How Contractors *Really* Size Air Conditioning Systems

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This paper presents results from 489 of the 5559 Florida air conditioning contractors surveyed (an 8.5% response rate) regarding equipment sizing methods in new residences. Air conditioning sizing is accomplished by using ACCA's Manual-J procedure by 33% of the respondents, software by 34.4% of the respondents, square-footage by 24.2% and other estimate procedures by about 8.4%. Those using square-footage estimates varied from 350 square-feet-per-ton to 700 square-feet-per-ton. Over a third of respondents indicated oversizing intentionally on some jobs, in order to avoid complaints, accommodate future expansions, enable quicker cooling down of homes, and to allow for lower cooling set points by homeowners.

The contractors' most popular method of sizing for air distribution was an estimate based on square footage. The variation was considerable, with responses of 0.8 cfm/ft^2 and 1.5 cfm/ft^2 both being common. One in four respondents indicated using methods that lead to inaccurate results. Some of the respondents chided others that size on square footage while others were critical of the Manual J method. A few respondents indicated their dissatisfaction with contractors who oversize systems, while others protested that undersizing is often done in order to achieve the low bid. Quoted comments of respondents are included throughout the paper.

INTRODUCTION

Accurate sizing of residential space-conditioning equipment is an important goal as improperly sized residential systems may increase energy use, aggravate peak load requirements, and reduce effective air dehumidification. Proper sizing of residential Heating, Ventilation and Air Conditioning (HVAC) equipment attempts to size machines large enough to meet thermal loads for peak periods, but small enough to be energy efficient and cost effective. Most researchers agree that there is an energy penalty for oversizing a cooling system. The penalty is approximately 10% for systems oversized by 50% (Henderson, 1992, Lucas, 1993). Those systems will run for shorter periods, resulting in a greater proportion of time running in an inefficient start-up mode. Moisture removal and interior air mixing are also reduced during short run times. Oversizing heat pump units can also lead to inefficiencies in the heating season due to poor operating efficiency at start-up, and anecdotal evidence also suggests that increased compressor duty cycling may lead to shortened system life.

Systems appear to typically be oversized. A study of 75 sites in the Northwest (Lucas, 1993) found that two-thirds were sized greater than that recommended by the Manual J procedure (ACCA, 1986), including a 15% sensible load oversize factor, while a study in Florida of over 400 homes found more than 50% oversized the cooling equipment more than 120% of Manual J (James, et. al., 1997).

Peak summer residential power demand is due primarily to air conditioning. Recent studies (Reddy and Claridge, 1993, Neal and O'Neal, 1994) have shown that cooling electrical demand can be substantially elevated as a result of machine oversizing for a given cooling load. Sub-metered AC data from two Florida studies (James, et. al., 1997, Parker et.al., 1996), also suggests that increased machine size will result in greater utility peak-coincident cooling loads. That is, during the time that the utility is experiencing their greatest summer demand, homes with oversized machines will tend to have a higher power usage than houses with properly sized systems.

Heat gains to buildings occur in a number of ways: conduction through building materials, radiation through windows, infiltration of unconditioned air through building openings, and internal generation of heat by appliances and occupants. Because of the complexity of heat transfer calculations, simplified methods for calculating heating and cooling loads have been developed. However, some of these methods are simply convenient while others may be based on forty-year old home-efficiency measures (Proctor, et. al., 1995). The most widely used calculation for residential heat gain and loss is the Manual J Method developed by the Air Conditioning Contractors of America (ACCA, 1986). Because the Manual J method still involves substantial calculation and numerous tables of multipliers, a number of alternative methods are also used. Computers have the potential to simplify the Manual J procedure, but further simplification may also be needed if accurate sizing is to be routinely accomplished for all new residential construction. An important reason to conduct the survey was the perceived laxity in the professionalism of residential AC sizing. Abrams (1986) summarizes the prevailing view:

The traditional methods of sizing residential air conditioning systems have included the ''front door rule,'' the ''bigger-is-better theory,'' and the ''meanest-dog-on-the-block syndrome.'' The ''front door rule'' calls for the installation of the largest unit that will fit through the front door of the house. It usually results in higher profits for the contractor and completely eliminates any possibility of an owner complaint of inadequate cooling capacity. The ''bigger-is-better-theory'' is applied after a load calculation indicates a reasonably sized unit and calls for adding another ton or so of capacity ''just to be safe.'' Finally, the ''meanest-dog-on-the-block syndrome'' calls for an air conditioner just as large as or, preferable, bigger than the current largest unit in the neighborhood.

A slightly better rule-of-thumb design method is based on the floor area of the house. Typically, it has been suggested that 1 t of cooling capacity be provided for each 500 ft^2 of house. Of all these design methods, only the ''square foor method'' is at all reasonable. However, it should be modified to 1 t per 700 to 1000 ft^2 for most well-designed and quality-built homes and then used only for estimating purposes. Most rules of thumb are based largely on experience with the poorly insulated and leaky houses of the past and are almost certain to lead to excess system capacity and higher costs for the homeowner.

In an effort to determine actual practices of contractors, the Florida Solar Energy Center, under a contract with the Florida Department of Community Affairs conducted a survey of Florida air conditioning contractors to identify how they size systems. While statistical results have been previously reported (Vieira, et. al., 1995), this paper considers in greater depth contractors' reasons for selecting their sizing methodology drawing upon written responses to the survey's open-ended questions.

DATA COLLECTION

Survey instrument

A 28-question survey instrument was mailed to the 450 members of the Florida Air Conditioning Contractor's Association (FACCA). In order to assure a respectable return rate, the FACCA members were sent a letter from their executive director and promised a free copy of the report. The survey was then sent to a purchased list of 5559 Florida HVAC contractors (this list included FACCA members too).

Ninety-two of the FACCA members completed the survey for a response rate of 20.4%, with 397 of the general mailing list completing the survey for a response rate of 7.1%. Another twenty surveys were returned with notes from the contractors explaining that they did not supply systems for new residential construction. The overall response rate was 489 out of 5,559 mailings, or 8.8%.

It seems likely that any bias in the sample is probably toward those with a greater interest in the subject, and possibly in the profession, hence the answers may be skewed towards more detailed methods of sizing. The high representation of FACCA members in the results also skew the results towards more detailed sizing methods (Vieira, et. al., 1995).

FINDINGS

Our analysis of the survey results found the following new residential AC sizing practices:

- Air conditioning sizing is typically accomplished by using the Manual-J procedure by 33% of the respondents, software is used by about 34% of the respondents, square-footage by 24% and other estimate procedures by about 8.4%.

- Of the 27 respondents reporting ''other'' methods, 29% used a utility's short form, 26% used their own calculations, 19% used load sheets or manuals, 11% hired other, 7.4% used personal experience and 7.4% indicated other considerations.

- Of the 127 contractors indicating they used an estimate based on the home's square feet, the most common responses were 500 square feet (36%), 400 square feet (19%), 600 square feet (13%), 450 square feet (9%) and 550 square feet (7%) per ton of cooling. The weighted average was 502 square feet per ton. The range was from 350-700 square-feet-per-ton.

- Fifty-two percent (52%) of respondents use a room-by-room method of sizing, while 41% use whole house and 6.3% use other methods.

- Contractors determine the air flow requirements for each room using a cubic-foot-per-minute (CFM) per square-foot estimate (30%), software (22%), ACCA's Manual-D (20)%, CFM-per-ton of cooling capacity (18%) and other methods by (10%).

- Of the 79 contractors providing a CFM per square foot estimate, 42 of them (53.2%) use 1.0 CFM/square foot—although with a great deal of variability within the group. A value of 0.8 CFM/square foot was the second most popular response (10.1%), and a value of 1.5 CFM/square foot was the next most popular response (8.9%). The mean was 1.04 CFM/square foot.

- Construction drawings are used for obtaining the required building parameters needed for determining the system capacity by 62% of the respondents, with 23% making their own measurements at site and 9.7% not using take-offs. Only 2.8% used other methods.

Inaccurate sizing methods and oversizing

When asked about contractor experiences with ''inaccurate sizing methods,'' some responses were humorous. One said that ''listening to the builder'' was the most unreliable method, while another indicated that ''listening to the home-owner'' was equally problematic.

- One out of four (25.2%) respondents reported some sizing method to be inaccurate. The methods reported are illustrated in Figure 1.

Given that the survey indicated that sizing practice is fairly evenly split between Manual J calculations, computer software and estimation by floor area, it is not surprising that each camp had strong opinions about the other methods. Many using Manual J or computerized methods regarded square footage as an inaccurate means of sizing. The comments of two of these were representative of many:

> *''Square footage is inaccurate because it does not account for exposure, window loads, extent of insulation and type or roof.''*

> *''Advised by a dealer that 750 square foot per ton is enough capacity for a normal residence— that is until the kids come home and the oven is turned on.''*

A number of those using square footage mentioned that not accounting for vaulted ceilings or large expanses of glass could lead to low estimates. However, the square footage camp strongly derided Manual J and computerized methods for generally undersizing units:

> *''Sometimes Manual J shows too small a system. In theory it may be correct, but some customers don't care about cooling costs— they want the temperature in a houses below 75°F.''*

> *''Manual J usually leaves the home short on cooling in this area of Florida. Customer complains on hot days.''*

> *''A certain builder of tract homes had consistently higher than Manual J heat gains; we installed a three ton (Manual J indicated 36,800 Btu/hr) and had to remove them and install 4-ton units to cool the structures. The whole subdivision needed ½ to one ton more than Manual J.''*

> *''Customers tend to require lower temperatures than Manual J calculates or recommends.''*

The most common reported reason for the perceived failure of Manual J or computerized methods was that customers desire lower temperatures than were assumed in the calculations. This was also a very commonly expressed reason for contractor oversizing of AC units.

Others complained that *''computer software is too much trouble.''*

Some 38.5% of respondents indicated that they have at times purposely oversized units. Figure 2 shows the common responses of the 177 respondents who offered explanation of why they oversize. The most popular reason was a customer request.

The survey shows that some contractors use sizing estimation values 50% larger than others for sizing units, and twice as large for determining room air flow. The disagreements on ''sizing philosophy'' are vividly illustrated by the tone of the responses. We received only a few responses emphasizing the need to size units small—a viable means to reduce interior humidity, and improve energy efficiency:

Figure 1. *Inaccurate Sizing Methods According to 25% of Contractors Surveyed (75% did not indicate a problem)*

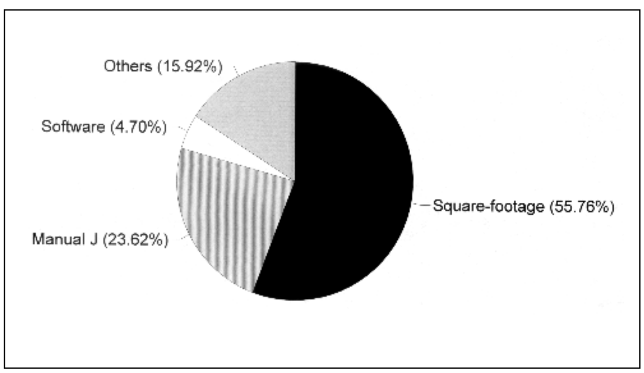
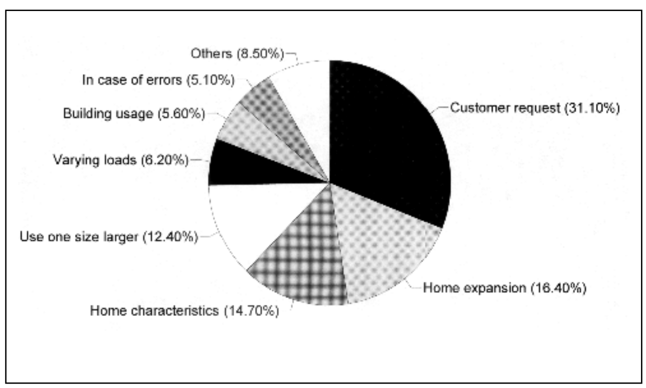


Figure 2. *Reasons for Sometimes Oversizing (38.5% indicated they have)*



''I feel I am one of the few contractors who believe in the proper size equipment (small). I am very careful not to oversize. I believe it adds a lot to the system efficiency and comfort.''

''Never oversize; leaves too much moisture.''

''Oversize at owner's insistence—they sign to assume responsibility for humidity etc.—two or three per year.''

However, these few respondents were completely outnumbered by the ''bigger is better'' school:

''I don't undersize and I never have complaints like some contractors. AC should do 75° on 100° day. I keep good reputation but undersizing beats my price sometimes.''

''Size units and ducting to keep customers happy not what theory proves. I try to put more air in master bedrooms and kitchens.''

''Oversize most of the time because of future expansion.''

''Oversize by 50% so customers will not complain.''

''If the units don't have enough capacity they will not cool down fast enough to make customers happy.''

''I do custom homes and people like it cooler.''

''I go to next half ton up all the time.''

Others indicated that oversizing is prevalent:

''We have observed most other AC contractors and architects grossly oversized units. Customers still believe bigger is better.''

''Some customers and contractors just don't believe load calculation. Especially if other bidding AC contractors specified larger equipment.''

''There are many who are oversizing systems and it is a mess.''

There were some contractors who indicated oversizing for energy efficiency under specific [legitimate] circumstances:

''When using two speed or variable speed equipment.''

''Better efficiency with two speed equipment.''

''Slightly oversize heat pump system to get extra heat to avoid the use of strip heat.''

''Always ½ ton larger on evaporator coil for higher efficiency as per manufacturer specs.''

Other contractors related sizing larger than load calculations because of building conditions such as installations in older homes or in new homes with high ceilings.

These findings leave one to wonder what size is ''accurate?'' Is it the size given by a calculated procedure? Is it the calculation adjusted for an older home or high ceilings or other buildings specific feature not readily accommodated by the procedure? Is it simply the size that will meet the customer's desire to maintain whatever conditions that they want? Is it simply the size that minimizes complaints?

Equipment used on last job

Respondents were asked to provide information about their most recent job, providing another source of information about sizing practices. Almost eighty percent of respondents completed some of these time-consuming questions.

- The floor area of the most recently completed job was an average of 2,148 square feet, with a median of 1,745.

- The cooling capacity on the most recent job showed definite tendencies towards half-ton sizes with 32.5% answering 36,000 Btu/hr (3-ton), 11.8% replying 30,000 Btu/hr, 9.8% answering 42,000 Btu/hr, 6.2% answering 48,000 Btu/hr and 5.6% writing 24,000 Btu/hr. The remainder of the responses were distributed from a low of 18,000 Btu/hr to a high of 186,000 Btu/hr. The mean cooling capacity was 41,776 Btu/hr.

- The cooling unit installed has a SEER less than 10.5 in 45.5% of the responses, 10.5 or greater and less than 11.5 in 27.0% of responses, 11.5 to less than 12.5 in 21.1% of the responses, 12.5 to 13.4 in 4.8% of responses, and a SEER equal or greater than 13.5 in 1.6% of the cases. The mean SEER was 10.9, with a median of 11.0.

General comments

General comments were provided by 100 respondents in response to ''We invite any additional comments.'' Excessive government regulations was listed by 13 respondents:

''I resent government intrusion into our business. The minimal benefit to the public is totally out of proportion to the increased costs.''

Installation comments were provided by 12, software comments by 11, offers of assistance by 10 and comments on load calculation methods by 9. A variety of other comments were given also. A number of contractors commented on the jobs going to the low bidder:

> *''More than ever before in my experience new home construction (projects especially) go to lowest bid. If you try to provide higher than code quality you will not do very much work. This is not really the builders fault, it is the result of buyers who are much more interested in kitchens, baths and low prices.''*

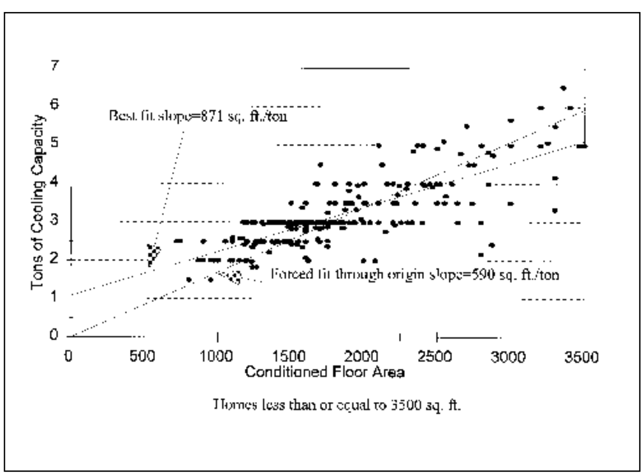
ANALYSIS OF SQUARE FOOTAGE VS. SYSTEM SIZE

Although only one in four respondents reported using square feet as the sizing method, it is still a worthwhile exercise to see how the data from the last job matches up against a square-foot-per-ton standard. The responses to size of house and size of cooling system are graphed in Figure 3 for houses 3500 square feet and under. Larger houses tend to have extremely large variations including very large AC units. Plotting these values would make the rest of the graph too narrow to see most of the data. The ''best-fit'' line in the figure represents the best least squares fit to the data (adjusted R-square = 0.611). The graph shows that:

- Units selected are frequently in half-ton increments, with many units being three tons regardless of size of house.

- The best fit to the data actually has an intercept of greater than one ton (1.12). The slope equates to 887 square feet per ton of cooling. Thus, a 2.5 ton unit would be the best prediction for a 1223 square-foot house, and a 3000 square-foot home would require a 4.5 ton unit.

Figure 3. *Regression of Cooling Capacity on Floor Area for Most Recent New Home AC Installation*



- There is more variety in air conditioner size as the house size increases.

A second line shown in Figure 3 forces a linear fit to the data to go through the origin (0 tons for 0 square feet). Contractors reported simple square-feet-per-ton units, not an intercept and slope. Thus this force through the origin should more closely approximates what contractors are doing .This forced ''best'' fit has a slope that equates to 590 square-feet- per-ton. Under this scenario, a 2.5-ton unit would be appropriate for a 1475 square foot house, and a 3000 square-foot house would require a 5.1 ton unit. Note that this forced fit regression line tends to fall below most of the data for houses 1500 square feet and under and above the data points for houses between 2500 and 3500 square feet. Because the internal loads (people, refrigerators, etc.) do not tend to linearly increase with house size, this trend is as expected.

The strength of these regression fits to the data are only moderate. If contractors were all using the same square-foot-per-ton criteria the regression would provide a better fit. Thus, it is apparent that no simple square-footage-per-ton measurement describes industry practice. However, that does not mean that every unit is carefully sized. The large number of three-ton units suggest that some contractors may not be sizing at all, just putting in an available unit of certain size in every house. Comments also showed a strong conviction of the viability of the square-foot method by among some contractors and a perceived lack of need for precise sizing by others. Compare these contractor remarks:

> *''I have worked in the business for 25 years and in upper level for last 16. We have found that almost always the square foot method is the most accurate. All the customers we have used this on are satisfied.''*

> *''I believe you should know how to calculate a load so you will know what affects your load, but many things are not always included and most homes generally use about the same tons per square foot and bidding would be more costly if you figured every house.''*

> *''Sizing of residential systems for normal to standard homes has been done millions of times by others. It is therefore a waste of time for an experienced contractor to spend much effort and time to attempt to differentiate 2-½ to 3 or 3 to 3-½, etc. It is insignificant in terms of energy usage!''*

CONCLUSIONS

The use of surveys of HVAC professionals seems to be a useful tool to understand industry practice, e.g., the sizing of systems for new homes. Based on the most popular answers the typical Florida contractor:

—Uses computer software or Manual-J for system sizing

—Sizes by room-by-room procedures

—Estimates air flow by square footage

—Uses construction drawings to obtain take-offs

There were significant differences in response to certain questions. Square-footage system sizing estimation methods were used by 24% of respondents, with ranges varying from 350 square feet per ton to 700 square feet per ton. Thirty-eight percent of respondents have at times purposely oversized units—often to provide lower interior temperatures at the homeowner's request. Of the 79 contractors who supplied estimates of their CFM-per-square-foot rule-of-thumb, 42 (53%) use 1.0 CFM/square foot. A value of 0.8 CFM/square foot was the second most popular response (10%), and a value of 1.5 CFM/square foot was the next most popular response (8.9%).

One of four respondents indicated they had found a sizing method to be inaccurate. There are strong convictions on the part of some contractors regarding proper sizing method with a vast majority of these determined to oversize to avoid call backs and meet lower temperature demands. A minority felt strongly, however, that equipment should not be oversized. Competition was often mentioned as an impediment to proper sizing. Some contractors complained that their competitors are undersizing to obtain low bids, while others indicated that they size accurately but have a difficult time explaining to buyers why their size is correct compared to the bids received from competitors.

Imagine taking the time to complete detailed procedures in order to size the units correctly, but not being able to convince the buyer that the other competitors are incorrect?. Why work so hard and not get the job? It might indeed be easier to put aside some professional preferences and use a quick estimating procedure to keep costs low. Furthermore, by providing a larger unit than needed, contractors may be able to reduce about their duct tightening efforts as the house conditions may remain comfortable (albeit at a greater energy cost). Thus, some of the economic forces of competition seem to work against detailed sizing methods. On the other hand, because unit cost increases with capacity, the economic forces of competition should reduce occurrences of gross oversizing. As a practical matter, it is likely that non-bidded jobs are where sizing estimates vary the most. Some contractors may go for ''bigger is better'' philosophy and do a quick estimate assuring to oversize, and charging for the bigger unit. Other contractors, knowing they have the job, will do a detailed calculation and choose a unit appropriately sized, charging enough to have made the detailed calculation worth the trouble.

There may be some hope for improvement. Computerized drafting and sizing methods may reduce the problem in new homes. As energy programs that work off computer-assisted-drafting (CAD) packages become more prevalent, the difficulty of calculating and entering the input data will be reduced. However, not all homes are designed on the computer. There are software tools that perform detailed sizing procedures and are user-friendly, but they still require the correct inputs. The other factor leading to better sizing arrangements may be requirements for sizing calculations as part of an energy code or building permit process. Florida requires an HVAC sizing calculation to be attached to the energy code form when submitted. The 1995 Model Energy Code (CABO, 1995) requires ASHRAE (ASHRAE, 1993) or ''equivalent computation procedure.''

ACKNOWLEDGMENTS

The authors would like to thank Mo Madani and Ann Stanton of the Florida Department of Community Affairs for their valuable insights, support and review of this project. Janet Ficarrotto and the board of directors of FACCA helped considerably by granting permission and then mailing the questionnaire to their members. Tim Merrigan, Denny Conlan, and Don Shirey provided valuable input to the design of the questionnaire. We would also like to thank David Fisher for checking a sample of questionnaires for valid computer entry, and Wanda Dutton for word-processing.

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