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Residential Cooling Load Calculation Methods Analysis

Contractor Recommendations
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Prepared for:
Pacific Gas & Electric Company
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INTRODUCTION

Proper sizing of air conditioning systems has been the subject of discussion throughout the years. It is generally accepted that "the right way" to specify an air conditioning system is to calculate the loads, select a piece of equipment that will provide comfort to the customer over a wide variety of conditions, and design the duct system to those loads and compatible with the equipment. Unfortunately for the HVAC industry and for the customer this is rarely practiced.

In order to design an efficient and effective air conditioning system the load must first be estimated. The Air Conditioning Contractors of America (ACCA) conducted an all industry study of residential cooling load calculations and developed Manual J to estimate these loads. Manual J was adopted by ACCA and the Air-Conditioning and Refrigeration Institute (ARI).

ACCA has also produced Manual S for selecting equipment and Manual D for duct design (revised in January 1995). Manual S selects air conditioners based on the estimated sensible and latent load calculated for the particular house in the local climate. If either the load calculation method or the sizing method is flawed or the incorrect input is used, the equipment will be incorrectly sized and will not perform as it should.

Field studies have shown that most equipment is substantially oversized compared to Manual J. A study for Pacific Gas and Electric Company (PG&E) found that 53% of the air conditioners were a ton or more oversized. In a study by Pacific Northwest Laboratories, a third of the air conditioners were a full ton or more oversized.

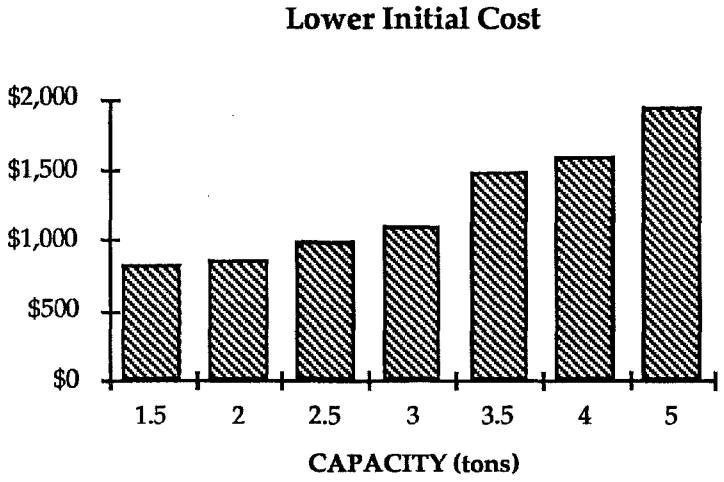
Because of the efficiency penalty of oversized air conditioners, PG&E commissioned a study by Proctor Engineering Group to compare common load calculations and sizing methodologies to Manual J calculated loads.

WHAT IS "PROPER" AC SIZING?

Since optimum efficiency is achieved at continuous running, it is important that the air conditioner be sized to achieve the longest run times possible. A properly sized air conditioner will operate at full load for only 72 hours of the year. This is known as the "2.5% Design". During the rest of the time it will operate at less than its potential efficiency.

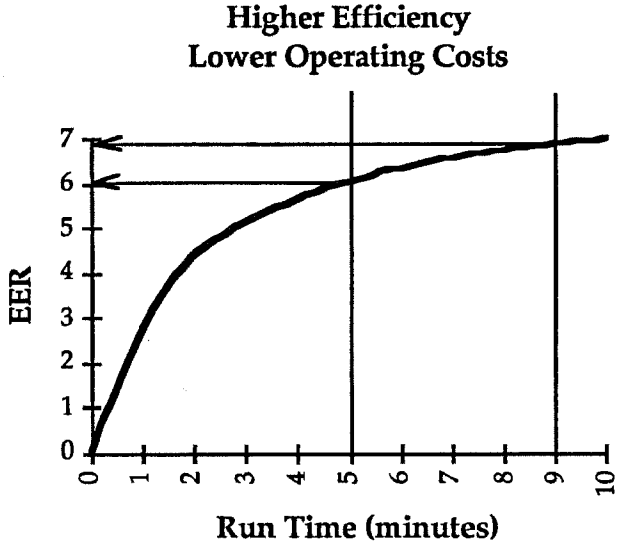
A properly sized air conditioner should provide maximum value to the customer as well as a reasonable profit and further customer referrals to the contractor.

ADVANTAGES OF PROPER SIZING



Initial Air Conditioner Cost (quoted wholesale)

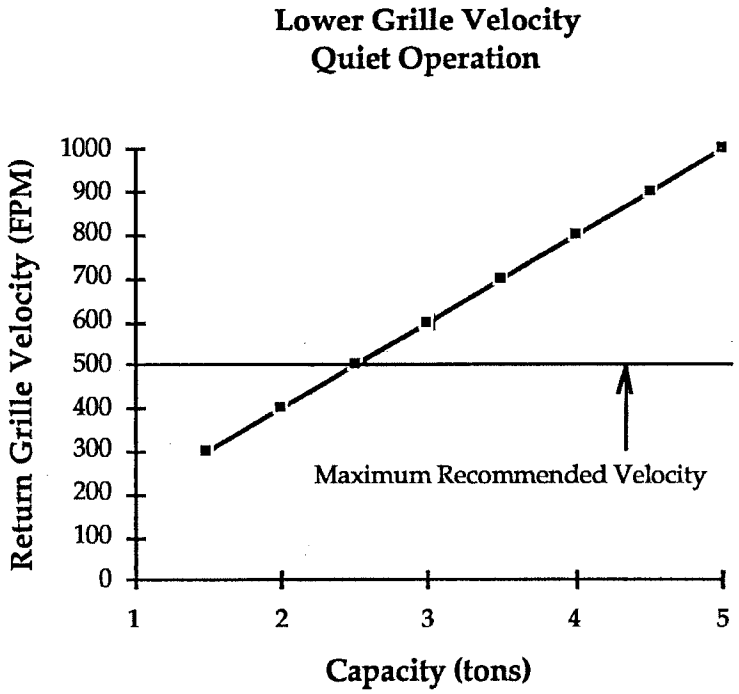
The customer is often dependent on the expertise of the contractor in selecting an air conditioner. Contractors generally size air conditioners at least a half ton larger than necessary and often oversize by a ton or more. A properly sized AC would cost the customer less. The contractor has the opportunity to discuss the value of the air conditioner based on the delivered efficiency and at the same time reduce the initial cost of the equipment.



Air Conditioner Efficiency vs. Run Time

Air conditioners are very inefficient when they first start operation. It is far better for the air conditioner to run longer cycles than shorter ones. The efficiency of the typical air conditioner shown above increases the longer it runs. If the on time of the air conditioner is only 5 minutes the efficiency (EER) is 6.2. If on the other hand a properly sized air conditioner were used (one 50 % smaller), the same amount of cooling would take place in less than 10 minutes, and the efficiency would rise to 6.9. This represents a savings of 10% for the customer. Most of the cooling season the cooling loads are well below the capacity of properly sized air conditioners, and for oversized units the short cycling is a substantial problem.

At the beginning of the air conditioner cycle the latent capacity of an air conditioner is very small, therefore, in humid climates properly sized air conditioners will do a far better job of removing moisture from the air than oversized units.



Return Grille Velocity for a Standard 2 ft. X 2 ft. Grille

When a properly sized air conditioner is used, it is far easier to have sufficient supply and return grille area to keep the velocities low and the noise at a minimum. One of the most common complaints about oversized air conditioners is that they "blast me with frigid air" and that "it is really noisy". A properly sized air conditioner will provide longer cycles and more consistent temperatures with better mixing of the air.

ACCA Manual D specifies a maximum return grille velocity of less than 500 feet per minute and a maximum supply outlet of less than 700 feet per minute.

STUDY DESCRIPTION

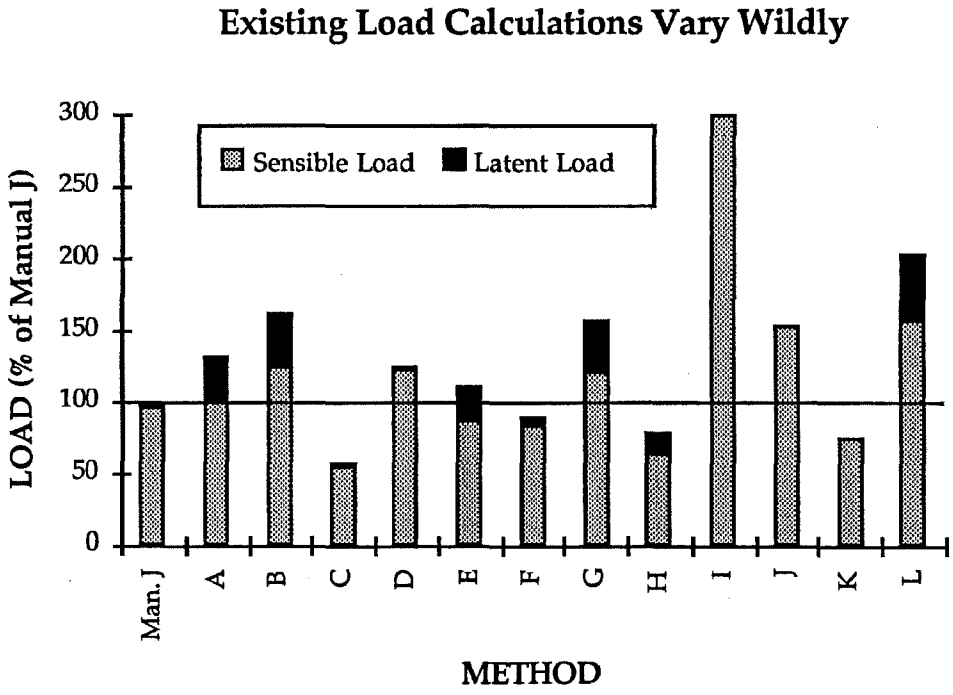
The PG&E study consisted of comparing over 40 different load calculation methods submitted by manufacturers, distributors, and contractors to Manual J. Manual J was used as a baseline because it is the most widely accepted load calculation methodology and is generally recognized as providing a conservative estimate of cooling load. Some experts believe that Manual J consistently overestimates the load by 20%.

In the second part of the study, four different equipment selection methods were compared to determine how close the selected equipment capacity came to the

calculated load. The capacity of an air conditioner is dependent not only on the outdoor conditions, but also on the actual indoor conditions. Proctor Engineering Group developed a procedure for estimating the actual indoor wet bulb conditions at design. By knowing both indoor and outdoor conditions the capacity of the selected air conditioner was determined.

For both parts of the study, loads were calculated for buildings of different age and construction in two different climate zones.

STUDY RESULTS - LOAD CALCULATIONS



The methods that yielded building loads no greater than 20% over Manual J were approved as received. This group included 4 worksheets, 1 calculator method, and 5 computer programs. After suggested changes were made an additional ten methods came within 20% of Manual J. This second group included 7 worksheets, 1 calculator method, and 2 computer programs. Altogether 50% of the submitted methods were approved.

On average, methods that were not approved estimated the load for at least one prototype building 45% greater than Manual J. In extreme cases the load was overestimated by more than 100%. Some of the methods that were reviewed were based on outdated information from as much as 40 years ago. These

methods ignored the latest developments in building insulation, windows, and air tightness.

Many of the submitted methods have been used for many years by local contractors. Since they have had few or no complaints of inadequate cooling they consider their method sufficient. Unfortunately they are significantly oversizing units particularly on newer more energy efficient homes.

Significant Shortcomings

A number of the methods did not calculate the latent load of the home. Many assumed that the latent load was 30% of the sensible load. The actual latent load is highly dependent on the air tightness of the home and the local climate. For hot dry climates the latent load will be far less than 30% particularly if the house has a large amount of air leakage from the attic. For humid climates the latent load can be higher than 30% of the sensible load if the house has a significant amount of air leakage.

Infiltration loads (air leakage) were not specifically addressed or were calculated by an oversimplified procedure. It was often assumed that infiltration rates were the same in all buildings or only depended on floor area. With the widespread use of blowerdoor testing we now know that homes vary significantly in their leakage rate.

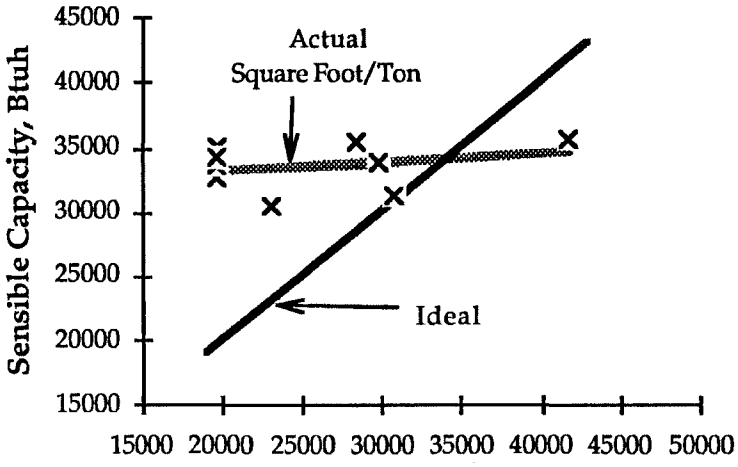
With the amount of data required to do an accurate load calculation, the possibility of errors is increased. Even the computerized methods of load calculation were seriously lacking in error checking procedures that could catch operator errors.

Many of the methods oversimplified the process and gave insufficient options for climate, building assemblies (windows, doors, walls, etc.), and shading.

The effect of duct leakage has only recently been investigated to any significant extent. As a result, cooling loads due to duct leakage is not included in any of the methods. Some new programs have begun to treat duct leakage as if it were infiltration. This is an inadequate treatment of duct leakage effects.

STUDY RESULTS - EQUIPMENT SELECTION

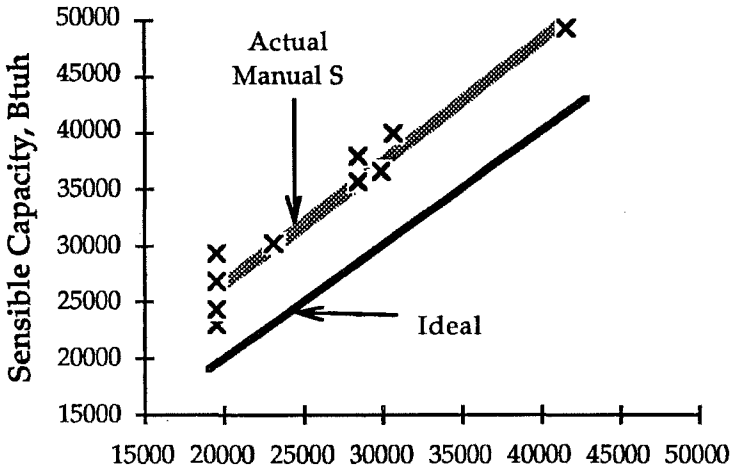
Square Foot/Ton
Oversizes for Energy Efficient Buildings
Undersizes for Older Buildings



Common Rule of Thumb Sizing Method

A common method used by contractors, the "square foot per ton" sizing methodology avoids calculating the cooling load of the building and proceeds directly from the square footage of the building to the size of the air conditioner. The more sophisticated of these methods uses mental categorization of a low, average, or high cooling load. Even with this level of sophistication this method falls far short of properly sizing air conditioners.

Manual S
Provides an Oversizing Margin
in Hot/Dry Climates



Manual J

Manual S is based on a design inside wet bulb temperature of 62°F. The actual indoor wet bulb temperature in much of the western United States (including California, Nevada, Arizona, New Mexico, and parts of Texas) is closer to 58°F or less. The amount of moisture in the air at design is less in Phoenix, Arizona than it is in Riyadh, Saudi Arabia.

Because Manual S controls oversizing only based on sensible capacity, and because the actual indoor conditions are not considered in equipment selection Manual S oversizes air conditioners in hot/dry climates.

Both Manual J and Manual S are conservative. If these two methods are applied there is no reason to add additional "safety factors" when selecting air conditioning equipment.

Other Selection Methods

Air conditioners selected based on standard indoor conditions of 80°F with 50% relative humidity will be incorrectly sized for the calculated design conditions of 75°F. Selection based on total capacity alone can result in improper sizing

depending on the local climate (it is possible to be oversized in sensible capacity and undersized in latent capacity).

Unfortunately many of the major manufacturers do not provide sufficient performance data on their equipment at the actual design conditions (75°F with different amounts of indoor humidity). It would be a major improvement if the manufacturers provided direct sensible and latent capacity data at 75°F for various indoor wet bulb temperatures.

RECOMMENDATIONS

- Check all numbers for consistency. For example, in typical construction total area of exterior walls facing North or East (including a wall to garage) is usually equal to the total area of the opposite South or West walls; ceiling area is usually equal to the building footprint area; window area is usually from 10% to 25% of the floor area; gross wall area is bigger than the window area.
- Use design outdoor conditions and daily temperature range exactly for your location per Manual J or ASHRAE otherwise use the data for the closest location with the similar climate.
- Use standard 75°F design indoor temperature.
- Consider both location and level of insulation of ducts.
- When selecting cooling factors for roofs, floors and walls consider their R-value and type, for example frame wall or masonry wall. Partitions and knee walls that separate a conditioned space from an unconditioned space like attic or garage shall be treated separately from the exterior sunlit surfaces.
- Pay great attention to window type, material and interior shading. An error in this area can throw off the window heat gain by as much as 100%.
- Always account for the effect of the overhang shading. This is one of the most efficient load reduction measures. When calculating this effect consider window height, overhang length and distance to the top of the window as shown on page 30, Manual J.
- Calculate infiltration rate depending on airtightness of the building.
- Calculate the latent load based on the number of people and the outdoor air humidity ratio. Do not use a "typical" multiplier of 1.3 or any other to calculate the total load from the sensible load. This implies that every building has a latent load that is exactly equal to 30% of its sensible load and that the quality of construction and location are not important. It also means that if you add a new source of the cooling load, for example

another window the moisture gains will also increase. This simply is not accurate.

- Consider ventilation load if appropriate.
- Select equipment based on the detailed manufacturers' performance data. Do not rely on the nominal tonnage since different units may have more than 10% capacity difference.
- Select equipment based on the ACCA Manual S without using any safety factors. This method selects the unit which has the sensible capacity at least equal but no more than 15% greater than the building sensible load, and the latent capacity equal or greater than the latent load at standard indoor conditions of 75°F dry bulb/62°F wet bulb temperatures. For PG&E's service territory using Manual S automatically means that the unit will be oversized by approximately 20% compared to Manual J load.

About the Authors:

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