Ohio in April 2000. The workshop was called “Residential HVAC Installation;” it overviewed the elements of this *Specification* and the Energy Star *Specification for Existing Ductwork*.

Face-to-face meetings and conference telephone calls with available members of the CEE Residential HVAC Quality Installation Specification Subcommittee were held at various times during the ten-month project duration. These meetings were used to refine the project direction and comment on draft documents.

The schedule of project milestones, with the authors’ comments, follows.

- **Initial White Paper ideas for review, 8/2/99.**
  - At this time, the White Paper was a plan for the project, rather than an overview of the project and its process.
- **Pre-draft of White Paper for review, 9/3/99.**
  - This document was incomplete. It was sent to members of the CEE Residential HVAC Quality Installation Specification Subcommittee for comments.
- **Matrix as a skeletal structure of the elements for the Specification, 10/4/99.**
This matrix or table was a very effective and efficient manner of communicating the intended Specification elements to project reviewers. In the final version of the Specification, these tables were renamed “Quick Reference Tables.” This was the first document that was distributed to all the reviews.

- **First draft of Specification without illustrations and sidebars, 11/17/99.**
  - This first draft of the Specification, without illustrations or sidebars, was the next review step beyond the matrix of Specification elements. The many comments from the matrix review were incorporated into this draft.

- **Second draft of Specification with illustrations and sidebars, 1/28/00.**
  - This draft received more attention from reviewers than the first draft without illustrations. This version looked more like a finished document and allowed reviewers to get a good idea of what the final Specification would look like.
  - It was at this time that Denise Rouleau, the project manager for CEE, articulated that we were having some difficulty conceptualizing the final Specification because we were caught somewhere between a pure specification—straight forward best-practice elements with no embellishments—and a training document. We had moved beyond a pure specification in the direction of a training document with the addition of illustrations and annotative sidebars. Ms. Rouleau’s observation helped us decide what would be included in the final version of the Specification and also helped us envision the ways in which the Specification will be used in the future.

- **Final Specification with illustrations and sidebars, 4/17/00.**
  - The final version of the Specification went into e-mail circulation on April 17, 2000. It was distributed to the CEE Residential HVAC Quality Installation Specification Subcommittee and the members of the panel of industry/organization experts for review. Although it was intended as the final version, some minor corrections and alterations were made by the authors independently and also at the request of the project manager based on reviewers’ comments.

**Practices selection process**

The process of selecting the best practices differed depending on the character of the Specification element or practice. The authors found it useful to break the potential practices or elements into four categories:

1) **Conventional elements/practices with conformity in execution**

These are proven standard practices for which there is common industry agreement regarding execution. These practices are commonly accepted and would probably be carried out in a similar manner by a divergent group of installers or technicians.

Examples include furnace filter maintenance, setback thermostat installation, and refrigerant line insulation. The sources used for these items included existing standards and codes, standard industry manuals, and HVAC texts.

The process of selection for these practices included determination of the most credible source and verification by reviewers.

These practices were the least likely to be contentious among industry reviewers.
Although this category includes common accepted practices, there is no assurance that these practices will be executed properly in the field—actually, poor installation is common. Examples include the installation of duct board or liner and provision for access for future maintenance of equipment. Because of the often-observed differences between the way an element should be installed and the way it actually is installed, we thought it necessary to include in the Specification even the simplest and obvious installation practices that impact energy use.

2) Conventional elements/practices with divergence in execution

These are proven standard practices for which there is industry disagreement or confusion regarding execution. These practices are commonly executed, but would probably be carried out in different ways by a divergent group of installers or technicians.

Examples include airflow measurement and refrigerant charge testing. The sources used for these items included existing standards and codes, standard industry manuals, HVAC texts, recent research, HVAC consultants, and industry experts. Many practices that fall into this category are relatively complex test procedures requiring a rigorous protocol for proper execution.

The process of selection for these practices included determining the most credible source, reviewing the latest relevant research, sorting out differences in required methods and equipment with the help of HVAC consultants and industry experts, and final verification by reviewers.

Some of these practices were contentious among industry reviewers.

The authors found these elements/practices to be the most curious of the four types listed here. It is easy, for example, to understand the ignorance or confusion regarding new practices, but what is the reason for confusion surrounding conventional practices? We suppose it is primarily do to the relative complexity of some practices, lack of proper training, conflicting information from manufacturers, lack of proper testing equipment, and the lack of understanding by the technicians and the industry educators of the importance some practices (for example, the importance of efficiency gains from ensuring proper coil airflow and refrigerant charge).

3) New elements/practices

These are proven practices that are just beginning to make their way into the industry. Because few installers or technicians have knowledge of them, there is not agreement regarding execution. Training organizations must integrate these practices into their programs and standards and codes must include them before they will become common practice.

Examples include duct blower use, duct leakage testing, and the use of durable duct sealing materials rather than duct tape. The sources used for these items included recent research, test equipment manuals, HVAC consultants, and industry experts.

The process of selection for these practices included determining of the most credible source, reviewing the latest relevant research, sorting out differences in required methods and equipment with the help of HVAC consultants and industry expert, and final verification by reviewers.

4) Elements and practices under development

These are unproven practices that are under development and show good potential for future use. No elements or practices of this type are included in the Specification.
The primary example of this category for this project is the airflow plate under development by The Energy Conservatory. The future integration of this device into the HVAC industry is likely, but field-testing is still under way, so it was not appropriate to include it in the Specification. (Ten years ago, the duct blower would have been included in this category, but now its viability for accurate duct leakage and airflow testing has been clearly demonstrated).

In the first draft of the Specification the authors included this device under airflow verification, with the hope that the field-testing would be completed by the final draft.

**Overcoming Obstacles to Industry Adoption of Best-Practice HVAC Installation: Making Market Transformation Work**

**Introduction**

As a result of this project, we learned many lessons about the obstacles and solutions to the adoption of best-practices equipment installation. Writing the specification, as arduous a task as it was, was simple compared with facilitating adoption of the Specification practices into the market place.

Many of the obstacles to industry adoption of best practices are interrelated. For example, the resistance of contractors to use complex—but necessary—test procedures is directly related to lack of adequate training.

The most effective market transformation activity available is the creation additional customer demand for best-practices installation of residential HVAC equipment and systems. This can be done by:

- Adopting this Specification as a requirement for residential installation. This can be done by local, state (state energy and/or building codes), and federal (e.g. low-income weatherization and related programs) governments and by local (housing authorities) and regional (energy utilities) organizations.
- Educating HVAC contractors regarding the efficacy of best-practices HVAC installation.
- Informing HVAC manufacturers that it is to their benefit in the long-term to promote the proper installation of their equipment.
- Informing customers that the best price is not always the best value. They need to have a better idea of the ways that best-practices HVAC installation can benefit them. This in turn will increase the demand for contractors using best-practices installation methods.

As best-practices HVAC installation becomes more common, installation methods will become more efficient, installation prices will decrease, and high quality installation will become more competitive.

Below is a discussion of the most notable obstacles to the adoption of the Specification. We have included suggested solutions to these obstacles; strategies for transforming the market to ease the adoption of this best-practices Specification and increase general residential HVAC system efficiency.
The general market segments and topics addressed are:

1) Contractors, installers, and technicians;
2) Manufacturers and suppliers of HVAC equipment;
3) Residential customers; and
4) Industry standardization.

**Contractors, Installers, and Technicians**

*Lack of adequate contractor training and professional standards*

**Obstacles**

Some of the elements of the *Specification* require test verification procedures that are unfamiliar to the average HVAC installer and technician. Examples are duct blower use for accurately determining airflow across an indoor cooling coil and for finding the leakage from ducted distribution systems. This unfamiliarity is due to the relative newness of some of the equipment required, the complexity of test procedures, the high opportunity cost of training, and to the substantial cost of the equipment.

In addition, contractors, installers, and technicians probably are not aware that best-practices installation can be good for them, at least in the long-term. Marketing education is also needed here.

**Solutions**

Of course, a deficiency of training can be solved by providing high quality training to all those in need. Training can only be appraised by its ability to enhance performance. If a trainee scores well on the exam, has fun, and meets new colleagues, it does not always lead to enhanced performance. A trainee’s performance must be evaluated after the training before the training regimen can be called successful.

Adequate training can help 1) convince members of the residential sector of the HVAC industry that these unfamiliar methods are important, 2) help installers and technicians feel more comfortable with complex test procedures and equipment, 3) introduce best-practice installation methods to the industry, and 4) increase the general competency of the trained individuals.

The North American Technician Excellence, Inc. (NATE) Air Conditioning Excellence HVAC certification program is likely to help eliminate this deficiency of knowledge. Its new certification program combines the knowledge and expertise of two industry leaders—Air Conditioning Contractors of America (ACCA) and Refrigeration Service Engineers Society (RSES)—under the umbrella of NATE, the nationally recognized, independent certification organization. NATE does not offer educational programs; they certify and publish detailed lists of the knowledge areas needed to earn certification.

Joel Kinsch, the Director of Technical Development for NATE was one of the participating reviewers of this *Specification*. Mr. Kinsch stated during the end of the review process that the only element in the *Specification* that is not now part of the NATE certification standard is duct
blowers and related testing. He said he intends to add duct blowers to the certification requirements.

We strongly believe that technicians need the equivalent of two years of classroom instruction, laboratory exercises, and supervised field training before being certified to work unsupervised. Best-practices, performance-based HVAC training must be focused on an appropriate industry standard. We recommend that the North American Technician Excellence, Inc. (NATE) Air Conditioning Excellence HVAC certification program be used as such a standard.

The authors of the Specification found a surprising degree of dissonance within the industry regarding some of the test verification and equipment maintenance methods. The ACCA manuals referenced here total almost 800 pages and the most popular HVAC textbook (Whitman and Johnson) contains over 1000 pages. Many of the energy problems, specifications, and testing procedures covered in the Specification are not covered in these industry standards and constitute an additional obstacle to understanding by technicians.

The energy and comfort problems noted in this White Paper and in many of the references listed in the bibliography stem from technicians’ incomplete understanding of HVAC operating principles and best practices. This lack of understanding is not surprising, considering how difficult it is to find accurate information about key topics like refrigerant charge and airflow.

Contractors must be informed of the efficacy of best-practices HVAC installation. Contractor adoption of best-practices installations can result in more comfortable customers, fewer calls-back, greater product/service differentiation, increased business diversification, and increased profits.

The high opportunity cost of training for contractors is a major obstacle to adequate training, especially for smaller contractors. The expense of training includes the cost of the training itself, the associated travel expenses, and the associated lost production time (opportunity cost). Many contractors have difficulty justifying this cost, especially in the short-term. If local codes require NATE certification, all contractors will be forced to train their installers and technicians, putting all contractors on a more equal footing regarding the burden of training costs.

Existing professional and trade organizations should be encouraged to adopt and promote best-practices installation methods (the efforts of NATE are exemplary). The formation of new professional and trade organizations with the objective of promoting the use of best-practices installation should be encouraged.

As demand for best-practices HVAC installation is fostered by other market transformation efforts, the demand for better HVAC education will increase.

**High cost of required equipment**

**Obstacles**

The most notable equipment cost obstacle is the duct blower. The three US manufacturers of duct blowers charge between $1300 and $1800 for this equipment. An associated cost is the training and technical assistance. Although this cost is not out of reach for most HVAC contractors, it is high enough to warrant strong justification, especially by smaller contractors.

The Energy Conservatory (TEC) sells more duct blowers than the other two manufacturers (Retrotec and Infiltec), by far. Since 1989 they have sold over 1000 units. Rob Nevitt of TEC
estimates that 80 percent of these Duct Blasters® have been sold to HVAC contractors. Assuming the other two manufactures have sold a combined 200 duct blowers to HVAC contractors, a total of 1000 contractors owning duct blowers is a very small percentage of the approximately 35,000 to 50,000 HVAC contractors nationwide. Of course, just owning a duct blower does not mean it will be used: It is probably safe to say that fewer than 50 percent of the units owned by HVAC contractors are used regularly.

The very low percentage of duct blower ownership and use by HVAC contractors is probably not only due to the high cost of the equipment. Additional reasons might include unfamiliarity with the equipment and its usefulness and questions about its accuracy in determining airflow rates and duct leakage.

**Solutions**

Additional demand for equipment for best-practices installation might reduce the high cost of some of the required test equipment.

In addition, as more HVAC contractors engage in best practices installation, resulting the increased demand for this equipment, the equipment prices are likely to decrease.

**The design process**

**Problems**

In the commercial sector, it is common practice for HVAC engineers to work with architects. These engineers select the proper equipment for the job, write specifications for equipment installation, and make certain that there is adequate room for the equipment and ducted distribution system.

The residential design process works differently. There is often little concern for best-practices equipment installation and it is rare that installation specifications are written or followed. In addition, because adequate space is infrequently provided for the HVAC equipment and the ducted distribution, HVAC installers must finesse the installation of the HVAC equipment and ducted distribution, sometimes with poor results.

We have found during our discussions with contractors during this project (and during training sessions we have conducted with HVAC installers) that the load calculation and sizing procedures required for best-practices design and installation are overly complex for many. However, few deny that accurate load calculation and sizing are important, especially for comfort cooling equipment.

The most common method used for load calculation is *Residential Load Calculation: Manual J* by the Air Conditioning Contractors of America (ACCA). As a result with some inaccuracies with this method, ACCA intends to revise this manual within the next few years. ACCA officials have stated that the revised method—the 8th edition—will be more complex than the current method and will require computer software. This increased complexity is likely to increase the resistance to this method within the residential HVAC industry.
Solutions

We suggest that whenever possible, the HVAC equipment installers 1) be encouraged to use this Specification and 2) be involved in the overall building design process to ensure adequate space for equipment, ductwork, and installing workers.

Regarding the complexity of load calculation and equipment sizing: We have found that many equipment suppliers offer the free service of load calculation and equipment sizing to their regular HVAC contractor patrons. This service is especially helpful to small contractors who are less likely than larger contractors to have a specialist on staff who calculates loads and selects equipment. We suggest that suppliers, who are more apt to find the required computer affordable than their small contractor patrons, be encouraged to offer this value-added service. It is good for their contractors and good for them.

If a contractor uses such a service, it is very important that the information they give to the supplier about the details of the building be accurate; the supplier has no way of knowing if the input data from contractor is correct or not. Although we have no research that appraises the accuracy of equipment selection resulting from the involvement of the supplier, we expect there are mixed results. Supplying contractors with forms for data-entry information and encouraging contractors to submit accurate information might increase the accuracy of suppliers load calculations.

With the increasing complexity of the Manual J procedures, perhaps the best hope of getting heating and air-conditioning systems accurately sized is to create a simplified procedure that can be completed in a few minutes from tables or a slide rule. This is difficult—if not impossible—to do on a national level because of the variations of weather. However, the development of regional simplified procedures with acceptable accuracy might very well be possible. We think further exploration of this simplification is important.

Manufacturers and Suppliers of HVAC Equipment

Manufacturers’ concern for proper and efficient installation and maintenance of their equipment

Obstacles

We suspect that some manufacturers are not concerned about the quality of installation of their equipment. This apparent lack of concern by some manufacturers for the efficient operation of the whole system is unfortunate and adversely affects the industry and customer.

Solutions

HVAC manufacturers should be informed and reminded that it is to their benefit to promote the proper installation of their equipment. They should be encouraged to adopt a broader conception of the “equipment sale” and the HVAC systems of which their equipment becomes a part. If a well designed, durable, and efficient piece of equipment is installed poorly, the resulting poor overall system performance can reflect negatively on the manufacturer.
The manufacturer’s involvement should not end with the sale. Manufactures should work with their “agent” installers to ensure that the equipment is installed according to best practices. This idea extends the time frame of the sale from when the equipment leaves the equipment supplier to when the installer finally checks out the equipment and the installation. The time frame can be extended even further to the proper maintenance of the equipment and system for the duration of the equipment’s useful life.

Manufacturers should require—or, at least, strongly urge—classroom and laboratory training for contractors, installers, and service technicians. They should provide more field technical trainers to help contractors with on-the-job training. Finally, manufacturers’ representatives should inspect a small percentage of jobs and provide feedback on how the contractor should improve practices. If all manufacturers would agree to do this, installation prices would rise but they would rise for all contractors. This cost increase would reflect added time and materials needed to attain an acceptable standard that is higher than today’s mostly unacceptable standard.

If one manufacturer requires training and another does not, the manufacturer requiring training is at a competitive disadvantage in the short-term, but probably not in the long-term. If this practice becomes routine, any competitive disadvantage borne by one manufacturer will vanish. Building codes could require proper installation training for contractors, or at least require certification by NATE. This would raise the standard for all manufacturers and installers, in turn moving the industry much closer to best-practices installation.

**Suggestions for the addition of feedback devices and information**

Manufacturers should consider building instrumentation into their air handlers and outdoor units to aid technicians in diagnosing comfort and energy problems. For example, manufacturers could include an inexpensive manometer for measuring external static pressure, and thermometers for measuring supply and return air temperatures. These “feedback devices” would be a great benefit to technicians and customers.

In addition to posting normal equipment pressures and temperatures on the nameplate and adding feedback devices for temperature and pressure, if the manufacturer included a label with a table of air handler static-pressure-versus-airflow, the technician would know appropriate static pressure, estimate airflow, and measure temperature change across the air handler in less than 5 minutes (or even over the phone with the help of the customer). A customer could note a change in the installed static pressure and temperature difference and relate it to a comfort or energy problem in the same way educated drivers note changes on their dashboard gauges.

Manufacturers and suppliers should be encouraged to assist in making the equipment selection process easier. They could do this by issuing bulletins with suggested equipment selection and settings based on a few sets of climactic parameters. Separate short bulletins for several climate region could go a long way to improving equipment selection by contractors and designers.
Residential Customers

Lack of consumers’ knowledge

Obstacles
Generally, the customer has no knowledge of the importance of best-practices installation of HVAC equipment. They do not know of the potential efficiency gains, the increased durability of equipment, the increased comfort levels, or the possibilities of lower long-term costs. Of course, if customers have no cognizance of the benefits of best-practices installation, they will not demand it.

Solutions
Customers must be educated regarding the benefits of best-practices HVAC installation. If they are aware, they are more apt to demand it and keep a watchful eye on HVAC installers and technicians. The North American Technician Excellence (NATE) association is now attempting to educate HVAC customers as part of their certification program. "We want to create interest and demand for certification on the consumer side of things. . .We are stepping up consumer awareness campaigns and have already reached 51 million readers in 30 states.’ A stronger interest in and understanding of the certification among consumers would help to contribute to the success of the program, as well as the success of the certified technicians. HVAC contractors, manufacturers, suppliers, and organizations interested in market transformation should support this effort by NATE.

Customers often look for the lowest price

Obstacles
Of course, HVAC contractors are in business to make a profit. They are under constant pressure from competitors. Unfortunately, in the short-term, doing the best work does not always yield the highest rate of profit. The best practices of HVAC installation included in the Specification result in highest system efficiencies for the equipment installed and lead to greater long-term retention of system efficiency. But best-practices contractors are not always rewarded with the job, especially when the competition is underbidding by hundreds of dollars because of inferior installation practices.

Solutions
Attempts should be made to create demand for best-practices installation of HVAC equipment. This will change customers’ perceptions that the lowest cost is the best value.

Best-practices installation should become part of appropriate codes and code officials should be trained to look for installation quality during their inspections.
Industry Standardization

The lack of standardization within the HVAC industry contributes to the difficulty of developing curricula and educating technicians. For example, the industry uses as many as ten different units of measurement for pressure. This makes the important concept of pressure difficult to teach and understand. To simplify this, we suggest that the industry adopt the metric Pascals/kiloPascals units and discontinue using the other units.

Another area of confusion is terminology. For example, there are a number of alternative terms for describing the service valves on a condenser and for describing other components of HVAC systems. The industry should produce a new, complete glossary and encourage manufacturers, trade schools, authors, and technicians to use a single term to describe each unique component. The uniformity that NATE certification will bring to the industry is likely to cause some of this dissonance to dissolve.

Another important standardization opportunity is for the industry to agree on steps and measurements to be taken during both installation and service calls. This might include a standard stick-on label, signed by the technician, certifying that the measured values listed on the label are correct. The values listed on this label might include total external static pressure, airflow, and temperature difference across indoor coil or heat exchanger. For air conditioners and heat pumps, label values might also include: indoor wet-bulb temperature, outdoor dry-bulb temperature, suction pressure and boiling temperature, head pressure and condensing temperature, superheat temperature, and subcooling temperature. (It isn’t necessary to measure all these parameters on every job and parameters listed depend on the charge-checking method used.) For gas furnaces, label values might also include: steady-state efficiency, percent oxygen or carbon dioxide, carbon monoxide ppm, flue-gas temperature, gas input, and chimney draft.

Another recommendation regarding standardization is the creation of a compendium of operating parameters for all popular models of air conditioners and heat pumps that goes back 15 years or more. Technicians often work on systems for which key manufacturing parameters are not available, such as: airflow and static pressure relationships, charge-checking and charging procedures, and heat pump performance-checking procedures for use during the heating season. This lack of information makes it difficult or impossible for them to make sure the equipment is operating at its highest efficiency. A compendium of operating parameters would eliminate this deficiency.

Major Specification Resource Documents

A handful of documents served as the major resources for the Specification. These resources are listed and discussed in this section. Scores more served as resources for the details of one or two Specification elements—these are cited at the end of this White Paper.

General Resources


This document served as a good overview document for the Specification. It was helpful as a format guide and a guide for selecting the elements to include.

This is probably the best textbook addressing the topics of the Specification. We used it as a resource when we needed clarification regarding an HVAC procedure, such as subcooling.


This document addresses most of the elements included in the Specification. We relied on it heavily for specification language, especially for the more conventional elements.

**Comfort Cooling Systems Resources**


This important paper, a literature overview and analysis by Neme, Proctor, and Nadel, written in February 1999, was funded by US EPA’s ENERGY STAR program. It served as a starting point for our research for the topics of comfort cooling systems and duct efficiency, leading us to other important documents.

From the studies they reviewed, Neme et al compile energy efficiency increases resulting from correcting the installation problems. We cited most of these potential efficiency gains in the Specification.

**Comfort Heating Systems Resources**


This was the best work we found for comfort heating systems (we found very few research papers addressing comfort heating efficiency gains from improved installation practices). Thorne’s thorough overview and analysis of potential installation efficiency gains lead us to other documents and gave us a skeletal structure for the Specification section on gas furnaces.

**Residential Ductwork**


This document, in the form of a matrix, served as a guide throughout the Specification writing process. We exchanged information with Mia South of EPA during this project. We used the specifications developed by Ms. South and her group of consultants for existing ducts and also as points of reference for our specifications regarding new ductwork.

This resource served well as a starting point for many of the verification test procedures included in the Specification. In addition, we found it very useful for installation practices of comfort cooling and heating systems.

Chapter 3 of this document addresses installation of residential ductwork. It was found useful enough to include as a companion document to the Specification.


This document served as an excellent source for recent research and thought, especially regarding ductwork. It served as a guide for the ductwork section of the Specification.

Annotated Specification

The annotations in the following Specification are of this text format.

The annotations either list the source of an element of the Specification or explain background regarding the process of selection of an element.


Chapter 1 – Abbreviations, Acronyms and Definitions

This section was not included in this White Paper. Please refer to the Specification of Energy-Efficient Installation and Maintenance Practices for Residential HVAC Systems for details.

Chapter 2 – Introduction

2.1 Introduction.

A growing body of evidence suggests that most heating, ventilating, and air-conditioning (HVAC) equipment – both standard and high efficiency – is improperly installed, with significant adverse consequences on residential equipment efficiency. Recent studies demonstrate that the manner of equipment installation may have a greater impact on actual equipment operation than its efficiency rating. Improved installation practices not only significantly increase system efficiency, they can also enhance occupant comfort, increase occupant health and safety, reduce equipment and maintenance costs, allow equipment downsizing, increase the installer’s profit margin, and increase equipment life.
2.2 Applicability.

This specification addresses the installation of residential space cooling, space heating and air-distribution systems. The focus is on the energy efficiency of newly installed systems and existing systems, and the long-term maintenance of the efficiency of systems. It also addresses the interaction of the components within systems.

2.2.1 Air Conditioners and Heat Pumps. Space-cooling equipment is addressed, including packaged systems, split-system cooling-only and heat pumps. The major elements addressed are equipment location, sizing, coil airflow, refrigerant charge, controls and maintenance of efficiency.

2.2.2 Gas Furnaces. Ducted central gas furnaces are covered. The primary items addressed are equipment location, sizing, heat exchanger airflow, controls and maintenance of efficiency.

2.2.3 Ducts and Air Handlers. Forced-air ducted distribution systems for both space cooling and heating are addressed. The major items covered are location, sizing, duct and plenum tightness, duct insulation values and maintenance of distribution efficiency.

For each of the specification elements, a verification method is provided. A number of the elements only require visual verification. Others, such as furnace heat rise, require verification with the use of inexpensive equipment and a simple test.

Finally, in some cases (such as duct leakage) more complicated test procedures are necessary for proper verification. When selecting these more complex test procedures, the most practical and accurate procedures were chosen for this specification, without losing sight of the cost of test equipment and the relative complexity of the methods.

2.3 ENERGY STAR® Specification for Existing Ductwork.

This Installation and Maintenance Practices for Residential HVAC Systems, where appropriate, complies with ENERGY STAR Specification for Existing Ductwork. For information about this ENERGY STAR Specification, call 888-STAR-YES or visit the ENERGY STAR web site at www.energystar.gov.

2.4 Relation of this Specification to Other Codes and Standards.

This Standard is intended to meet or exceed existing codes and regulations and to conform to accepted building practices. It is not intended to replace existing codes and standards. The contractor should comply with all relevant codes, standards, and manufactures’ specifications.

2.5 Quick Reference Tables.

The following quick reference tables list the elements of this specification. The Quick Reference elements are keyed to the numbers of the Specification text.

The Quick Reference Tables are not included in this annotated Specification.
Chapter 3 – Air Conditioners and Heat Pumps: Split and Packaged Systems

3.1 Selection and Sizing of Space-Cooling Equipment: Specification.

3.1.1 Equipment Efficiency Ratings.

(a) Air conditioners and heat pumps should comply with the required efficiency of local or utility energy codes or, as a minimum, meet ENERGY STAR efficiency levels.
   (1) Central air conditioners and air-source heat pumps: minimum 12 SEER.
   (2) Air-source heat pumps: minimum 7.6 HSPF.
   (3) Gas-fired heat pump: COP of 1.26 for heating and 1.32 for cooling.
   (4) Air conditioners and heat pumps should be equipped with thermostatic expansion valves, which compensate for variations in airflow and refrigerant charge better than fixed orifice valves.

(b) Verification of Efficiency for Split Systems.
   (1) The efficiency of split systems must be verified by the latest edition of Directory of Certified Unitary Equipment Standards by ARI.
   (2) An evaporator coil should be installed which is verified to be a rated match with the condenser coil, as listed in the current Directory of Certified Unitary Equipment Standards by ARI.
   (3) All equipment should be properly tagged (nameplate) and easily identified by make and model number. [Source: Craig Sherman at SMUD]

(c) Verification of Efficiency for Packaged Systems.
   (1) The efficiency of packaged systems must be verified by the latest edition of Directory of Certified Unitary Equipment Standards by ARI.

3.1.2 Equipment Selection. Equipment should be selected in accordance with the most recent edition of Residential Equipment Selection (Manual S) by ACCA, or a comparable industry-accepted method.

3.1.3 Load Calculation. An accurate load calculation must be performed before equipment is selected.
This load should be calculated with the most recent edition of *Residential Load Calculation* (Manual J) by ACCA, or a comparable industry-accepted method. Computer software programs based on the most recent edition of Manual J are acceptable.

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Sizing cooling equipment properly is an important factor affecting efficiency, energy consumption, and peak load. Over-sizing by 50% or more is typical, resulting in inefficient operation, poor comfort, and maintenance problems like iced coils and failed compressors.

Manual J, the most commonly used method for sizing residential space cooling and heating, is in the process of being revised. The revision—the 8th edition—is scheduled for publication within the next few years. Field studies have demonstrated that the cooling load process used in Manual J, 7th edition "... is very conservative in its estimation of cooling loads and that air conditioners sized using Manual J will actually be able to meet cooling loads for more than 97.5% of summer hours" [emphasis added]. In other words, the method suggested in the 7th edition oversizes cooling equipment.

(a) For the purpose of load calculation, the interior design temperature used should be 75°F for cooling and 70°F for heating. [Source: California Energy Commission 1999]

(b) For cooling-only equipment (not heat pumps) cooling capacity should be no more than 1.15 times the calculated total cooling load. [Source: Manual J and Manual S, Hammon et al 1999 and SMUD 1998]

**Exception:** If certified equipment is not manufactured that meets the above requirement, selected equipment may be as much as one-half ton larger than the calculated total Btuh cooling load.

(c) Air conditioners and heat pumps with multi-speed/variable-speed compressors should be sized within the cooling capacity range of the equipment as specified by the manufacturer. [Source: SMUD 1998]

(d) The latent cooling capacity of air conditioners and heat pumps must equal or exceed the calculated latent load, with no specific excess limit on latent capacity. [Source: SMUD 1998]

(e) Select cooling airflow based on desired sensible load ratio. Sensible load ratio = sensible load ÷ (sensible load + latent load). This will vary according to the characteristics of the building and the local climate. (See Manual S by ACCA, Section 1-5, Estimating the Cooling CFM.)

(f) For heat pumps:

1. In warm or moderate climates, heat pumps should be selected so that total capacity is no greater than 115 percent of the total calculated load. [Source: Hammon et al 1999 and SMUD 1998, page 2]

2. In cold climates, heat pumps should be selected so that total capacity is no greater than 125 percent of the total calculated load. [Source: Manual S]

3. Select a heating balance point temperature appropriate for outdoor design conditions without significantly over-sizing for comfort cooling. Generally, low-range balance points are associated with climates that are predominately hot because the heating load is small relative to the cooling load. Conversely, high-range balance points are associated with...
climates that are predominately cold because the heating load is larger. [Source: Manual S and Manual H]

(4) The most appropriately selected manufacturer’s supplemental heat package should be installed so that the combined operation of the heat pump compressor and the supplemental heaters satisfies the design heat load. Supplemental heaters assist the heat pump compressor in heating the house when the outdoor temperature is below the design balance point temperature. [Source: SMUD 1998, page 3]

3.1.4 Verification. Before installation, check sizing of the air conditioner or heat pump by comparing Manual J load calculation with the rated capacities (total, sensible and latent) at design conditions.

3.1.5 Benefits. Oversizing comfort-cooling equipment can lead to efficiency losses of from 2 - 10 percent, higher equipment cost, poor dehumidification performance caused by short cycles, and premature equipment degradation, according to reports by the U.S. EPA ENERGY STAR program. On the positive side, correctly sized equipment can lead to reduction in the size of air distribution ducts, resulting in increased efficiency of the ducted distribution system.

3.1.6 Discussion. Using a mathematical sizing procedure, such as Manual J, requires know-how and time. If a designer performs many load calculations each week, he or she will become proficient quickly and will become skilled from experience.

Improper sizing leads to customer complaints, system inefficiencies, and premature equipment degradation. Because it is difficult to properly adjust for improper sizing once the equipment has been installed, sizing “by the book” (Manual J or a comparable method) is strongly encouraged.

Many suppliers offer a free load-calculation service to their installers. If such a service is used, it is vitally important that the installer make sure the method being used is based on Manual J. It is also important that the installer provide accurate job information – such as house dimensions, insulation values, and window U-values and solar transmittance – to the person calculating the load.

The appropriateness and accuracy of values obtained by rules of thumb versus values obtained by formal engineering calculations is a contentious issue among the scientific, engineering, and technical community. Many scientists and engineers believe that rules of thumb are a scourge and result in poor design. Other engineers and technicians have great confidence in rules of thumb and use them daily. The large percentage of design and equipment selection is done by rules of thumb, making this contentious issue a central and largely neglected problem facing the industry.

The design of residential HVAC systems and selection of components is performed by designers and contractors in a number of different ways including the following.

1) Using hand calculations, according to ACCA Manuals J, D, and S.

2) Using computer programs based on ACCA Manuals J, D, and S.

3) Using simplified procedures and forms based on ACCA Manuals J, D, and S.

4) Using rules of thumb based on field experience, measurements, and ACCA manuals.
5) Using rules of thumb based on company policy, regional consensus, or habit.

We have found that the last choice currently dominates decision-making for residential design and equipment selection. The most common rule of thumb is sizing based on square footage of floor space—one ton per 400, 500, or 600 square feet being common rules for cooling. Computer-generated load calculations and recent field experience suggest a range of 700-to-1100 square feet per ton might be more efficient. Rules of thumb for heating systems vary more because of a far greater variation of winter design temperatures compared to summer design temperatures and run from 30-to-75 Btuhr per square foot of heated floor space. These commonly used rules of thumb often result in heating and cooling systems that are 150% to 300% of the correct size as determined by the latest ACCA procedures.

Sometimes, even simpler rules of thumb are used such as installing one 2-or-3-ton cooling unit in a small- or medium-sized home and two 2-or-3-ton units in a larger home. Yet another economic determinant of size and selection in some regions are agreements between general contractors and HVAC contractors on an installed price per ton, which gives HVAC contractors incentive to install larger systems. The most important point we can make to contractors is that air-conditioners and heat pumps are currently being significantly oversized. If we can get that point across, contractors may start using sizing software or at least adjust their rules of thumb.

Manufacturers publish simplified procedures and forms to aid contractors in estimating equipment size. Many other good designers and contractors use the fourth option, combining ACCA procedures and computer calculations with rules of thumb based on experience and field testing. They argue that field conditions, plan changes, and variable installation practices make it impossible to accurately predict system performance without testing and field adjustment.

We found that a minority of designers use the first option because the ACCA source documents are very complex and require great dedication and time to follow. Using computer programs based on ACCA Manuals J, D, and S is a very good choice because the procedure is simplified and the calculations are automatic. The best computer-design programs allow the designer to draw the home and its rooms, and position the air handler. Then the computer calculates room-by-room heat gain or loss, calculates airflow rate for each room, draws the branch-duct runs, and sizes the ducts. Many conscientious contractors use these computer design programs with excellent results.
Heat pumps are more complicated to size and select than air conditioners because of the wide variations in US climates and the fact that the same compressor will supply the entire cooling load and most of the heating load. This complexity is likely to deter many would-be users. With the publication of the 8th edition of Manual J, ACCA indicates that the complexity of the sizing process will increase, exacerbating the problem.

Although the load sizing and equipment selection process is contentious and is subject to wide variegations in practice, we felt it important to include load calculation “by the book” in this Specification. This Specification is intended for use across the US; even though rules-of-thumb might work in a particular locale, they will not work for all locales. A calculation method is the only viable option. The ACCA manuals are the best documents available for the residential sector.

### 3.2 Placement of Equipment: Specification.

3.2.1 Follow manufacturer’s recommendations for placement of indoor equipment (some equipment is approved only for installation in conditioned space).
3.2.2 Placement of split and packaged systems should minimize ductwork length.
3.2.3 Allow sufficient space around indoor and outdoor units for proper operation and servicing. Minimum clearances between equipment and adjacent structures, walls, or other objects shall be: [Source: Craig Sherman at SMUD, Manual H, and Electric Power Research Institute 1985]
   (a) On the side containing the service panel, 36 inches,
   (b) On all other sides, 12 inches,
   (c) Above vertical discharge unit, at least 48 inches,
   (d) As specified by manufacturer and local codes.
3.2.4 If visual inspection indicates that airflow to the outdoor coil might be restricted, verify with this test:
   (a) Run the unit for 15 minutes. Measure the temperature of the ambient air to determine if the air entering the unit is significantly warmer than the ambient air temperature. If it is, recirculated exhaust air is being pulled into the entering air stream.
3.2.5 Avoid placement of outdoor equipment under building eaves where collected rainwater, snow or ice can fall on the unit or airflow to the outdoor coil may be restricted. Also avoid areas where snow drifts.
3.2.6 For heat pumps, protect the outdoor unit from strong prevailing winds. If possible, locate the outdoor unit on the downwind side of the building in a sunny spot.
3.2.7 For outdoor units, allow clearance for water to drain away. Check the outdoor unit cabinet condensation and defrost drain hole locations and be sure they are not blocked by the mounting pad or rack.
3.2.8 Inform building occupants to keep the area within 3 feet of the outdoor unit free of any vegetation or structures that will obstruct airflow into or out of the equipment.
3.2.9 Where snowfall is:
   (a) Below 20 inches annually, the outdoor unit may be placed on a ground-level concrete pad constructed at least 3 inches above the surrounding grade level,
   (b) From 20 to 40 inches annually, the outdoor unit should be mounted on a rack that elevates the equipment at least 12 inches above the ground-level pad,
(c) More than 40 inches, the outdoor unit should be mounted on a rack that elevates the equipment at least 16 to 24 inches above the ground-level pad.

3.2.10 Benefits.
(a) Proper clearances from permanent and temporary obstructions, like snow, helps ensure maximum operating efficiency of the cooling equipment.

3.3 Indoor Coil Airflow: Specification.

3.3.1 Measured airflow over the indoor coil should be the equivalent of 400 CFM per ton for a wet coil (condensation on coil) and 425 CFM per ton for a dry coil (no condensation on coil), plus or minus 50 CFM (for low sensible-load-ratio areas, the airflow will be on the low side of this CFM range, for higher sensible-load-ratio areas, the airflow will be on the high side of the range).

3.3.2 Indoor coil airflow always should be measured after any duct and plenum sealing has been completed, if practical. If this is not practical, do a visual inspection for big leaks and leaky building cavity returns before measuring airflow. If large leaks are found, temporarily block the return side of the system. At that point, measuring airflow with a duct blower is probably the only way to get a reasonable accurate CFM.

3.3.3 Verification. Check airflow at installation start-up and servicing.
(a) **Most Accurate Method.** The preferred verification method for airflow measurement is a calibrated duct blower. Refer to Duct Blower Test for Ensuring Proper Airflow, Section 3.13.1.

*Most experts agree that instruments using calibrated orifices, like the Minneapolis Duct Blaster or The Energy Conservatory’s prototypical orifice-plate airflow-measuring system are the most accurate measuring systems for residential HVAC. The fan-powered flow-measuring device known as the Duct Blaster® or duct blower provides the most accurate airflow measurements, according to most experts who’ve used it. It usually takes longer to perform than other airflow measurement methods. The Energy Conservatory—the primary manufacturer of these devices—claims ±5 percent accuracy.*

*Because we found that most experts agree that a duct blower test results in the highest degree of test accuracy, we selected this test as the primary. We understand that there are obstacles to this recommendation—the two primary ones being that the duct blower and other required equipment is expensive and its use for this test is complex—but we feel that the increased accuracy is worth these trade-offs.*

(b) **Alternate Method 1.** Supplementary Heat Test (temperature rise) for Ensuring Proper Air-Handler Fan Flow. Refer to Section 3.13.2.

*The easiest and most common airflow measurement for heat pumps with electric supplemental heat is temperature rise across auxiliary heat coils. Some experts trust the test if it is done by a trained technician and consider the temperature-rise method to be the best hope for getting airflow measured accurately on the job. However, a majority of experts, contacted for interviews, believe that the temperature-rise method has very limited uses because of its poor accuracy. All experts agree that the temperature probe must not be exposed to infrared radiation from the auxiliary heating coils of the heat pump. The main problem with this test is that temperatures in the airstreams vary widely and methods of averaging these varying temperatures are not established.*

(c) **Alternate Method 2.** Flow hood Test for Ensuring Proper Airflow. Refer to Section 3.13.3.

A few experts mentioned various static-pressure measurements across air handlers, DX coils, or various types of filters as a reasonably accurate option if the manufacturer's installation literature is available. Most manufacturers provide a table of airflow values, corresponding to measured static pressure across these devices. Experts don't agree on how much accuracy to ascribe to this proposed airflow-estimating method. Several experts mentioned that the manufacturer's test conditions used long straight sections of duct—very unlike field conditions. Other experts expressed doubt about the accuracy and repeatability of static-pressure measurements in general. Even getting the probe in the right location can be difficult, as with combustion furnaces with DX coils.

The authors had not included this test method because of experts' reports of inaccuracy. However, it was added at near the end of the editorial process as a result of one expert making a strong case that it is accurate enough if performed properly and it is a commonly performed test.

3.3.4 Benefits. Field studies suggest that about 70 percent of installed residential cooling systems have inadequate airflow at the indoor coil. One study showed that the inadequate airflow of 320 CFM per ton, rather than 400 CFM, for fixed orifice (capillary tube) air conditioners results in a loss of 6-15 percent efficiency. Thermal expansion valve (TXV) units do not suffer as large a loss in efficiency for low airflow.

3.4 Refrigerant Charge: Specification.
Manufacturer’s recommendations must be followed for refrigerant charge. Coil airflow should be adjusted and verified before refrigerant charge checked. Refrigerant charge-checking is particularly important with split-system air conditioners and heat pumps.

Currently, many HVAC technicians connect a gauge set to the condenser service valves to get a preliminary clue about how the system is operating. The technician applies some experience-derived rule of thumb related to this design parameter and corrects refrigerant charge to get a number he or she is satisfied with. There are two main problems with this approach: 1) Manufacturers and industry experts agree that the airflow should be verified before checking charge; 2) Connecting the gauges can result in a refrigerant leaks or contamination; 3) The pressures are measured to determine temperatures, which may be measured directly. Modern infrared or thermistor thermometers may be a better way to check refrigerant charge.

3.4.1 Verification.  
(a) **Superheat Method.** For systems with fixed metering devices (capillary tube or fixed orifice), the evaporator superheat method should be used along with manufacturer’s recommendations. Refer to Section 3.14.1. [Source: Tenenbaum 1990, Whitman and Johnson 1987 and conversations with HVAC consultants]  
(b) **Subcooling Method.** For systems with thermostatic expansion valves (TXV), the subcooling method should be used along with manufacturer’s recommendations. Refer to Section 3.14.2. [Source: Tenenbaum 1990, Whitman and Johnson 1987 and conversations with HVAC consultants]  
(c) When the outdoor temperature is below 80°F use Simulating Design Temperatures for Superheat and Subcooling Tests. Refer to Section 3.14.3. [Source: conversations with HVAC consultants]  
(d) Weighing the refrigerant may be used along with manufacturer’s recommendations. Refer to Section 3.14.4. [Source: Tenenbaum 1990, Whitman and Johnson 1987 and conversations with HVAC consultants]

These refrigerant charge verification methods are all standard in the industry.

We decided not to include the Approach Method. Lennox Industries promotes this method, which subtracts outdoor air temperature from condenser discharge temperature. The advantage of the approach method is that the technician doesn’t need to connect the gauge set. Lennox Industries places approach-method charge-checking procedures inside all their outdoor units. Common approach values are between 2 and 7 degrees. The approach method probably gives less accurate values than subcooling or superheat, but approach may lend itself to the development of some rules-of-thumb, either single values or tables. We felt it was not well known enough to include.

3.4.2 Benefits. Improper charge is probably the most significant contributor to loss of efficiency for space cooling equipment. Overcharging can cause flood back, slugging, and premature compressor failure. Undercharging prevents adequate cooling of the air passing over the coils, and can cause continuous operation, compressor overheating and failure. Both of these
conditions lower cooling efficiency. Field studies conducted over the last eight years found that about 75 percent of installed cooling equipment was improperly charged. These studies show that fixed-orifice equipment suffers an efficiency loss of 10-20 percent for overcharging and a 20 percent loss in efficiency for a 20 percent undercharge of refrigerant. Thermal expansion valve (TXV) equipment is less sensitive of refrigerant levels. A 20 percent overcharge or undercharge for typical TXV equipment demonstrated about a 5 percent loss in efficiency.

3.4.3 Discussion. As demonstrated by field tests, installing and servicing technicians frequently overlook or do not know the proper procedure for refrigerant charging. The efficiency losses resulting from improper charging are significant enough to warrant verification at installation and servicing.


3.5.1 Suction lines for split systems should be insulated with a minimum of 3/8-inch thick closed-cell elastomeric pipe insulation to prevent condensation and to slow heat transfer.

3.5.2 Refrigerant line insulation exposed to weather should have a waterproof covering providing protection from ultraviolet light and weather damage.

3.5.3 Refrigerant line length. [Source: SMUD 1998 and Craig Sherman at SMUD with Jeffery Warther at Carrier]

   (a) The maximum horizontal length is 50 feet. Check with equipment manufacturer whenever horizontal length is greater than 50 feet.
   (b) The maximum vertical length is 20 feet. Check with the manufacturer whenever the vertical length is greater than 20 feet.
   (c) Use long-radius bends, long-radius elbows and a minimum of fittings to minimize line friction losses.

3.5.4 Use long-radius bends and a minimum of fittings to minimize line friction loses.

3.5.5 Verification. Visual inspection for integrity of suction-line insulation. Visual inspection and refrigerant charge testing for integrity of line seal.

3.5.6 Benefits. Suction refrigerant line insulation increases the operating efficiency of the equipment. Liquid lines should not be insulated because the heat loss to the outdoor air during cooling season increases the efficiency of the unit.

Refrigerant line leaks adversely affect operating efficiency and can result in equipment breakdown.

3.6 Fan-Delay Relay: Specification.

If not already included in the cooling equipment, heat pump or thermostat, a fan-delay relay should be installed to continue the operation of the air handler blower for a minimum of one minute, or a manufacturer’s present time delay, after the compressor cycles off. [Source: SMUD 1998, page 6]

   Exception: In hot, humid climates a fan-delay relay is not required. In such a climate, it has been found that in delayed shutdown of the air handler fan can reintroduce significant amounts of water vapor back into the house due to the evaporation of water on the evaporator coil.

This important exception was raised by some of our consultants and industry experts from hot, humid climates.
3.6.1 Verification. Time the operation of the blower after the compressor shuts down.

3.6.2 Benefits. The fan-delay relay increases efficiency by 1) purging the ducted distribution system of conditioned air and 2) extracting the maximum cooling capacity from the evaporator coil.

3.7 Cooling/Heating Programmable Thermostats: Specification.

3.7.1 Programmable thermostats should be installed for interior temperature control and should have the following features: [Source: California Energy Commission 1999, page 93 and EPA Energy Star web site]

(a) Thermostats should be ENERGY STAR labeled.
(b) Separate weekday and weekend programs, each with up to four customized temperature settings – two for occupied periods and two for energy-saving periods when the house is unoccupied or when the occupants are sleeping.
(c) Thermostat must have ability to maintain room temperature plus or minus 2°F of setpoint temperature.
(d) Thermostat must have a hold feature that allows users to temporarily override the programmed settings without deleting them.
(e) The maximum recommended setpoint increase for cooling is 8°F. The maximum recommended setpoint decrease for heating is 10°F.
(f) Verification. Check for proper operation at installation.

3.7.2 Thermostat should be mounted on an interior wall in an area of average temperature and away from direct sunlight, distribution supply airflow, stairwells, water pipes, appliances and sources of electrical interference.

This is an attempt to coordinate this Specification with ENERGY STAR specifications. The details of this section are taken from the ENERGY STAR programmable thermostat specification.


Source: SMUD 1998, page 5 and comments from reviewers and consultants.

3.8.1 Thermostats should be “intelligent-recovery, staging,” or “ramping” types that do not allow supplemental heat to activate a) during temperature pick-up at the end of an automatically programmed temperature setback or b) when an occupant increases the thermostat offset.
3.8.2 Change-over from heating to cooling and back must be manually activated; it may not be automatic. (Exception: A full-featured comfort management zoning system, which maintains a dead band between the cooling and heating setpoints.)
3.8.3 Thermostats that are not “intelligent-recovery” or “ramping” are not acceptable unless an outdoor lockout thermostat is used as a component of the control system (see Section 3.9).
3.8.4 Indoor thermostat must have an emergency heat switch that will:
   (a) Permit all supplemental heaters to be energized under control of the indoor thermostat – with the compressor and outdoor thermostat bypassed – when the compressor or refrigerant system is inoperative; and
   (b) Activate an indoor indicator light whenever the system is operating on emergency heat.
3.8.5 Verification. Verify proper operation at installation.
3.8.6 Benefits. If a heat pump thermostat is not working properly, the expensive supplementary heat can be unnecessarily activated by an increase in thermostat temperature setting or during pick-up time after a programmed temperature offset. This can lead to higher energy costs for temperature setback.
3.8.7 Discussion. Because occupants adjust comfort thermostats, and programming is often complicated, make certain the occupants understand how to operate the programmable thermostat. This is especially important at the initial installation of the device.


Source: SMUD 1998, page 5 and comments from reviewers and consultants.

3.9.1 An outdoor-lockout thermostat is required regardless of the type of indoor thermostat installed.
3.9.2 The outdoor thermostat must lock out the supplemental heat when the outdoor temperature is greater than the heat pump balance point (usually 25-40°F, depending on the climate). Caution: Emergency heat should not be subject to lockout under any circumstances.
3.9.3 Wire the outdoor-lockout thermostat so the supplemental heater is not subject to lockout during the outdoor-coil defrost cycle.
3.9.4 Locate the outdoor-lockout thermostat in a location that will allow the sensing bulb to determine the true outdoor temperature, not the supply or outdoor air-stream temperatures.
3.9.5 Verification. Verify proper operation at installation.
3.9.6 Benefits. If a non-intelligent or non-ramping comfort thermostat is installed, expensive supplementary heat can be unnecessarily activated by an increase in thermostat temperature setting or during pick-up time after a programmed setback. This can lead to higher energy costs for temperature setback. An outdoor-lockout thermostat prevents this from occurring, but allows supplementary heat to be activated during the outdoor-coil defrost cycle.


Source: SMUD 1998, page 5 and comments from reviewers and consultants.
If installing a new heat pump, select a model with microprocessor defrost control (this control “learns” to defrost only when needed). For an existing system, if the defrost control is an electronic combination time/temperature device where defrosting the outdoor coil is initiated at a pre-selected time interval (provided the outdoor coil is below the present initiation temperature), set the time interval to provide the highest defrost efficiency for local weather conditions.

3.10.1 Verification. Follow manufacturer’s verification procedures.
3.10.2 Benefits. Excessive defrosting of the outdoor coil during cold weather reduces the efficiency of heat pump operation. Of course, an iced outdoor coil also reduces efficiency. The control for defrosting of the outdoor coil must be adjusted to optimize efficiency – just enough to keep the coil free of ice without any unnecessary operation.

3.11.1 When installing comfort cooling equipment, an open space shall be provided around electrical panels and equipment sections requiring servicing. These spaces shall be a minimum of 30 inches wide by 36 inches deep, or as specified by local code. Items requiring maintenance include filters, air handler blowers, refrigeration coils and controls.

We found that limited access to existing HVAC equipment and ductwork and limited working space for the proper installation of new HVAC equipment and ductwork are significant problems in the field. Of course, existing HVAC equipment and ducts can’t be properly serviced and maintained if service technicians don’t have access. New equipment, especially ductwork, can’t be properly installed if installation space is limited for the installer or for the ductwork itself.

The architect/designer should allow enough physical space for installing the cooling equipment and ducts so that technicians have adequate physical space to fasten ducts to the air handler on all sides of the connection. Technicians should have adequate physical space to seal the joints between the duct and air handler on all sides of the connection.

Source: Craig Sherman at SMUD and discussions with HVAC consultants.

3.11.2 Minimum clearances between equipment and adjacent structures, walls or other objects shall be:
   (a) On the side containing the service panel, 36 inches;
   (b) On all other sides, 12 inches, or
   (c) As specified by manufacturer and local codes.
3.11.3 All doors leading from the mechanical room to the outdoors should be large enough to allow easy passage of equipment. [Source: Interview with Marshall Hunt]

3.11.4 Verification. Visual inspection at installation.
3.11.5 Benefits. Adequate clearance for the maintenance of important equipment components allows the equipment to be serviced properly and regularly, thereby ensuring the maintenance of maximum equipment efficiency.


3.12.1 Follow manufacturer’s regularly scheduled maintenance program guidelines.
3.12.2 All equipment literature, including installation instructions and maintenance records, should be affixed to the equipment by means of a plastic storage pocket or other appropriate means.
3.12.3 The following items should be inspected and properly maintained at annual servicing for the purpose of maintaining system efficiency.
   (a) Filters. Verify with visual inspection whether filter requires cleaning or replacement
       (1) Clean or replace filter(s) as required. Do not attempt to clean a filter that is designed to be thrown away.
       (2) Make sure the filter compartment(s) are tight fitting. Make tight fitting or seal as necessary.
       (3) If appropriate, educate occupants about recommended filter cleaning or changing.
(b) **Indoor and outdoor coils.** Check for debris, cleanliness and any obstruction to free airflow through the coils. Clear debris and clean, if necessary.

1. To clean outdoor coil:
   
   [i] Turn off power to condensing unit.
   
   [ii] To avoid damaging the coil fins, clean the condenser coil using a bristle brush, or vacuum using a soft bush attachment, or lightly spray water or other cleaner.
   
   [iii] Turn power to condensing unit back on.

2. To clean indoor coil:

   [i] Turn power off to air handler and compressor.

   [ii] If no access panel exists, create a re-sealable access panel in a workmanlike manner.

   [iii] The indoor coil cleaning shall be done using a brush, vacuum, or air pressure. If a cleanser is used, rinse the coil with water from a spray bottle before proceeding with the next step.

   [iv] Check condensate drain line for clogging, rust, etc. Clean as needed.

   [v] Access panel shall be closed and sealed with approved tape or mastic. Identify access panel with permanent label or marker.

   [vi] Turn power back on to air handler and compressor.

(c) **Indoor coil airflow.** Measure the coil airflow to verify it is within the recommended range. Use procedures in Section 3.3. Clean coil if required.

(d) **Refrigerant charge.** Refrigerant charge should match the manufacturer’s recommendations. Verify refrigerant charge at servicing unless you know the unit was recently charged using superheat or subcooling and there are no indications of low capacity. See Section 3.4.

(e) **Refrigerant lines.** Check for damage to lines and fittings. Inspect for damage to line insulation.

(f) **Air handler blower belts.**

   1. Check for wear, slippage and proper alignment.
   
   2. Adjust belt tension or replace belt if required.

(g) **Air handler blower motor.**

   1. Lubricate according to manufacturer’s recommendations.
   
   2. Check the blower motor and blower bearings, whether belt-driven or direct-drive with the power off.

      [i] Hold the motor casing with one hand and grab the shaft with the other hand. Move the shaft up and down and side to side. The shaft will, under normal conditions, slide in and out of the motor case a slight amount. However, if there is excessive “play” or movement (side to side), or if there is a “sticky” spot as you spin the shaft, the bearings are bad. If this is the case, it is recommended that the motor be replaced.

      [ii] Belt-driven blower bearings can be checked by turning off the power to the blower, disconnecting the belt and spinning the blower with your hand; the blower wheel should rotate several times on its own. If the bearings are bad, they should be replaced.

(h) **Air handler blower vanes.**

   1. Check for proper rotation of blower. Adjust if necessary.
   
   2. Check for buildup of dust, dirt and debris. Any dirt buildup on the blower vanes will greatly reduce airflow.
   
   3. Clean if necessary.

      [i] Turn off power to blower.
[ii] Clean blower vanes using a brush, vacuum or hot water. If water or cleansers are used, rinse the blower components and allow them to dry before proceeding. Protect the blower motor from water and chemicals.
[iii] When the blower is extremely dirty, the blower assembly should be removed, separated from the blower motor and power washed. Allow the blower components to dry before proceeding. Reinstall the blower assembly and motor.
[iv] Turn power to the blower unit back on.
[v] Check and adjust airflow across the coil if necessary.
[vi] Controls. Verify the proper operation of all controls, including high-limit switches, defrost controls and outdoor-lockout thermostats. See Sections 3.6, 3.7, 3.8, 3.9, and 3.10.

3.12.4 Benefits. Proper maintenance of equipment and controls will retain system efficiency, extend the life of the equipment and ensure occupant comfort.

3.12.5 Discussion. The maintenance items listed here can impact system efficiency. Not all maintenance items are included here, especially those that do not directly influence system efficiency.

Items listed above in this section are those that impact efficiency. We did not include items that might have an impact on health and safety, such as proper electrical connections. Therefore, this is not a complete list of all the items that should regularly be maintained and checked.

Some involved with the design of this Specification felt that health and safety should be included; others thought not. From the beginning, the concept of this Specification was focused on installation practices that impact efficiency. Although health and safety are very important, these items are addressed elsewhere and were thought to be beyond the scope of this Specification.

Source: Whitman and Johnson, various ACCA manuals, and comments from consultants and industry experts.

Verification Tests


3.13.1 Duct-Blower Test for Ensuring Proper Airflow. [Source: Primarily the Minneapolis Duct Blaster operator’s manual by The Energy Conservatory]

(a) Objective of test. The measurement of air-handler airflow. The most accurate test of the air handler airflow is done with a duct blower in conjunction with the air handler’s blower. Airflow is measured after duct-leakage testing and duct sealing because measuring airflow in leaky ducts is inaccurate. During the test, the return is blocked so all return air comes through the duct blower where the airflow can be measured.

(b) Required equipment.

(1) Duct blower, a fan-powered flow-measuring device.
(2) A digital or analog manometer and tables for translating pressures to flows. The tables for the specific duct blower being used.
(3) A contractor using an Aeroseal Incorporated, aerosol-applied duct-sealant system or an equivalent product.

(c) **Setup.**

1. Set up a static pressure gauge to measure the duct pressure at the supply plenum, or a few feet away from the supply plenum, in a main supply trunk with reference to the house. Once the measurement probe is located properly (select a location that gives the highest pressure), tape the static pressure probe to hold it in place. The openings in the probe must be perpendicular to the airflow in the plenum or duct.
2. Make sure all supply registers and return grilles are open and not taped. Leave filters installed. If filters are dirty, replace or clean.
3. Perform required duct sealing to conform to standards explained in Section 5.13.1 before measuring airflow.

(d) **Conducting the test.**

1. Turn on the system air handler by setting the thermostat fan switch to the “on” position. Systems without a fan “on” switch will need to run in cooling mode to operate at the higher of two speeds (heating usually uses a lower speed), or in heating mode for heating-only systems. If the air handler provides both heating and cooling, make sure you activate the fan speed for the appropriate application – heating or cooling. A useful verification check is to clamp an ammeter around the color wire you think corresponds to heating or cooling to determine if the wire is energized. Proceed with the test.
2. Make sure the system air handler is on higher speed (for cooling). Measure and record the normal operating duct static pressure with reference to the house. This is the reference pressure, \( P_{sp} \), to be used later. Do not remove the static-pressure probe after this measurement.
3. Shut off power to the air handler. Connect the duct blower to blow into the single return register or into the air handler at the blower compartment. All the return air should now come through the duct blower. Use the following procedures to connect the duct blower.
   - [i] For single-return systems: Remove the grille at the single return register. Connect the duct blower through its flexible tube or directly to the register.
   - [ii] For multiple-return systems: Block the return plenum’s main return entry to the air handler. Filters are often located in a good location for this temporary blockage. Alternatively, the main return can be disconnected and supported temporarily, while this large duct is moved slightly to block its opening into the air handler. If the duct blower is connected to an air handler, located outside the conditioned space, the door or access panel between the conditioned space and the air handler location must be opened.
4. Turn on the air-handler fan. Make sure the air-handler fan is running on its normally higher speed – at the speed corresponding to your desired airflow test – heating or cooling.
5. Turn on the duct blower to blow into the air handler, increasing airflow until the manometer measuring supply-plenum static pressure reads the same as in Section 3.13.1 (d)(2), \( P_{sp} \), with reference to the house.
6. Measure and record the airflow through the duct blower. Refer to the duct-blower instruction book, if necessary. This is total system airflow in cubic feet per minute (CFM).
   - [i] If supply-duct pressure cannot be achieved with the duct-blower fan and the air-handler fan turned on, remove the flexible duct extension – if you have used it – from the duct blower, and connect the duct blower directly to the air-handler compartment. If high
enough pressure still cannot be reached, proceed to the next step, Section 3.13.1 (d) (6) [ii].

[ii] With the duct-blower and the air-handler fans turned on, measure and record the following: a) the maximum pressure (Pmax) with reference to the house, and b) the maximum duct blower-fan flow in CFM (Bmax) at the maximum pressure, Pmax. Then use the equation in the sidebar (left) to estimate total air-handler airflow, Q.

(e) **Interpreting the results.** This airflow measurement should yield an accuracy of ±5 percent or better. [Source: The Energy Conservatory]

### 3.13.2 Supplementary Heat Test (temperature rise) for Ensuring Proper Air Handler Fan Flow.

(a) **Objective of test.** This test measures air-handler airflow for 1) heat pumps with electric supplementary heat and 2) electric resistance furnaces with cooling coils. A simple method for determining system airflow for this equipment is measuring the temperature rise across electric-resistance heating coils. These electric-resistance coils share the same air stream as the heat pump’s indoor coil, or the external evaporator coil of the air conditioner. The measured temperature rise, together with the wattage of the resistance heat, is used to calculate airflow.

(b) **Limitations of test.** This test is valid only for 1) heat pumps with electric supplementary heat and 2) electric resistance furnaces with cooling coils.

(c) **Required equipment.**

1. Volt-ohmmeter
2. Ammeter
3. Accurate thermometer

(d) **Conducting the test.**

1. Engage electric resistance heating coils and the blower, making sure that the heat pump’s compressor is off.
2. Measure amperes of current, feeding both wires to the electric-resistance heat strips and add these ampere measurements together.
3. Measure voltage between the two hot-wires feeding the strips.
4. With a radiation-shielded thermometer, measure the temperature rise (delta T) of the air across the heat strip, after at least 5 minutes of operation. Keep the thermometer out of the line-of-sight of the hot coils. Move the thermometer around, looking for a stable average supply temperature.
5. Apply this formula to calculate airflow in CFM: $\text{CFM} = \frac{3.16(\text{volts} \times \text{amps})}{\Delta T}$.

(e) **Interpreting the results.** This airflow measurement should match system-design airflow and manufacturer’s specifications. The accuracy of this test depends on the averaging of the measured temperatures, which can vary widely. Measuring a temperature profile across both the length and width of the duct with an accurate thermometer, and averaging the temperature profiles with a calculator, will usually produce accuracy of around ±25 percent. [Source: Telephone interview with Ron Rothman of the Energy Conservatory]

### 3.13.3 Flow Hood Test for Ensuring Proper Airflow. [Source: Discussions with HVAC consultants]

(a) **Objectives of test.** This test measures the fairly laminar airflow at return registers. Measuring supply-register airflow isn’t as accurate because supply air is more turbulent and because supply registers along walls don’t allow the flow hood to be centered over them. The
flow-hood inlet must be larger than the return registers, although 10 percent of the register may be blocked with tape to allow the flow hood to cover the entire opening.

(b) **Limitations of test.** This test works best on systems with one to four return registers located in areas where a flow hood can cover the registers and be centered over them. Return airflows should be well within the range of the flow hood’s accuracy.

(c) **Setup.** Perform required duct sealing to conform to standards explained in Section 5.13.1 before measuring airflow.

(d) **Conducting the test.**
   1. Turn on the air handler to run at the higher fan speed, normally used for cooling.
   2. Center the flow hood over the return register, covering it completely. If the register is larger than the flow hood, seal up to 10 percent of the register with tape before covering it.
   3. Read and record the airflow. Add together the airflows of the return to get the total system airflow.

3.13.4 **Static Pressure Test for Estimating Airflow.** [Source: Leon Neal of Advanced Energy Corporation and Chris Neme of Vermont Energy Investment Corporation]

(a) **Objective of Test.** This test can roughly estimate airflow if the manufacturer’s table for static pressure versus airflow is available. It is often used to judge the cleanliness of an evaporator coil.

(b) **Limitations of the test.** Static pressure can vary widely from point to point within the measurement area, especially when ducts take an abrupt change of direction near the air handler. Access to both sides of the coil for testing static pressure can be difficult and requires great care and planning to avoid damaging the coil.

(c) **Required equipment.**
   1. Digital or analog manometer
   2. Static pressure probe or pitot tube
   3. Drill and bits
   4. Screw or nut drivers

(d) **Conducting the test.**
   1. Use a drill with a drill-stop to establish a hole or use existing openings to gain access to both sides of the coil or air handler.
   2. Attach two static pressure probes to tubes leading to the ports of the manometer. For analog manometers, attach the high-side port to the probe inserted downstream of the coil or air handler.
   2. Optional. If only one static pressure probe or pitot tube is available, take the readings on each side of the coil and subtract their values. Disregard positive or negative signs given by a digital manometer.
   3. Consult manufacturer’s literature for a table, relating static pressure difference to airflow. Find airflow for the static pressure measured above.

(e) **Interpreting the results.** Coils and air handlers have static pressure ranging from 0.20 IWC (50 Pascals) and 0.80 IWC (200 Pascals) as found in the field. This variation results from the air-handler and duct design, duct size and obstructions to airflow.

3.14 **Tests for Ensuring Proper Refrigerant Charge.**

3.14.1 **Evaporator Superheat Test for Refrigerant Charge.** [Source: Tenenbaum 1990, Whitman and Johnson 1987, and discussions with consultants and industry experts]
(a) **Objective of test.** Determine proper refrigerant charge for the efficient and safe operation of the equipment. Adjusting the charge to produce the ideal superheat temperature for the current indoor and outdoor temperatures optimizes system performance and efficiency. Superheat is an excellent indicator of correct system performance for all types of air conditioners and heat pumps with capillary or fixed-orifice expansion devices, operating in the cooling mode.

(b) **Limitations of test.** Follow manufacturer’s recommendations for the evaporator-superheat test. If manufacturer’s recommendations are not available, abide by these limitations:

1. This test is only to be used for fixed orifice/capillary systems and not for thermostatic expansion value (TVX) systems.
2. This test should only be done when the outdoor temperature is at least 80°F. Indoor temperature should be higher than 70°F.

(c) **Required equipment.**

1. Refrigeration gauge set.
2. Accurate, contact digital thermometer or infrared thermometer with auxiliary devices (as needed) to accomplish good contact for the thermometer probe.
3. Sling psychrometer.

(d) **Conducting the test with outdoor temperature greater than 80°F.**

1. Determine the recommended superheat temperature from the permanent sticker inside the condenser unit, from manufacturer’s literature, or from a manufacturer’s slide rule.
2. Measure the compressor-suction pressure at the suction-service valve. Add 2 pounds per square inch of gauge pressure (psig) for line losses between the evaporator and compressor. Then convert this pressure to a boiling-point temperature using temperature-pressure tables for the system’s refrigerant.
3. Measure the suction-line temperature at the evaporator’s outlet.
4. Subtract the boiling-point temperature determined in Section 3.14.1 (d)(1) from the measured temperature in Section 3.14.1 (d)(2). This is the superheat temperature.
5. Measure the dry bulb temperature of the air entering the outdoor coil.
6. Measure the wet bulb temperature of the return air.
7. Find the ideal superheat value from the table or slide rule provided by the manufacturer.
8. If the actual superheat is greater than the ideal superheat obtained from the table, add refrigerant, 2-4 ounces at a time.
9. If the actual superheat is less than the theoretical, remove refrigerant, 2-4 ounces at a time. Refrigerant must be removed into an empty Department-of-Transportation-approved (DOT-approved) recovery cylinder or one containing the same refrigerant as the system.
10. Allow the system to run for 10 minutes to adjust to the new operating conditions. Repeat the superheat procedure until the measured superheat temperature is within one degree of the ideal superheat temperature.

(e) **Interpreting the results.** Correcting the charge to produce the manufacturer’s recommended superheat temperature ensures efficient operation of the heat pump or air conditioner.

3.14.2 **Subcooling Test for Ensuring Proper Refrigerant Charge.** [Source: Tenenbaum 1990, Whitman and Johnson 1987, and discussions with consultants and industry experts]

(a) **Objective of test.** Determine proper refrigerant charge for the efficient operation of the equipment.
(b) **Limitations of test.** Follow manufacturer’s recommendations for the evaporator subcooling test. If manufacturer’s recommendations are not available, abide by these limitations: This test is only to be used for thermal expansion valve (TXV) systems when the outdoor temperature is at least 80°F.

(c) **Required equipment.**
   1. Refrigeration gauge set.
   2. Accurate, contact digital thermometer or infrared thermometer with auxiliary devices as needed to accomplish good contact for the thermometer probe.

(d) **Setup.**
   1. Heat pump or air conditioner should be running in the cooling mode for 10 minutes prior to the test.

(e) **Conducting the test with outdoor temperature greater than 80°F.**
   1. Measure the compressor discharge pressure. Convert this pressure to the condensing temperature, using temperature-pressure tables for the system’s refrigerant. Or, simply measure the surface temperature of a protruding loop of tubing in the center of the condenser between that section’s inlet and outlet.
   2. Measure the temperature of the liquid refrigerant leaving the condenser.
   3. Subtract the liquid-refrigerant temperature measured in Section 3.14.2 (e)(2) from the condensing temperature determined in Section 3.14.2 (e)(1). This is the subcooling temperature.
   4. Find the correct subcooling temperature from the permanent sticker inside the condenser unit, from manufacturer’s literature or from a manufacturer’s slide rule. Add refrigerant if the measured subcooling temperature is below the recommendation. Subtract refrigerant if the subcooling temperature is higher than recommended. Refrigerant must be removed into an empty DOT-approved recovery cylinder or one containing the same refrigerant as the system.
   5. Allow the system to run for 10 minutes to adjust to the new operating conditions. Repeat the subcooling procedure, until the measured subcooling temperature matches manufacturer’s recommendations or is 10° to 15°F.

(f) **Interpreting the results.** The metering device must be supplied with subcooled liquid. This is one of the main design requirements of all refrigeration systems. A subcooling temperature between 10° and 15°F is common for a properly functioning residential air conditioner, but it is better to use manufacturer’s specifications for subcooling if they are available.

3.14.3 **Simulating Design Temperatures for Superheat and Subcooling Tests.** [Source: Discussions with consultants and industry experts]

(a) **Objective of test.** Blocking a portion of the condenser’s airflow makes it possible to perform a superheat or subcooling test when outdoor temperature is below 80°F because the reduced airflow simulates hot weather.

(b) **Required equipment.**
   1. Digital thermometer. (Note: A differential digital thermometer makes this test easier).
   2. Probes for measuring air temperature and refrigerant-tubing surface temperature.
   3. A tarp or piece of cardboard or plastic for blocking the condenser.

(c) **Conducting the test**
   1. Measure the condensing temperature by measuring the surface temperature of a condenser pipe loop near the vertical center of the condenser.
(2) Measure outdoor temperature and subtract from condensing temperature obtained in (1) to arrive at the “condenser split.”
(3) To simulate 95°F outdoor temperature, add this condenser split to 95°F, the outdoor temperature being simulated (design temperature).
(4) Block condenser airflow until reaching the condensing temperature obtained in (3). Block equal areas of each condenser circuit. Or, block the fan outlet in such a way as to retard the airflow equally across the outlet of the condenser fan.
(5) Check superheat or subcooling as outlined previously.
(d) **Interpreting the results.** By making the condenser unit run at design conditions, the measured superheat and subcooling values better simulate design conditions under which the unit was tested.

### 3.14.4 Weigh-In Refrigerant Test to Ensure Proper Refrigerant Charge.

*Source: Tenenbaum 1990, Whitman and Johnson 1987, EPA information and discussions with consultants and industry experts*

(a) **Objective of test.** This is the preferred method of achieving the correct charge: It can be used 1) for new installations, 2) for systems where the refrigerant has leaked out, 3) to correct refrigerant charge if found to be incorrect after checking superheat or subcooling or 4) to remove existing refrigerant in an EPA-approved manner and recharge the system by weighing in the correct amount of refrigerant whenever superheat or subcooling tests can’t be employed.

(b) **Required equipment.**

1. Approved DOT-approved refrigerant cylinder evacuated to recommended vacuum.
2. Refrigerant recovery/recycle unit with clean filter-drier elements.
3. Manufacturer’s instructions for recovering and recycling refrigerant.
4. Electronic scale or graduated cylinder for measuring refrigerant.
5. Gauge set.
6. Air-conditioner or heat-pump manufacturer’s literature listing the weight of refrigerant needed by the system.

(c) **Setup.**

1. Measure airflow and correct low airflow as described in Section 3.13.
2. Check refrigerant charge by superheat or subcooling tests as described in 3.14.1 and 3.14.2, if possible.
3. If superheat test or subcooling tests are inappropriate (as in winter), or if superheat or subcooling temperature is incorrect, or if a leaking system has only a partial charge, follow the procedure outlined in (d), below.

(d) **Conducting the test.**

1. Follow the recovery/recycle unit’s operating instructions for connecting hoses.
2. Recover the refrigerant into a DOT-approved cylinder, noting the weight of refrigerant recovered and recycled.
3. Connect the EPA-approved recovery cylinder or disposable cylinder to the gauge manifold. To prepare for liquid charging, connect the gauge manifold to the liquid valve of the recovery cylinder. If using a disposable cylinder, turn it upside down.
4. With the compressor off, open the cylinder’s valve and suction service valve, and let the liquid refrigerant flow in.
5. If liquid stops flowing before the complete charge has entered, reconfigure the gauge manifold and cylinder to charge with vapor through the suction service valve.
(6) With the compressor running, add the remaining refrigerant as a vapor. Before opening path between the cylinder and the system, check the low-pressure gauge to make sure the cylinder pressure is higher than the system’s suction pressure.
(7) Weigh in the remainder of the charge.
(8) Check performance after 10 minutes of operation using superheat test, subcooling test, or a combination of other indicators including: temperature difference across evaporator and condenser, compressor suction and discharge pressures, evaporator- and condenser-saturation temperatures, and other indicators as provided by the manufacturer.
(e) **Interpreting the results.**
(1) The charge should be no more than one ounce greater or less than the manufacturer’s specifications. Manufacturers provide a variety of charts and tables to assess heat-pump performance during the heating season. This information can be used to verify that the weighing-in procedure was successful. In the cooling mode, use procedures in Section 3.14.4 to simulate design conditions for checking the weighing-in procedure by superheat or subcooling.

**Chapter 4 - Gas Furnaces**

Compared with cooling equipment, there are fewer studies examining the manner in which furnace installation and operation elements influence system efficiency. The reason for this is unclear; we suspect it is because furnace operation is generally less complex than that of air conditioners and heat pumps, so less can go wrong. In addition, natural gas, the most common fuel used in furnaces, is usually less expensive than electricity, the fuel used by air conditioners and heat pumps. Thus, the economic incentive to study furnaces is comparatively less.

### 4.1 Selection and Sizing of Gas Furnaces: Specification.

#### 4.1.1 Equipment Efficiency Ratings.
(a) Gas heating equipment should comply with the required efficiency of local or utility energy codes or, as a minimum, meet ENERGY STAR efficiency levels.  
(1) Furnaces: minimum 90 Annual Fuel Utilization Efficiency (AFUE).  
(2) Boilers: minimum 85 Annual Fuel Utilization Efficiency (AFUE).

`These efficiencies are higher than those listed in the International Energy Conservation Code-2000. Because this Specification is intended to be parallel to and coordinated with EPA ENERGY STAR guidelines, ENERGY STAR equipment efficiencies were selected for the Specification.`

(b) **Verification of Furnace Efficiency.**
(1) The AFUE value of newly installed furnaces should be verified by the latest edition of the GAMA Directory (Consumers’ Directory of Certified Efficiency Ratings for Residential Heating and Water Heating Equipment) by the Gas Appliance Manufacturers Association.

4.1.2 Equipment should be selected in accordance with the most recent edition of Residential Equipment Selection (Manual S) by ACCA, or a comparable industry-accepted method.
4.1.3 An accurate load calculation must be performed before equipment is selected. This load should be calculated with the most recent edition of *Residential Load Calculation* (Manual J) by ACCA, or a comparable industry-accepted method. Computer software programs based on the most recent edition of Manual J are acceptable.

(a) For the purpose of load calculation, the interior design temperature used should be 70°F. [Source: *Manual J and California Energy Commission 1999*]

(b) The selected furnace capacity should be no less than 100 percent of the calculated Btuh heating load. [Source: *Manual S*]

(c) Selected furnace capacity should be no more that 1.4 times the calculated Btuh required. [Source: *Manual S*]

**Exception:** See Sections 4.1.3 (1) and 4.1.3 (2), below.

(1) If the furnace air handler is also supplying comfort cooling, make sure that the air handler blower can supply the desired cooling CFM, within 10 percent. [Source: *Manual S, page 2-3*]

(2) If there are no air handlers having the correct combination of heating capacity – single- or dual-firing rates – and blower performance (for heating and cooling), ignore the 1.4 oversizing rule and select the smallest furnace that will provide the appropriate cooling airflow. [Source: *Manual S, page 2-3*]

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Manual J, the most commonly used method for sizing residential space cooling and heating, is in the process of being revised. The revision—the 8th edition—is scheduled for publication within the next few years. Field studies have demonstrated that the cooling load process used in Manual J, 7th edition “... is very conservative in its estimation of cooling loads and that air conditioners sized using Manual J will actually be able to meet cooling loads for more than 97.5% of summer hours” [emphasis added]. In other words, the method suggested in the 7th edition over sizes cooling equipment. We did not find studies indicating that Manual J over sizes heating equipment.

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4.1.4 Furnaces should be selected with the proper heating capacity and blower performance. Blower performance should be matched to output of furnace and ducted distribution system.

4.1.5 If the furnace air handler is also supplying comfort cooling, make sure that the air handler blower has the capacity and automatic controls to operate at the appropriate CFM for both comfort heating and cooling. [Source: *Manual S, page 2-3*]

4.1.6 If the furnace air handler is also supplying comfort cooling, the capacity of the air handler blower should be adequate to overcome the external static resistance imposed by the combined heating and cooling units at the airflow required for heating or cooling, whichever is greater. [NFPA 90B 1996, page 13]

4.1.7 **Verification.** Before installation, check sizing of the furnace by comparing Manual J load calculation to the rated output of the furnace.

4.1.8 **Benefits.** Oversizing a furnace by more than 1.4 times can lead to loss in seasonal efficiency, higher equipment cost, comfort sacrifices due to short cycling, and premature degradation of the furnace and/or the vent system. [Source: *Manual S, Thorne 1998, and discussions with consultants]*
4.1.9 **Discussion.** Using a mathematical sizing procedure, such as in Manual J, requires know-how and time. If a designer performs many load calculations each week, he or she will become proficient quickly. Improper sizing leads to customer complaints, system inefficiencies, and premature equipment degradation. Because it is very difficult to properly adjust for improper sizing once the equipment has been installed, sizing “by the book” (Manual J or a comparable method) is strongly encouraged.

Many equipment suppliers offer a free load calculation service to their installers. If such a service is used, it is vitally important that the installer make sure the method being used is based on Manual J. It is also important that the installer provide accurate job information – such as house dimensions, insulation values, window U-value, window solar transmittance, and house tightness – to the person calculating the load.

*The design of residential HVAC systems and selection of components is performed by designers and contractors in a number of different ways including the following.*

1. Using hand calculations, according to ACCA Manuals J, D, and S.
2. Using computer programs based on ACCA Manuals J, D, and S.
3. Using simplified procedures and forms based on ACCA Manuals J, D, and S.
4. Using rules of thumb based on field experience, measurements, and ACCA manuals.
5. Using rules of thumb based on company policy, regional consensus, or habit.

We have found that the last choice currently dominates decision-making for residential design and equipment selection. Rules of thumb for heating systems vary more than for cooling because of a far greater variation of winter design temperatures compared to summer design temperatures and run from 30-to-75 Btuh per square foot of heated floor space. These commonly used rules of thumb often result in heating systems that are 150% to 300% of the correct size as determined by the latest ACCA procedures.

Manufacturers publish simplified procedures and forms to aid contractors in estimating equipment size. Many other good designers and contractors use the fourth option, combining ACCA procedures and computer calculations with rules of thumb based on experience and field testing. They argue that field conditions, plan changes, and variable installation practices make it impossible to accurately predict system performance without testing and field adjustment.
We found that a minority uses the first option because the ACCA source documents are very complex and require great dedication and time to follow. With the publication of the 8th edition of Manual J, ACCA indicates that the complexity of the sizing process will increase, exacerbating the problem. Using computer programs based on ACCA Manuals J, D, and S is a very good choice because the procedure is simplified and the calculations are automatic. The best computer-design programs allow the designer to draw the home and its rooms, and position the air handler. Then the computer calculates room-by-room heat gain or loss, calculates airflow rate for each room, draws the branch-duct runs, and sizes the ducts. Many conscientious contractors use these computer design programs with excellent results.


4.2.1 The temperature rise or airflow across the heat exchanger should be within the range stated by the manufacturer. [Source: Manufacturers’ information and discussions with HVAC consultants and industry experts]

(a) **Alternate Method 1.** If a manufacturer’s specification for the ideal temperature rise is not available, adjust the fan flow across the heat exchanger so the temperature rise is between 40°-70°F. This temperature rise range corresponds to 18-12 CFM per 1000 Btuh, respectively, based on CFM = 1000 Btuh/(Temperature rise x 1.08). Measure with a thermometer inserted in the return plenum and the supply plenum. The thermometer inserted in the supply plenum must be “out of sight” of the hot heat exchanger so that it is not affected by radiant thermal energy.

(b) **Alternate Method 2.** Verify air handler airflow with Duct Blower Test for Ensuring Proper Airflow. Refer to Section 4.9.1.

(c) **Alternate Method 3.** Verify air handler airflow with Flow Hood Test for Ensuring Proper Airflow. Refer to Section 4.9.2.

4.2.2 **Verification.**

(a) Verify heat-exchanger temperature rise or airflow after sealing the distribution system and doing other work that might alter temperature rise/airflow.

4.2.3 **Benefits.** The proper temperature rise across the heat exchanger can save as much as 2 percent of the fuel consumption. Increasing airflow lowers the temperature of the supply air, resulting in decreased conductive heat transfer from the air to the space around the ducts.

Checking the airflow across the heat exchanger of a furnace is considerably easier than checking the airflow across a cooling coil. This is because the temperature rise across a furnace heat exchanger is only influenced by the airflow. On the other hand, temperature drop across a cooling coil is influenced by airflow and refrigerant charge.

4.3 Blower Thermostat Control: Specification.

4.3.1 Set the air handler blower-on and blower-off temperatures according to the manufacturer’s recommendations. [Source: HVAC consultants and industry experts]

4.3.2 **Alternate Method.** On non-electronic controls, set the blower-on temperature to 115°F and the blower-off temperature to 90°F.

4.3.3 **Verification.** Verify proper settings with a radiation-shielded thermometer at installation.
**Exception:** New furnaces have electronic blower thermostats that may or may not be adjustable. Check these controls for adjustment options. These controls usually turn the fan on about 45 seconds after the furnace burner fires and off from 90 seconds to 5 minutes after the burner stops firing. Sometimes the timing can be adjusted to increase efficiency. If the manufacturer recommends against adjustment, do not attempt to it.

4.3.4 **Benefits.** A properly adjusted blower thermostat control increases efficiency by purging the ducted distribution system and heat exchanger area of conditioned air before the air-handler blower cycles off.

4.4 **Fan-Delay Relay: Specification.**

If not already included as a furnace control, air handler or thermostat, a fan-delay relay must be installed to continue the operation of the air-handler blower for a minimum of one minute, or a manufacturer’s preset time delay, after the burner cycles off. [Source: SMUD 1998, page 6]

4.4.1 **Verification.** Time the operation of the blower after the burner cycles off.

4.4.2 **Benefits.** The fan-delay relay control increases efficiency by purging the ducted distribution system and heat exchanger area of conditioned air before the air-handler blower cycles off.

4.5 **Programmable Thermostat Control: Specification.**

4.5.1 Programmable comfort thermostats should be installed for interior temperature control and should have the following features: [Source: California Energy Commission 1999, page 93 and EPA Energy Star web site]

(a) Thermostats should be ENERGY STAR labeled.

(b) Separate weekday and weekend programs, each with up to four customized temperature settings – two for occupied periods and two for energy-saving periods when the house is unoccupied and/or when the occupants are sleeping.

(c) Thermostat must have ability to maintain room temperature within 2°F of set temperature.

(d) Thermostat must have a hold feature that allows users to temporarily override the programmed settings without altering or deleting them.

(e) The maximum recommended setback is 8-10°F.

4.5.2 If an existing electronic thermostat has settings to improve comfort and increase efficiency – such as cycles per hour or cycle times – the service technician should adjust these settings for maximum comfort and efficiency.

4.5.3 **Verification.** Check for proper placement and operation when servicing the furnace.

4.5.4 **Benefits.** Savings for temperature offset vary depending on climate, equipment, and house envelope characteristics. Studies have demonstrated savings from 1-3 percent per 1°F of eight-hour offset for heating (for temperature offsets within a range of 5-10°F). Two eight-hour setback periods per 24-hour period double the savings. [Source: Residential Controls for Heating and Cooling, 1997, Honeywell, Inc.]

4.5.5 **Discussion.** Significant temperature setback in some cases can lead to moisture problems because indoor surface temperatures decrease during temperature setback, increasing the chance of the condensation of water vapor on these surfaces.

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*This is an attempt to coordinate this Specification with ENERGY STAR specifications. The details of this section are taken from the ENERGY STAR programmable thermostat specification.*
4.6 Thermostat Anticipator Control: Specification.

Space heating thermostats have anticipators as a feature. Thermostats with adjustable analog anticipators should have the anticipator set to the manufacturer’s recommended setting. If no manufacturer’s recommendation is available, set the anticipator within a range of 1.0-1.25 times the thermostat circuit current.

4.6.1 Verification. With amperage meter, check amperage at thermostat until current is stabilized. Set anticipator accordingly.

4.6.2 Benefits. The proper adjustment of a thermostat anticipator can save as much as 2 percent of energy consumption, increase occupant comfort, extend the life of the heating equipment and reduce the chance of corrosion occurring in the combustion vent system.

An analyst in Minnesota discovered the dramatic effect an improper anticipator setting could make when he inadvertently improperly set the setting just after the installation of a new 82% AFUE gas furnace. A data logger monitored the furnace operation during the two weeks of improper anticipator setting and after the bad setting was corrected—the furnace burner cycles decreased from an average of 100 per day to and average of 25 per day. The outdoor temperature was not a factor in these results.


4.7.1 When installing a furnace, adequate clearance should be provided on all sides to allow for easy access for periodic inspection and maintenance. Items requiring maintenance include filters, heat exchangers, air-handler blowers, refrigeration coils, and controls.

We found that limited access to existing HVAC equipment and ductwork and limited working space for the proper installation of new HVAC equipment and ductwork are significant problems in the field. Of course, existing HVAC equipment and ducts can’t be properly serviced and maintained if service technicians don’t have access. New equipment, especially ductwork, can’t be properly installed if installation space is limited for the installer or for the ductwork itself.

The architect/designer should allow enough physical space for installing the furnace and ducts so that technicians have adequate physical space to fasten ducts to the air handler on all sides of the connection. Technicians should have adequate physical space to seal the joints between the duct and air handler on all sides of the connection.

We suggest that whenever possible, the HVAC equipment installer be involved in the overall building design process to ensure adequate space for equipment, ductwork, and installing workers.

4.7.2 All doors leading from the mechanical room to the outdoors should be large enough to allow easy passage of equipment.

4.7.3 Verification. Visual inspection and measurement.

4.7.4 Benefits. Adequate clearance for the maintenance of important equipment components allows the equipment to be serviced properly and regularly, thereby ensuring the maintenance of maximum equipment efficiency.
4.7.5 **Discussion.** If technicians do not have easy access to equipment components that require periodic inspection and cleaning, these components will go without service and equipment efficiency will suffer. Unfortunately, technicians frequently are provided with too little space to install the equipment with adequate clearance for maintenance. If possible, it is best if the installing technician is part of the design team so that it can be ensured there is ample space for the equipment, ductwork, and proper maintenance.

4.8 **Maintenance Items: Specification.**

4.8.1 Follow manufacturer’s regularly scheduled maintenance program guidelines.

4.8.2 All equipment literature, including installation instructions and maintenance records, should be affixed to the equipment by means of a plastic storage pocket or other appropriate means.

4.8.3 The following items should be inspected and properly maintained at annual servicing for maintaining system efficiency.

(a) **Steady-state efficiency test.** At each servicing, a steady-state efficiency test should be performed with the proper efficiency testing equipment. This testing is not required for condensing furnaces. Steady-state efficiency should be within the range recommended by the manufacturer of the equipment.

(b) **Filters.** Verify with visual inspection whether filter requires cleaning or replacement

   (1) Clean or replace filter(s) as required. Do not attempt to clean a one-time-use, throwaway filter.

   (2) Make sure the filter compartment(s) are tight fitting. Make tight fitting or seal as necessary.

   (3) If appropriate, educate occupants about recommended filter cleaning or changing.

(c) **Furnace gas manifold pressure.** Verify with gas pressure test.

   (1) Turn the combination gas valve to the “pilot” position so that no gas flows through the control valve. Locate the pressure tap plug on the gas valve or manifold. Remove the plug and connect your manometer. The manometer must be calibrated in inches of water pressure. Check the manufacturer’s specifications for normal operating manifold pressure. This is usually 3-4 inches of water for natural gas units, 10-11 inches of water for propane units.

   (2) Turn the valve control knob to the “on” position. Turn up the necessary thermostat(s) so the furnace will fire. Check the pressure on your manometer. If adjustment is required, locate and remove the cap covering the pressure regulator adjustment screw on the combination gas valve. Adjust pressure upward or downward, as necessary.

   (3) Make sure the movement of the adjustment screw affects the pressure reading on your manometer. If it does not, or if the pressure wavers when you are not moving the adjusting screw, replace the gas pressure regulator.

   (4) Do not operate the appliance at a different gas pressure than that recommended by the manufacture.

   (5) Finally, turn the control knob back to “pilot,” remove your manometer from the pressure tap, replace the tap plug and return the control knob to the “on” position.

(d) **Burner orifices.** Make sure the burner orifices are properly sized for the gas type and burner input.

(e) **Heat-exchanger temperature rise.** Verify heat-exchanger temperature rise is within the recommended range. See Section 4.2 for details.
(f) **Cooling evaporator coil.** Inspect for cleanliness and clean, if necessary. See Section 3.12.3 (b) for details.

(g) **Blower thermostat control.** Verify proper operation and settings. See Section 4.3 for details.

(h) **Air-handler blower belts.**
   1. Check for wear, slippage and proper alignment.
   2. Adjust belt tension or replace belt if required.

(i) **Air handler blower motor.**
   1. Lubricate according to manufacturer’s recommendations.
   2. Check the blower motor and blower bearings, whether belt-driven or direct-drive, with the power off.
      
      [i] Hold the motor casing with one hand and grab the shaft with the other hand. Move the shaft up and down and side to side. The shaft will, under normal conditions, slide in and out of the motor case a slight amount. However, if there is excessive “play” or movement (side to side), or if there is a “sticky” spot as you spin the shaft, the bearings are bad. It is recommended that the motor be replaced rather than trying to rebuild the existing motor.
      
      [ii] Belt-driven blower bearings can be checked by turning off the power to the blower, disconnecting the belt, and spinning the blower with your hand; the blower wheel should rotate several times on its own. If the bearings are bad, replace them.

(j) **Air-handler blower vanes.**
   1. Check for proper rotation of blower. Adjust if necessary.
   2. Check for buildup of dust, dirt and debris. Any dirt buildup on the blower vanes will greatly reduce airflow.
   3. Clean if necessary.
      
      [i] Turn off power to blower.
      
      [ii] Clean blower vanes using a brush, vacuum, or hot water. If water or cleansers are used, rinse the blower components and allow them to dry before proceeding. Protect the blower motor from water and chemicals.
      
      [iii] When the blower is extremely dirty, the blower assembly should be removed, separated from the blower motor and thoroughly cleaned. Allow the blower components to dry before proceeding. Reinstall the blower assembly and motor.
      
      [iv] Turn power to the blower unit back on.
      
      [v] Check and adjust airflow if necessary.

(k) **Controls.** Verify the proper operation of all controls, including comfort thermostats, comfort thermostat anticipators, and furnace blower fan and limit control. See Sections 4.4, 4.5, and 4.6.

4.8.4 **Benefits.** Proper maintenance of equipment and controls will retain system efficiency, extend the life of the equipment, and ensure occupant comfort.
4.8.5 **Discussion.** The maintenance items listed here can impact system efficiency. Not all maintenance items are included here, especially those not directly influencing system efficiency.

> *Items listed in the above section are those that impact efficiency. We did not include items that might have an impact on health and safety, such as proper venting or testing for carbon monoxide. Therefore, this is not a complete list of all the items that should regularly be maintained and checked.*

> *Some involved with the design of this Specification felt that health and safety should be included; others thought not. From the beginning, the concept of this Specification was focused on installation practices that impact efficiency. Although health and safety are very important, these items are addressed elsewhere and were thought to be beyond the scope of this Specification.*

> *Source: Whitman and Johnson, various ACCA manuals, and comments from consultants and industry experts*

**Verification Tests**

4.9 **Tests for Ensuring Proper Air-Handler Airflow.**

4.9.1 **Duct-Blower Test for Ensuring Proper Airflow.** [*Source: Primarily the Minneapolis Duct Blaster operator’s manual by The Energy Conservatory]*

(a) **Objective of test.** The measurement of air-handler airflow. The most accurate test of the air handler airflow is to use the duct blower in conjunction with the air handler’s blower. Airflow is measured after duct-leakage testing and duct sealing because measuring airflow in leaky ducts is inaccurate. During the test, the return is blocked so all return air comes through the duct blower where the airflow can be measured.

(b) **Required equipment.**

1. Duct blower, a fan-powered flow-measuring device.
2. A digital or analog manometer and tables for translating pressures to flows. The tables for the specific duct blower being used.
3. A contractor using an approved aerosol applied duct sealant system may use the aerosol system manufacturer’s computer-driven diagnostics program and protocol.

(c) **Setup.**

1. Set up a static pressure gauge to measure the duct pressure at the supply plenum, or a few feet away from the supply plenum, in a main supply trunk with reference to the house. Once the measurement probe is located properly (select a location that gives the highest pressure), tape the static pressure probe to hold it in place. The openings in the probe must be perpendicular to the airflow in the plenum or duct.
2. Make sure all supply registers and return grilles are open and not taped. Leave filters installed. If filters are dirty, replace or clean.
3. Perform required duct sealing to conform to standards explained in Section 5.13.1 before measuring airflow.

(d) **Conducting the test.**

1. Turn on the system air handler by setting the thermostat fan switch to the “on” position. Systems without a fan “on” switch will need to run in cooling mode to operate at the higher
of two speeds (heating usually uses a lower speed), or in heating mode for heating-only systems. If the air handler provides both heating and cooling, make sure you activate the fan speed for the appropriate application – heating or cooling. A useful verification check is to clamp an ammeter around the color wire you think corresponds to heating or cooling to determine if the wire is energized. Proceed with the test.

(2) Make sure the system air handler is on higher speed (for cooling). Measure and record the normal operating duct static pressure with reference to the house. This is the reference pressure, Psp, to be used later. Do not remove the static-pressure probe after this measurement.

(3) Shut off power to the air handler. Connect the duct blower to blow into the single return register or into the air handler at the blower compartment. All the return air should now come through the duct blower. Use the following procedures to connect the duct blower.

[i] For single-return systems: Remove the grille at the single return register. Connect the duct blower through its flexible tube or directly to the register.

[ii] For multiple-return systems: Block the return plenum’s main return entry to the air handler. Filters are often located in a good location for this temporary blockage. Alternatively, the main return can be disconnected and supported temporarily, while this large duct is moved slightly to block its opening into the air handler. If the duct blower is connected to an air handler, located outside the conditioned space, the door or access panel between the conditioned space and the air handler location must be opened.

(4) Turn on the air-handler fan. Make sure the air-handler fan is running on its normally higher speed – at the speed corresponding to your desired airflow test – heating or cooling.

(5) Turn on the duct blower to blow into the air handler, increasing airflow until the manometer measuring supply-plenum static pressure reads the same as in Section 4.9.1 (d)(2), Psp, with reference to the house.

(6) Measure and record the airflow through the duct blower. Refer to the duct-blower instruction book, if necessary. This is total system airflow in cubic feet per minute (CFM).

[i] If supply-duct pressure cannot be achieved with the duct-blower fan and the air-handler fan turned on, remove the flexible duct extension – if you have used it – from the duct blower, and connect the duct blower directly to the air-handler compartment. If high enough pressure still cannot be reached, proceed to the next step, Section 4.9.1 (d) (7) [ii].

[ii] With the duct-blower and the air-handler fans turned on, measure and record the following: a) the maximum pressure (Pmax) with reference to the house, and b) the maximum duct blower-fan flow in CFM (Bmax) at the maximum pressure, Pmax. Then use the equation below in the sidebar to estimate total air-handler airflow, Q.

(e) **Interpreting the results.** This airflow measurement should yield an accuracy of ±5 percent or better. [Source: The Energy Conservatory]

4.9.2 **Flow Hood Test for Ensuring Proper Airflow.** [Source: Discussions with HVAC consultants]

(a) **Objectives of test.** This test measures the fairly laminar airflow at return registers. Measuring supply-register airflow isn’t as accurate because supply air is more turbulent and because supply registers along walls don’t allow the flow hood to be centered over them. The flow-hood inlet must be larger than the return registers, although 10 percent of the register may be blocked with tape to allow the flow hood to cover the entire opening.
(b) **Limitations of test.** This test works best on systems with one to four return registers located in areas where a flow hood can cover the registers and be centered over them. Return airflows should be well within the range of the flow hood’s accuracy.

(c) **Setup.** Perform required duct sealing to conform to standards explained in Section 5.13.1 before measuring airflow.

(d) **Conducting the test.**

1. Turn on the air handler to run at the higher fan speed, normally used for cooling.
2. Center the flow hood over the return register, covering it completely. If the register is larger than the flow hood, seal up to 10 percent of the register with tape before covering it.
3. Read and record the airflow. Add together the airflows of the return to get the total system airflow.

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**Chapter 5 - Ducts and Air Handlers**

There was discussion regarding the focus and limits of this section of the Specification. Some reviewers wanted to include the details of duct sealing and duct support. Others felt that this was undermining the original objective of the Specification. As a compromise, it was decided to eliminate the details of duct sealing and duct support from this Specification and make Duct Installation and Sealing Specification [Chapter 3 of PG&E 1999 Residential Contractor Program Installation Standards] by Pacific Gas and Electric available as a companion document. This excellent document addresses these areas extremely well.

This document will be made available by the Consortium for Energy Efficiency.

5.1 **Duct Location: Specification.**

5.1.1 Locate all ducts within the conditioned spaces (living areas) and semi-conditioned spaces of the building.  

**Exception:** Ductwork may be located in unconditioned spaces, such as garages, attics or crawl spaces, if it is not possible to install it within conditioned or semi-conditioned spaces. Ductwork located in these areas will need to be heavily insulated and airtight to be efficient.

5.1.2 Ducts should not be located in exterior wall cavities.

5.1.3 All distribution-air enclosures must be hard-ducted, that is, building-framing cavities, closets, crawl spaces, and chases must not be used as distribution-air enclosures. However, ductwork may be housed by, or pass through these spaces. [Source: Manual D]

There was some objection to this element. Residential Duct System: Manual D by ACCA, 1995, states “Panned joist and stud spaces are not recommended because of problems that are associated with leakage.” Some reviewers felt that if panned airways are treated properly—sealed thoroughly—they present no added propensity for duct leakage and resulting loss in efficiency. However, the probability of improper treatment of panned airways is so great, it was finally decided to recommend against their use, especially since Manual D had already done so.
5.1.4 Panned floor joists should not be used for air distribution. [Source: Manual D]

5.1.5 A crawl space should not serve as a distribution plenum.

5.1.6 Existing crawl-space plenums should be abandoned and replaced with a sealed duct system. [Source: PG&E 1998]

5.1.7 **Benefits.** Duct-system efficiency depends on duct leakage, insulation levels, surface area, location and thermal conditions surrounding the ducts. Ductwork located within conditioned or semi-conditioned spaces loses less energy by conductive heat transfer and leakage than if located in unconditioned spaces, such as attics, garages or crawl spaces. Ducts located in exterior walls prevent the full insulation of the cavity within which they are located and are likely to allow a high level of heat transfer between the ducted air and the outdoors, either by conduction or air leakage. Building cavities, like floor-joist cavities and crawl spaces, are unlikely to be airtight. Avoiding their use as ducts and plenums produces tighter duct systems.

5.1.8 **Strategy.** Lay out the duct system on a floor plan, accounting for the direction of joists, hip roofs, firewalls and other possible obstructions. Determine supply register and return grille locations and types, duct lengths and connections for the installation of an efficient, cost-effective duct system given the construction limitations.

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**ACCA’s Manual D and Manual T and various SMACNA manuals were used as the resources for this section. Because these manuals explain proper duct layout so completely, the fine details were not repeated here.**

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5.2 **Duct System Design: Specification.**

Ducts, supply registers and return grilles should be sized and selected with the use of *Residential Duct Systems*, Manual D, 1995 or later, by ACCA; *Residential Comfort System Installation Standards Manual*, 1998 or later, by SMACNA; or a comparable industry-accepted method. Before duct sizing can be calculated, individual room loads should be done with the most recent edition of *Residential Load Calculation*, Manual J, by ACCA, or a comparable industry-accepted method.

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**Many designers, even mechanical engineers, calculate total load and room-by-room loads with a computer program, and then size the ducts by rules of thumb or with a duct calculator (ACCA), rather than the full ACCA procedure described in Manual D.**

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5.2.1 **Verification.** Use Manual D and Manual J procedures for verification before installation. Airflow and static pressure should be as specified by the equipment manufacturer.

5.2.2 **Benefits.** If ducts are undersized for adequate airflow, system efficiency can be adversely affected. In addition, occupant comfort may be reduced and complaints are likely to increase. Careful duct system layout and sizing can reduce static-pressure losses. As a result, the blower often can be operated at lower speeds, in turn reducing the power required to move the correct quantity of air through the heat exchanger, filter or coil.

If ducts are oversized, material installation costs are higher, putting the installer in a less competitive position. Properly sized ducts provide conditioned air where it is needed quietly and efficiently.
5.2.3 **Discussion.** Using a mathematical sizing procedure, such as in Manual D, requires know-how and time. If a designer performs many duct-sizing calculations each week, he or she will become proficient quickly. However, many system designers/installers for small-to-medium-sized businesses do not find the need to do duct sizing calculations frequently, so are likely to find the process time consuming and difficult. Many equipment suppliers offer free duct-sizing service to their installers. If such a service is used, it is vitally important that the installer provide accurate job information to the person sizing the ducts.

For this section, the most often used design manuals for residential ductwork were chosen—those by ACCA and SMACNA. There was no suggestion by the reviewers that other methods or documents be recommended.

5.3 **Leakage, Ducts and Plenums: Specification.**

5.3.1 **Allowable Leakage, Air Distribution Systems.**

(a) **Method 1.** Duct Leakage per 400 CFM Airflow: No more than 25 CFM of leakage (the sum of supply and return leakage) for each 400 CFM of measured airflow across the indoor coil and/or heat exchanger for new ducted systems or no more than 40 CFM of leakage for each 400 CFM of measured airflow across the indoor coil and/or heat exchanger for existing ducted systems.$^{30}$

For new ductwork this is the same as Title 24 of California and for existing ductwork it is the same as the ENERGY STAR Specification for Existing Ductwork. Both of these specifications state allowed duct leakage as a percentage of air handler airflow. The authors thought that duct leakage should also be stated as an absolute value per 400 CFM of measured airflow. The rational is that many HVAC technicians would be able to relate more easily to this method of stating the leakage limits. The percentage statement in 5.3.1 (b) and the absolute leakage per 400 CFM measured airflow in 5.3.1 (a) are equivalent. The authors convinced the ENERGY STAR duct research group to state their leakage specification in Specification for Existing Ductwork as an absolute value, as well as a percentage (as in Method 2, below).

(b) **Method 2.** Duct Leakage to Airflow Percentage: The sum of supply and return leakage divided by the measured air handler fan flow shall be no more than 6 percent for new ducted systems or no more than 10 percent for existing ducted systems.$^{31}$

For new ductwork this is similar to Title 24 of California and for existing ductwork it is the same as the ENERGY STAR Specification for Existing Ductwork. Both of these specifications state allowed duct leakage as a percentage of air handler airflow, as stated below in 5.3.1 (b).

5.3.2 **Verification.** Use Total Duct Leakage and Percentage Duct Leakage Test. Refer to Section 5.13.1.
5.3.3 **Benefits.** Properly sealing ducts and plenums with traditional duct sealing techniques of hand-applying sealant to seams, among others, can save 10 percent in existing homes and 15 percent for new homes. If duct leakage is reduced, cooling and heating equipment can be downsized for additional savings. Reducing leakage can also increase cooling and heating output at registers. Savings are greater for new than for existing installations because retrofitters do not have full access to duct, plenum, and boot joints.

The Electric Power Research Institute states that energy savings from duct improvement measures will save the average customer $300 per year. The US Department of Energy states that energy wasted from leaking residential ducts is equivalent to the energy used by 13 million cars each year. In addition, tighter ducts can reduce the entry of dust, excess humidity, basement and garage fumes (including car exhaust), and radon gas in affected regions.

Research results indicate an average increase in duct delivery efficiency from 64 percent to 76 percent results in a corresponding decrease in HVAC energy use of 18 percent.

5.3.4 **Correction Strategy.**

(a) All joints and seams of ductwork and plenums should be sealed with approved material. Refer to the supplementary document *Duct Installation and Sealing Specification* for details.

(b) Verify cooling coil airflow and/or heat exchanger temperature rise after sealing ducted distribution system.

5.3.5 **Discussion.** Repairing duct leaks should proceed in a cost-effective manner, that is, the largest and easiest-to-fix leaks should be treated first. An example of this type of leak is a joint disconnection. Secondly, leaks experiencing the greatest pressure differentials during air-handler operation should be sealed. These include leaks close to the air-handler blower, such as those at the supply and return plenum. Next, move on to less significant leaks.

5.4 **Duct-Sealing Materials and Methods: Specification.**

Please refer to *Duct Installation and Sealing Specification*, a supplement to this Specification.

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There was discussion regarding the focus and limits of this section of the Specification. Some reviewers wanted to include the details of duct sealing and duct support. Others felt that this was undermining the original objective of the Specification. As a compromise, it was decided to eliminate the details of duct sealing and duct support from this Specification and make Duct Installation and Sealing Specification [Chapter 3 of PG&E 1999 Residential Contractor Program Installation Standards] by Pacific Gas and Electric available as a companion document. This excellent document addresses these areas extremely well.

The Consortium for Energy Efficiency will make this document available to interested parties.

5.5 **Duct and Plenum Insulation: Specification.**

5.5.1 **Insulation, New and Existing Installations: Specification.**
(a) Duct and plenum insulation should be installed according to the supplementary document *Duct Installation and Sealing Specification*.

*Early on in the process writing this Specification, we did not allow the use of duct board and duct liner because of questions regarding their longevity. There was some strong objection to this. After discussion with a few selected reviewers, it was decided to allow the use of duct board and duct liner as long as the installation recommended by the manufacturers is strictly followed.*

*Duct Installation and Sealing Specification, a supplement to this Specification, calls for strict compliance with the manufacturers’ installation guidelines.*

(b) All duct insulation R-values should be based on insulation only, excluding air films, vapor barriers or other duct components.

(c) All thermal insulation should be installed without voids, gaps or tears.

(d) All insulation should be installed according to the manufacturer’s recommendations, ensuring durability and rated insulation R-value. Existing ductwork should be insulated in accordance with the ENERGY STAR *Specification for Existing Ductwork and Duct Installation and Sealing Specification*. If any elements of this Specification and the two listed just above conflict, the most stringent element shall be followed.

(e) Any insulation installed on the exterior of a building exposed to the weather must be protected from degradation by the weather.

(f) **Verification.** Visual inspection.

(h) **Benefits.** Duct-system efficiency depends on duct leakage, insulation levels, surface area, location and thermal conditions surrounding the ducts. Ductwork located where significant temperature differences exist between the air in the duct and the air surrounding the duct – such as attics, garages or crawl spaces – experiences significant conductive heat transfer unless insulated properly. The R-value levels selected for this specification are cost effective.

5.5.2 **Insulation, New Installations: Specification.**

(a) Supply and return ducts and plenums in conditioned spaces do not require thermal insulation.

**Exception:** Where needed, ducts should be insulated to prevent condensation on duct surfaces. Insulation used for this purpose should have a vapor barrier on its surface closest to the outside.

(b) Supply and return ducts, plenums and distribution boxes in unconditioned spaces should be insulated with a minimum R-value of 6.

(c) Supply and return ducts, plenums and distribution boxes located on the exterior of the building (such as a packaged system having some ductwork outdoors) should be insulated to at least an R-8 value.

*These insulation R-values are primarily based on the International Energy Conservation Code-2000 (page 89).*

(d) **Verification.** Visual inspection of insulation to ensure that the actual R-values meet these requirements. Check for excessive compression of insulation and insulation voids, both of which decrease overall insulation effectiveness.
5.5.3 Insulation, Existing Installations: Specification.

(a) Supply and return ducts and plenums in conditioned spaces do not require thermal insulation.

Exception: Where needed, ducts should be insulated to prevent condensation on duct surfaces. Insulation used for this purpose should have a vapor barrier on its most external surface.

(b) Supply and return ducts, plenums and distribution boxes in unconditioned spaces should be insulated with a minimum R-value of 6.

Exception 1: Inaccessible parts of the distribution system do not require thermal insulation. Inaccessible means nearly impossible to insulate because of location or obstructions.

[Source: EPA ENERGY STAR Specification for Existing Ductwork]

Exception 2: If ducts are already thermally insulated to a level of R-4 or greater, no additional insulation is required. [It is not cost-effective to add duct insulation to an existing R-value of 4 or greater]

(c) Supply and return ducts, plenums and distribution boxes located on the exterior of the building (such as a packaged system having some ductwork outdoors) should be insulated to at least an R-8 value.

These insulation R-values are based on the EPA ENERGY STAR Specification for Existing Ductwork.

(d) Verification. Visual inspection of insulation to ensure that the actual R-values meet these requirements. Check for excessive compression of insulation and insulation voids, both of which decrease overall insulation effectiveness.

5.6 Room-Pressure Imbalances: Specification.

Pressure differences during air-handler operation between 1) closed rooms and the outdoors, and 2) between the main body of the house and outdoors with all interior doors closed should be no more than 0.01 inches water gauge (3 Pascals), positive or negative. [Source: Tooley and Moyer 1995, page 9.10]

We found no research indicating the percentage savings from room-pressure imbalances, but there was significant research done in Florida in 1991 showing the surprising increase in air changes per hour in houses when the air handler is on and the interior doors are closed, resulting in room-pressure imbalances.

5.6.1 Verification. Check pressure difference from each room to the outdoors using Room Pressure Imbalances Test. Refer to Section 5.14. This test should always be done after the ductwork is sealed.

5.6.2 Correction Strategy. If the pressure difference is more than 0.01 inches water gauge (3 Pascals), provide for pressure relief (bring the pressure difference down to a magnitude of 0.01 inches water gauge, or less) by one of the following methods: [Source: Tooley and Moyer 1995, page 9.10]

(a) Undercut door by appropriate amount or add a transfer grille to the door.

(b) Install pass-over or pass-under transfer ducts in attics, basements, crawl spaces, or tuck-under garages.
(c) Design and install a wall transfer grille between the room and the main body of the house. (Note: Grilles with sound-dampening capabilities are preferred.)
(d) Add a return-air grille or supply-air register to the room.
(e) Install a jumper duct.

5.6.3 **Benefits.** Restricted airflow between spaces in a house during air handler operation pressurizes some spaces and depressurizes others. These pressure differentials can increase space-conditioning energy use by increasing exfiltration and infiltration and by causing the air handler to run longer. Field studies have demonstrated as much as a tenfold increase in house air leakage when interior doors are closed and the air handler is operating. Appropriate pressure relief not only decreases the space conditioning energy use, it also increases occupant comfort by increasing conditioned airflow to the room in question.

5.6.4 **Discussion.** If a room with a closing interior door has a supply register, but not a return grille, the closed interior door can block the pathway of supply air back to the return grille. The door acts as a damper to the proper airflow within the conditioned space, resulting in too-hot or too-cold temperatures and “stuffy” air quality.

5.7 **Selection and Location of Supply Registers: Specification.**

5.7.1 At least one supply-air register should be installed in each habitable room that can be closed off from the main body of the dwelling with a door. Each register should be of sufficient size and correct type to properly handle the required CFM and air velocity to meet the design heating/cooling requirements. [Source: SMUD 1998, page 9]

5.7.2 Supply registers should be selected to optimize room air distribution and duct static pressure while keeping air velocity below 700 feet per minute to control noise. [Source: Hammon et al 1999, Appendix A; Manual D; Manual T and SMACNA 1998]

5.7.3 Supply registers should be selected for proper throw, drop and spread to maximize comfort and efficiency. Floor supplies should be located under windows. In cooling-dominated regions, ceiling and high side-wall supplies should be located some distance away from the exterior wall and designed for a throw that reaches the exterior wall.

5.7.4 **Benefits.** Reducing duct surface area – shorter length and reduced diameter – reduces duct leakage and conductive heat transfer, making the duct system more efficient. As building envelopes and windows have improved, the need to install supply registers under windows on exterior walls may no longer exist. If supply registers are installed on or near interior walls, duct runs can be reduced and system efficiency can be increased.

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Some of the comments in the “Benefits” section here might be seen as novel or out of line by some HVAC installers. The comments certainly suggest breaking with the tradition of locating supply registers on outside walls under windows. Some of the reviewers of this Specification have installed supply registers on inside walls, thereby reducing conditioned air energy loss due to leakage and thermal transmission. Changes in the industry are slow because the risks are often high. This is a change that should be tried by installers because it not only has the potential for making a ducted system more efficient, but also less expensive to install.

5.8 **Selection and Location of Return Grilles: Specification.**
5.8.1 Return-air grilles shall be located to provide pressure-balanced air circulation during air handler operation.

5.8.2 Return grilles should be selected to optimize airflow within the occupied space and grille face velocity should be kept to 500 feet per minute or less. [Source: Manual D; Manual T and SMACNA 1998]

5.8.3 It is preferred to place a return-air grille in every room having a supply-air register and an operable interior door, except for bathrooms and kitchens.

5.8.4 **Benefits.** The proper placement of return grilles reduces the occurrence of pressure imbalances between closed rooms during air handler operation. These pressure imbalances can increase space-conditioning energy use by increasing air leakage and causing the air-handler blower to run for longer periods. In addition, they can affect occupant comfort by adversely impacting indoor air quality.

5.9 **Duct Support: Specification.**

Please refer to the supplementary document *Duct Installation and Sealing Specification* for details.

There was discussion regarding the focus and limits of this section of the Specification. Some reviewers wanted to include the details of duct sealing and duct support. Others felt that this was undermining the original objective of the Specification. As a compromise, it was decided to eliminate the details of duct sealing and duct support from this Specification and make Duct Installation and Sealing Specification [Chapter 3 of PG&E 1999 Residential Contractor Program Installation Standards] by Pacific Gas and Electric available as a companion document. This excellent document addresses these areas extremely well.

This document will be made available by the Consortium for Energy Efficiency.

5.10 **Volume Dampers: Specification.**

5.10.1 Supply branch ducts should be equipped with volume dampers to allow for manual balancing of the distribution airflow. The balancing dampers should be located at the takeoff end of the branch duct rather than at the supply-air register. [Source: EWEB 1996, page 7]

5.10.2 After installation, the distribution system should be balanced to ensure the maximum comfort for the occupants. [Source: ACCA Manual D]

5.10.3 Volume dampers should have a means of fixing the position of the damper after the air distribution system is balanced.

5.10.4 **Servicing.** Check distribution balance at servicing. Interview occupants to determine if their thermal comfort is suffering from improper balancing.

5.10.5 **Correction Strategy.** If volume (balancing) dampers have not been installed, put one in each supply branch. After installation, balance the distribution system.

5.10.6 **Benefits.** Volume dampers allow the balancing of the air distribution after installation. This can significantly increase occupant comfort and increase the energy efficiency of the comfort-conditioning system by ensuring that the proper amount of conditioned air flows to each conditioned room.

5.10.7 **Discussion.** When a conditioning system supplies both space heating and cooling, different air-handler blower speeds are used (usually a higher speed for cooling). Since few
systems are re-balanced seasonally to adjust for the different air-handler airflow, a compromise must be made in the design and the balancing of the air distribution system. It is common to select the greater of the two airflow rates for the design of duct branches and registers serving each room. For the purpose of balancing, it is recommended that the higher of the fan speeds be used.

In houses where manual dampers need to be changed seasonally, an automatic zoning system with motorized dampers is the best way to achieve comfort. Two-story homes, homes with occupied basements, and homes with rooms that get intense sun, will need zoning. Zoning can also be done using multiple systems.


5.11.1 When installing the air handler and ductwork, adequate clearance should be provided on all sides to allow easy access for periodic maintenance. Items requiring maintenance include filters, heat exchangers, volume dampers, air handler blowers, refrigeration coils and controls.

Too often the HVAC contractor isn't involved in the planning and scheduling of work early enough in the construction process. The mechanical contractor arrives on the job to discover that the architect and builder haven't provided adequate space for installation of the forced-air system. Carpenters, plumbers, and electricians may have installed immovable objects in spaces that should have been reserved for the ducts, which are after all among the buildings most important and least flexible components in terms of location. To complete the HVAC installation on time and within budget, corners are cut and best practices are overlooked.

From our discussions with installers and researchers, we have found the major problems are:

• Under-sizing ducts and installing too few returns are the biggest obstacles to obtaining proper airflow. These duct design-and-installation problems often leave the heating and cooling capacity of the air handler greatly oversized compared to the air-moving capacity of its blower and ducts.

• Duct leakage resulting from insufficient installation clearances that don't allow complete fastening and sealing of major duct components.

• Improper airflow from dirty indoor coils that are extremely difficult to clean because of lack of access.

• Duct airflow problems relating to the necessity of routing ducts around obstacles and fitting the equipment into a too small space.

We suggest that whenever possible, the HVAC equipment installer be involved in the overall building design process to ensure adequate space for equipment, ductwork, and future maintenance.

5.11.2 All doors leading from the mechanical room to the outdoors should be large enough to allow easy passage of equipment. [Source: Interview with Marshall Hunt]

5.11.3 Verification. Visual inspection at installation.
5.11.4 **Benefits.** Adequate clearance for the maintenance of important equipment components allows the equipment to be serviced properly and regularly, thereby ensuring the maintenance of maximum equipment efficiency.

5.11.5 **Discussion.** If technicians do not have easy access to equipment components requiring periodic inspection and cleaning, these components will go without service and equipment efficiency will suffer. Unfortunately, technicians frequently are provided with too little space to install the equipment with adequate clearance for maintenance. If possible, it is best if the installing technician is part of the design team so ample space for the equipment and ductwork is ensured. During construction, personnel installing the ductwork should have the first opportunity to work in tight spaces, such as framing cavities and chases, because ducts are larger and less flexible than plumbing pipes and electrical wires.

### 5.12 Maintenance Items: Specification.

The following items should be inspected and properly maintained and adjusted at annual servicing for the purpose of maintaining system efficiency.

5.12.1 **Filters.** Verify with visual inspection whether filter requires cleaning or replacement.
   - (a) Clean or replace filter(s) as required. Do not attempt to clean a one-time-use, throwaway filter.
   - (b) Make sure the filter compartment(s) are as tight as possible.
   - (c) If appropriate, educate occupants regarding recommended filter cleaning or changing.

5.12.2 **Duct obstructions and debris.**
   - (a) Check registers and grilles for blockage by carpeting, rugs, furniture or other obstructions.
   - (b) Check register and grille boots for clothing, toys or other obstructions.
   - (c) Clear ducts of any obstruction.
   - (d) Educate occupants, if necessary, about obstructing the flow of distribution air out of supply registers and into return grilles.

5.12.3 **Duct leaks and duct disconnections.**
   - (a) Check by visual inspection and repair, if required.
   - (b) Other tests may indicate significant duct leaks. These include static-pressure changes, indoor-coil airflow rate or temperature rise across the furnace heat exchanger. If any of these tests indicate significant leakage or disconnection, find and repair them.

5.12.4 **Volume dampers.** Check for proper placement, operation, and position.
   - (a) If volume dampers have not been installed in supply branches, install if proper balancing is not possible without them.

5.12.5 **Balancing.** Check for proper system balance, room by room, for heating and cooling. Balance with volume dampers if required.

5.12.6 **Duct sealing materials.**
   - (a) Check the integrity of duct-sealing materials wherever you are able to visually inspect.
   - (b) Other tests may indicate significant duct leakage resulting from failed duct-sealing materials. These tests include static pressure changes, indoor-coil airflow rate or temperature rise across furnace heat exchanger.
   - (c) Replace or repair duct-sealing materials, if necessary.

5.12.7 **Duct Insulation.**
   - (a) Check the integrity of duct insulation and vapor barrier wherever you are able to visually inspect.
(b) Replace or repair if necessary. See Section 5.5 for details.

5.12.8 Check room-pressure differences after installation and at servicing. See Section 5.6 for details.

5.12.9 **Benefits.** Proper maintenance of the forced-air distribution system will help retain system efficiency, extend the life of the equipment and ensure occupant comfort.

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**Items listed above in this section are those that impact efficiency. We did not include items that might have an impact on health and safety, such as proper electrical connections. Therefore, this is not a complete list of all the items that should regularly be maintained and checked.**

Some involved with the design of this Specification felt that health and safety should be included; others thought not. From the beginning, the concept of this Specification was focused on installation practices that impact efficiency. Although health and safety are very important, these items are addressed elsewhere and were thought to be beyond the scope of this Specification.

*Source: Various ACCA manuals, and comments from consultants and industry experts.*

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**Verification Tests**

5.13 **Tests for Ensuring a Tight Ducts.**

5.13.1 **Duct Leakage per 400 CFM Airflow and Duct Leakage to Airflow Percentage Tests.**

*[Source: The Energy Conservatory Duct Blaster Manual]*

(a) **Objectives of tests.**

(1) **Method 1.** Duct Leakage per 400 CFM Airflow: To determine total sum of supply and return leakage from ducted distribution system to surrounding areas and the amount of this leakage per 400 CFM of measured air-handler airflow.

*For new ductwork this is similar to Title 24 of California and for existing ductwork it is the same as the ENERGY STAR Specification for Existing Ductwork. Both of these specifications state allowed duct leakage as a percentage of air handler airflow, as stated below in 5.3.1 (b).*

*The authors thought that duct leakage should also be stated as an absolute about per 400 CFM of measured airflow. The rational is that many HVAC technicians would be able to relate more easily to this method of stating the leakage limits. The percentage statement in 5.3.1 (b) and the absolute leakage per 400 CFM measured airflow in 5.3.1 (a) are equivalent.*

(2) **Method 2.** Duct Leakage to Airflow Percentage: To determine total sum of supply and return leakage from ducted distribution system to surrounding areas and the percentage of this leakage to the total air handler airflow. The leakage test shall be performed at a pressure difference of 0.1 inch water gauge (25 Pascals).

*For new ductwork this is similar to Title 24 of California and for existing ductwork it is the same as the ENERGY STAR Specification for Existing Ductwork. Both of these specifications state allowed duct leakage as a percentage of air handler airflow.*
(b) **Required equipment.**

1. Duct blower.
2. Digital manometer with hoses.

(c) **Setup.**

1. Any door or access between the conditioned space and locations containing ducts shall be closed if the ducts are in unconditioned space (example: attic access panels must be closed). If the duct location is conditioned (example: conditioned basements) the door or access shall be opened during the test.
2. Seal all the supply registers and return grilles, being careful not to damage floor, wall and ceiling finishes.
3. Open a window or door to outside. If the duct blower is attached to the duct system in a garage, then the garage door to outside shall be opened. If ducts are in an unconditioned basement, then the basement door or windows to outside shall be opened. If ducts are in the attic, air must be able to flow freely from the attic space to the outdoors.

(d) **Conducting the test.**

1. Attach the duct blower to the duct system at the air handler blower access so as to pressurize the duct system. If the system fan access is unsuitable for connecting the duct-pressurization device, then make the connection at the return grille nearest to the return plenum.
2. Install a duct pressure probe at both a supply and a return grille or supply and return plenums. Then connect the probes to a manifold using equal lengths of hose to average the pressures in supply and return.
3. Adjust the duct-blower airflow until the pressure between the ducts and the surrounding area is 0.1 inch water (25 Pa).
4. Record duct-blower airflow: This airflow is the sum of supply and return duct air leakage at 0.1 inch water (25 Pa).
5. **Method 1.** Duct Leakage per 400 CFM Airflow: The maximum leakage allowed is found by dividing the measured air handler airflow (see Sections 3.13 or 4.9, Tests for Ensuring Proper Air-Handler Airflow) by 400 CFM. This quotient is then multiplied by 40 for existing duct systems or 25 for new duct systems. The duct-blower airflow (duct leakage CFM) from Section 5.13.1 (d)(4) must be equal to or less than this value. For example, if the measured air handler airflow is 1200 CFM, divide this by 400 CFM to get the answer of 3. For new ducted systems, 75 CFM or less of duct leakage is allowed (3 x 25 CFM) and for existing ducted systems, 120 CFM of duct leakage is allowed (3 x 40 CFM).
6. **Method 2.** Duct Leakage to Airflow Percentage: The duct-blower airflow from Section 5.13.1 (d)(4) is then divided by the result from the selected test procedure listed in Sections 3.13 or 4.9, Tests for Ensuring Proper Air Handler Airflow. The resulting quotient is then multiplied by 100 to convert the answer to a percentage. This is the percentage duct leakage. For example if the measured air handler airflow is 1200 CFM and the duct leakage CFM from Section 5.13.1 (d)(4) is 70 CFM for a new system, divide 70 CFM by 1200 CFM and multiply the answer by 100. This yields 5.8 percent leakage, and complies with the specification for new duct systems.

(e) **Tolerances.**

1. All pressure measurements shall be plus or minus 0.008 inches of water gauge (0.2 Pascals) or 1 percent of reading.
5.13.2 **Test for Determining Duct Leakage to and from Outdoors.** Please Note: This test procedure is not required for compliance with this Specification. It is included here for the information of the Specification user. [*Source: The Energy Conservatory Duct Blaster Manual*]

(a) **Objective of test.**

To determine leakage from ducted distribution system to the exterior of the building envelope. This is accomplished by first pressurizing the house with a blower door to 0.1 inch water gauge (25 Pascals) and then pressurizing the duct system with a duct blower fan until a zero pressure difference exists between the duct system and the inside of the house. Measuring duct leakage to and from the outdoors is often used with whole-house diagnostic procedures for troubleshooting both ducts and the building shell. In this test, the conditioned zones and the ducts are pressurized to the same pressure with reference to outdoors. Since the ducts are sealed and no pressure difference exists between the ducts and the house, all the leakage measured by the duct blower is to the outdoors. This is directly related to potential energy savings from duct sealing.

(b) **Required equipment.**

1. Blower door.
2. Duct blower.
3. Digital manometer with hoses.
4. Materials for temporarily blocking supply registers and return grilles.

(c) **Setup.**

1. Take all appropriate safety precautions to prevent damage of weak structure or ductwork.
2. Remove the air filter(s) from the duct system.
3. Seal all supply and return registers.
4. If ductwork is installed in attics, crawl spaces, or garages, open these spaces to the outdoors so that leaking ducts will not pressurize these spaces.

(d) **Conducting the test.**

1. In a centrally located exterior doorframe, install the blower door to pressurize the home. The blower-door fan should be blowing air into the dwelling.
2. Connect the duct blower to the air handler or to a large return register, oriented to pressurize the ducts.
3. Connect an airflow manometer to measure the fan with reference to the outdoors.
4. Check manometer(s) for proper settings. Dial-and-needle manometers may need warm-up and calibration. Digital manometers require selection of the correct-mode, range, and fan-type settings.
5. Turn on the blower door and pressurize the house to 0.1 inch water gauge (25 Pascals).
6. Connect a manometer to measure pressure differential between the house and ducts. Turn on the duct blower and pressurize the ducts to obtain a house-to-duct pressure difference of zero pressure difference. Make sure the blower door is still pressurizing the house to 0.1 inch water gauge (25 Pascals). Adjust house pressure and zero house-to-duct pressure again with the duct blower, if necessary.

   [i] The best location for measuring duct pressure is often in or near the supply or return plenum. Select a location on the opposite side of the duct system as the duct blower fan. For example, if the duct blower fan is connected to a return register, the supply plenum is a good reference pressure location.
(7) Record duct-blower airflow. This airflow is duct leakage to the outdoors at the test pressure.
(8) After testing and associated air sealing are complete, restore filter(s), remove seals from registers, and check air handler.
(9) Separating supply-duct leakage from return-duct leakage is desirable in many cases because supply leakage is a more serious energy problem than return leakage. Sometimes, however, return leakage is a very important energy and durability factor – in hot, humid climates or in very cold climates, for example. An option for distinguishing supply leakage from return leakage is outlined below.
   (i) Option. Physically separate supply ducts from return ducts. Install a barrier of cardboard or another suitable material between supply and return ducts at the air handler. Often the filter slot will work well for this purpose. Installing a barrier at the return inlet to the air handler allows the supply ducts to be tested with the duct blower attached to the air handler. The return ducts can then be tested with the duct blower attached to a return register. Disconnecting supply or return plenums, and temporarily blocking their inlet to the air handler, is another option for separating the duct leakage measurement.

5.14 Room-Pressure Imbalances Testing.

5.14.1 Room-Pressure Imbalances Test. [Source: Tooley and Moyer 1995]
(a) Objective of test. This test identifies restricted airflow in the duct system and dwelling resulting from closed interior doors.
(b) Required equipment.
   (1) Manometer. A digital unit that records pressure in units of Pascals is preferred because of its greater accuracy.
   (2) One length of plastic hose that will fit on one of the pressure taps of the manometer. The pressure hose must be long enough to extend from the tested room to the outdoors. Another length of hose can be used to extend under the door and into the room being tested or the manometer may simply be located in that room.
(c) Setup.
   (1) Duct sealing should be completed before this test is done.
   (2) Air distribution filters should be clean.
   (3) Air handler should be operating.
   (4) All interior doors should be closed.
   (5) House exterior envelope closed (windows and exterior doors closed tightly).
(d) Conducting the test.
   (1) While standing in the room to be tested, attach one end of the pressure hose to one of the pressure taps on the manometer. Place the other end of the hose outdoors. You are reading the pressure differential between the room in which you are standing with the manometer and the outdoors.
   (2) Close the door of the room, taking care not to completely close off the hose if it runs under the door (compressing the hose will not affect the test, but completely closing it off will yield invalid results).
   (3) Measure the pressure difference between the closed room and the outdoors with differential manometer. Read and record the pressure differential.
(4) Stand in the main body of the house with the manometer, with all the interior doors closed. Read and record the pressure differential between the main body of the house and the outdoors.

(e) **Interpreting the results.**

(1) If the pressure difference between the 1) closed room and the outdoors or, 2) the main body of the house and the outdoors is more than ±0.01 inches water gauge (±3 Pascals), pressure relief is recommended. Refer to Section 5.6.2 for options.

### Key References and Organizations.

*Consumers’ Directory of Certified Efficiency Ratings for Residential Heating and Water Heating Equipment* – commonly called the GAMA Directory – by the Gas Appliance Manufacturers Association. This directory is published each April and October. The cost is $5.00 per issue. It is available from:

- GAMA Efficiency Certification Program
- Intertek Testing Services
- 3933 U.S. Route 11
- Cortland, NY 13045-0950
- Telephone: 607-758-6636

*Residential Comfort System Installation Standards Manual* by the Sheet Metal and Air Conditioning Contractors’ National Association (SMACNA). This manual is available from:

- SMACNA
- 4201 Lafayette Center Drive
- Chantilly, VA 20151-1209
- Telephone: 703-803-2989

*Directory of Certified Unitary Equipment Standards* by the Air-Conditioning & Refrigeration Institute (ARI). This directory is available from:

- ARI
- 4301 North Fairfax Drive, Suite 425
- Arlington, VA 22203
- Fax: 703-528-3816

*Residential Duct Systems: Manual D* by ACCA

*Residential Load Calculation: Manual J* by ACCA

*Residential Equipment Selection: Manual S* by ACCA

These manuals are available from:

- Air Conditioning Contractors of America
- 1712 New Hampshire Avenue, NW
- Washington, DC 20009
- Telephone – 202-483-9370


Available from:
ENERGY STAR - Specification for Existing Ductwork

For information about this ENERGY STAR Specification, call 888-STAR-YES or visit the ENERGY STAR web site at www.energystar.gov.

[End of Specification]

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Endnotes

1 Denise Rouleau of CEE made the initial calls to those on this list.

2 One of the project contractors, Rick Karg, and Ms. South co-presented a workshop at the Affordable Comfort Conference in Ohio in April 2000. The workshop was called “Residential HVAC Installation.” It overviewed the elements of this Specification and the Energy Star Specification for Existing Ductwork. This workshop gave Karg and South an opportunity to receive first-hand reaction from the eighty attendees. The primary concern of the attendees regarding the Specification was the complexity, especially the complexity of duct testing.

3 Rex Boynton, NATE president estimates that there are 500,000 HVAC technicians in the US. NATE is making an effort to significantly increase the number of certified technicians: “. . . we would like to certify as many technicians as we can. We are shooting toward 50 percent of this. . . number to become certified.” NATE has certified over 9,200 technicians as of May 2000. Source: The Air Conditioning, Heating and Refrigeration News, May 8, 2000, pages 1 and 34.

4 Residential Equipment Selection: Manual S describes how to use the manufacturer’s written information to achieve optimum comfort and energy efficiency. Manual S emphasizes the importance of using sensible and latent load data to size and select residential cooling equipment. It gives directions about how to regulate heat-pump auxiliary heat, select fan speeds, select indoor coils, and match cooling equipment to the humidity of particular climates. Our research suggests that the information in Manual S is not well known and not often used, perhaps because of its complexity. For example, fan speed is often selected on the basis of noise reduction and evaporators are chosen by their availability on the distributor’s shelves. Manufacturers should help installers understand the complex information better.


6 The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) publishes such a glossary for the HVAC industry: ASHRAE Terminology of Heating, Ventilation, Air Conditioning, and Refrigeration. This publication addresses the commercial and industrial sectors of the HVAC industry, rather than the residential sector. It serves as a good model for our suggestion of a residential glossary.


10 Properly sizing a heat pump is a complex process if it is done “by the book.” This complexity is probably the primary reason that heat pumps are—apparently—sized with general rules instead of the methods detailed in Manual J and Manual S. Following is an outline of the complex ACCA Manual S sizing procedure:

A. List the design parameters:
   - Cooling.
- Outdoor dry-bulb temperature.
- Indoor dry-bulb temperature.
- Indoor wet-bulb temperature.
- Sensible load from procedure D, Manual J.
- Latent load from procedure D, Manual J.

- Heating.
  - Outdoor dry-bulb temperature.
  - Indoor dry-bulb temperature.
  - Sensible heating load.
  - Emergency heat requirement.

- If there is a ventilation load on the return side or return duct gain, also need.
  - Entering dry-bulb temperature, cooling.
  - Entering wet-bulb temperature, cooling.
  - Entering dry-bulb temperature, heating.

B. Size the equipment for cooling:

- Find the approximate cooling CFM.
  - Calculate the sensible heat ratio (SHR) with this equation:
    \[
    SHR = \frac{\text{Sensible Load}}{\text{Sensible Load} + \text{Latent Load}}
    \]
  - Use this table to determine the appropriate temperature difference (TD):

<table>
<thead>
<tr>
<th>SHR</th>
<th>Leaving Air Temp.</th>
<th>Room D-B Temp.</th>
<th>TD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Below 0.08</td>
<td>54</td>
<td>75</td>
<td>21</td>
</tr>
<tr>
<td>0.80 to 0.85</td>
<td>56</td>
<td>75</td>
<td>19</td>
</tr>
<tr>
<td>Above 0.85</td>
<td>58</td>
<td>75</td>
<td>17</td>
</tr>
</tbody>
</table>

- Use this sensible heat equation to estimate the blower CFM:
  \[
  CFM = \frac{\text{Sensible Load}}{1.1 \times TD}
  \]

- Search for candidate equipment.
  - Appropriate CFM.
  - Parameters from step A, above.
  - If warm to moderate climate, the cooling capacity should not exceed the total cooling load by more than 15%.
  - If cold climate, the cooling capacity can exceed the cooling load by as much as 25%.
  - If the candidate package is short on sensible or latent capacity, check the next larger package.
  - If the capacities of the candidate package exceed the loads, check the next smaller package.
  - If the candidate package is short of sensible capacity, it might be fine if it has excess latent capacity. Add one-half of the excess latent capacity to the short sensible capacity.
o If the candidate package is short of sensible capacity, an increase in fan speed will produce more sensible capacity and less latent capacity.

o If the candidate package is short of latent capacity, a decrease in the fan speed will produce more latent capacity and less sensible capacity.

C. Evaluate the corresponding equipment heating performance:

o Construct the balance point diagram on graph paper from the manufacturer’s information.
  ▪ Graph the heating performance data. Use integrated capacity data; include “defrost knee” in the graphed heating performance line.
  ▪ Graph the performance of the building.
    o First point is Manual J design temperature and design heat load in Btuh.
    o Second point is building balance temperature (where internal gains equal heat loss).
    o Balance point should be from 15 to 35°F.

D. Determine the supplemental heat requirement:

o Supplemental heat + reserve heat = emergency or auxiliary heat.

o Electric resistance coils usually provide supplemental heat. It is activated when the outdoor temperature is below the heating balance point.

o The installed capacity should be equal to or just greater than the difference between the design heating load and the output of the heat pump when it operates at the winter design temperature.

E. Determine the emergency heat requirement:

o Emergency heat is the total amount of heat that can be activated if the compressor fails: electric resistance coils usually provide it.

o Check local codes and utility requirements.

F. Select the resistance heating coil(s) for supplemental and emergency heat:

o Coils can be activated in banks or stages to offer more control over single-stage coils.

\[ \text{Manual J} \]

11 The 8th edition of Manual J is scheduled for publication within the next two years. The 8th edition is specified here because the previous editions are believed to oversize for cooling load. “Many observers have long believed that Manual J is very conservative in its estimation of cooling loads and that air conditioners sized using Manual J will actually be able to meet cooling loads for more than 97.5% [the standard design percentage] of summer hours. These beliefs were confirmed by a recent study in Arizona which suggested that air conditioners sized using Manual J are large enough to meet the cooling needs of a home in virtually every hour of the summer. ACCA subsequently acknowledged that Manual J is outdated and leads to over sizing, particularly in newer homes.” (Neme et al. 1999).

12 The 8th edition of Manual J will include these new features:

• New procedures for multi-zone systems, dwellings with one or two exposures, homes with unusually large glass area and solariums;
• Duct load estimates that are fully compatible with the ASHRAE 152 duct system efficiency standard;
• National Fenestration Rating Council label data for estimating glass load;
• Window shading options;
• Attic radiant barriers;
• Tile roofs (red, white and gray), white metal roofs and sensitivity to shingle color (white, gray or black);
• Log walls and structural foam panels
• Aerated autoclave concrete block walls and insulated concrete walls;
• Options for infiltration loads based on blower door test or Lawrence Berkeley Labs. Leakage area model
• Internal load options and sensitivities;
• Estimated loads generated by any type of ventilation system;
• Blower heat and hot water piping loads; and
• Winter humidification loads. (Source: ACCA News, July/August, 1999, p. 1)

The increased complexity of the 8th edition of *Manual J* will require computer software for cooling and heating load calculations. Once again, the direction of the residential HVAC industry is demanding increased installer knowledge and more expensive tools, in this case a computer and software.

The authors of this Specification suspect that most residential HVAC installers do not use *Manual J* or a similar method for the calculation of cooling and heating loads. They are probably less likely to do so if a computer is required for the load calculation. As a solution to this problem, we suggest that HVAC installers encourage their equipment suppliers to offer the service of *Manual J* load calculation. Many suppliers offer this value-added service to their contractors now.

There are advantages to equipment suppliers performing load calculation services to their contractors: They can more easily absorb the cost of the software (estimated to be from $450 to $800) and suppliers will use the software often—perhaps many times in one day—and will remain familiar with it, eliminating the necessary “relearning” a contractor would have to do using the software just a few times each month. However, the supplier’s load calculations are only as accurate as the house data supplied to them by the HVAC installer. Installers must be reminded of the importance of supplying accurate building data.

13 Bob Davis, Bruce Manclark, Gary Nelson, Jack Orum, and Tom Downey.
14 The test procedure was added at the request of Chris Neme of Vermont Energy Investment Corporation.
17 Telephone conversation with Clay Coombs, Lennox Industries
19 Honeywell Corporation, *Residential Controls for Heating and Cooling*, 1997,
20 Telephone conversation with Tom Downey.
23 The 8th edition of *Manual J* is scheduled for publication in April of 2000 or later. The 8th edition is specified here because the previous editions are believed to oversize for cooling load. “Many observers have long believed that Manual J is very conservative in its estimation of cooling loads and that air conditioners sized using Manual J will actually be able to meet cooling loads for more that 97.5% [the standard design percentage] of summer hours. These beliefs were confirmed by a recent study in Arizona which suggested that air conditioners sized using Manual J are large enough to meet the cooling needs of a home in virtually every hour of the summer. ACCA subsequently acknowledged that Manual J is outdated and leads to over sizing, particularly in newer homes.” (Neme et al. 1999).
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26 See Improving Residential Gas Furnace and Boiler Installation Practices by Jennifer Thorne, page 5-6. Proctor (1991) estimates a 2 percent saving possibility from anticipator adjustment. David Pogany of the Sustainable Resources Center in Minneapolis has a small sample of data that indicates the savings from properly setting furnace anticipators can be much more significant than 2 percent (telephone and letter correspondence with D. Pogany, August, 1999).
27 David Pogany, Senior Energy Analyst, Sustainable Resources Center, Minneapolis, MN. Letter to R. Karg and data logger output for client #13005.
30 For existing ducted systems, based on Specification for Existing Ductwork, an ENERGY STAR® specification, 2000.
31 For existing ducted systems, based on Specification for Existing Ductwork, an ENERGY STAR® specification, 2000.