The Impact of Residential Air Conditioner Charging and Sizing on Peak Electrical Demand

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Electric utilities have had a number of air conditioner rebate and maintenance programs for many years. The purpose of these programs was to improve the efficiency of the stock of air conditioning equipment and provide better demand-side management.

The study examines the impacts of proper servicing, system sizing, and equipment efficiency on the utility peak demand from steady-state operation of residential central air conditioners. The study is based on the results of laboratory tests of a three-ton, capillary tube expansion, split-system air conditioner, system capacity and efficiency data available from manufacturer's literature, and assumptions about relative sizing of the equipment to the cooling load of the residence. A qualitative discussion is provided concerning the possible impacts of transient operation and total energy use on utility program decisions.

The analysis indicates that proper sizing of the unit is the largest factor affecting energy demand of the three factors (sizing, charging, and efficiency) studied in this paper. For typical oversizing of units to cooling loads in houses, both overcharging and undercharging showed significant negative impact on peak demand. The impacts of SEER changes in utility peak demand were found to be virtually independent of oversizing. For properly sized units, there was a small peak benefit to higher efficiency air conditioners.

Introduction

Electric utilities programs can have a significant influence on the customer's choice of air conditioning equipment. Many utilities are required by regulatory agencies to make a valid attempt to influence customers' decisions in order to provide a good economic choice for the individual customer. For demand-side planning purposes, the utility's influence on the individual customer choices should be such that all electricity users benefit from programs sponsored by electric utilities. Such benefit is typically obtained when the individual decision adds less demand to the utility peak but uses approximately the same electrical energy. This decision provides for maximum use of fixed costs of the central electric system (plants, distribution system, etc.) and delays the need for additional generation capacity which is more expensive than existing capacity. Federal and state governments can also impact the choice of central air conditioners/heat pumps through requirements mandated by legislation. The National Energy Efficient Appliances Act requires an SEER of 10 for all split-system central air conditioners or heat pumps manufactured after January 1, 1992, and an SEER of 9.7 for all package systems manufactured after January 1, 1993 [1].

Electric utilities have much broader choices in programs to impact customer choices concerning central air conditioners and heat pumps. Examples of programs which utilities have include:

(a) low-cost financing based upon equipment efficiency (i.e. higher SEER receive financing at a lower interest rate)

(b) incentives to dealers based upon equipment efficiency

(c) inspection programs to assure proper sizing and correct installation prior to payment (from financing programs)

(d) guarantee programs (comfort guarantee, service guarantees, etc.)

(e) dealer training programs - proper sizing, proper quotation procedure, loads calculations, etc.

(f) technical training of service technicians (proper airflow, proper charge, troubleshooting)

(g) technical training on installation (ductwork quality, sizing, location of ducts, supplies, and returns)

(h) special incentives for instruments and equipment necessary to do quality installation and service.

To properly evaluate a program for its potential utility and customer benefits, it is necessary to know how the program can impact the utility coincident peak demand, the air conditioning/heat pump annual energy use, and the life of the equipment. Some computer studies have been performed concerning the impacts of increased equipment efficiencies on customer energy use and utility diversified peak demands [2, 3]. These studies have not been validated by field results and many technical questions still exist concerning proper modeling of air conditioning from the aspects of load, equipment operation, the impact of humidity, and occupant behavior.

This paper examines the effect of refrigerant charging (proper servicing of the equipment), system sizing, and efficiency on the steady-state, coincident peak utility demand of a residential central air conditioning system. The study is based on the results of laboratory tests of a three-ton, capillary tube expansion, split-system air conditioner, system capacity and efficiency data available from manufacturer's literature, and assumptions about relative sizing of the equipment to cooling load on a residence. A qualitative discussion is provided concerning the possible impacts of transient operation and total energy use on utility program decisions.

Experimental Setup and Results

To assess the effect of refrigerant charging on the performance of an air conditioner, a nominal 3 ton unit was obtained from a major manufacturer. The unit had capillary tube expansion and had a rated SEER of 9.7 [4]. A capillary tube unit was used because the manufacturer of the unit felt that this was more representative of many of the units currently in the stock of air conditioners in the field. Two subsequent studies have been performed on units with TXV and orifice expansion[5, 6].

A series of tests was run on the unit to determine its capacity and power as functions of refrigerant charge and outdoor temperature. The unit was charged to manufacturer's specifications to determine the proper refrigerant charge in the unit. This proper charge was 140 ounces. Tests were then run at 20% under, 10% under, proper, 10% over, and 20% overcharge for four outdoor temperatures: 82, 90, 95, and 100°F. All tests were conducted in psychrometric facilities under controlled temperature and humidity conditions. Indoor conditions were 80°F dry bulb and 67°F wet bulb. Complete details of the tests can be found in reference 4.

Figure 1 presents the capacity variation for the test air conditioner from 82°F to 100°F at various states of charge from -20% to +20%. Note that there is a "cross-over" point on these curves at about 96% correct charge below which charge level higher outdoor temperatures produce greater capacity than low outdoor temperatures. Above a refrigerant charge of about 96% correct charge, higher outdoor temperatures produce lower capacities.

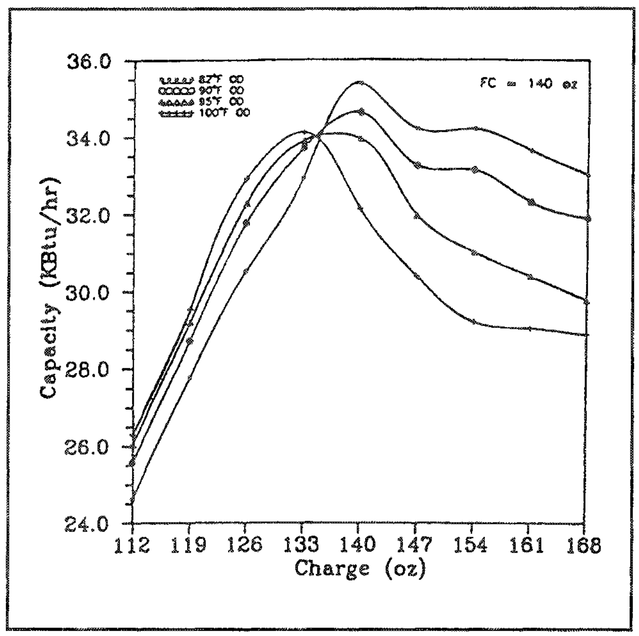

Figure 1. Measured Capacity as a Function of Charge and Temperature for a Capillary Tube Expansion Air Conditioner [4]

Figure 2 shows the measured power demand of the outdoor unit as a function of outdoor temperature and for charges ranging from -20% to +20% of proper charge. (Note: the tests were done in a laboratory setting with no indoor air handler. To approximate a true system in a house the draw of a three-ton air handler is added to the

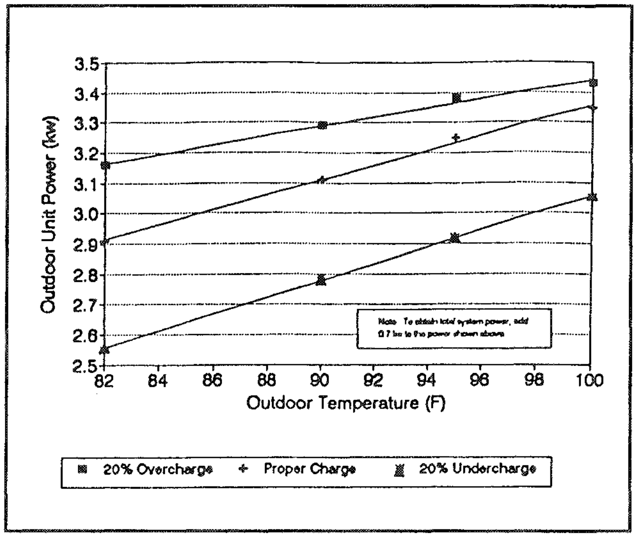

Figure 2. Linear Variation of Power with Respect to Temperature for Three Charging Conditions [4]

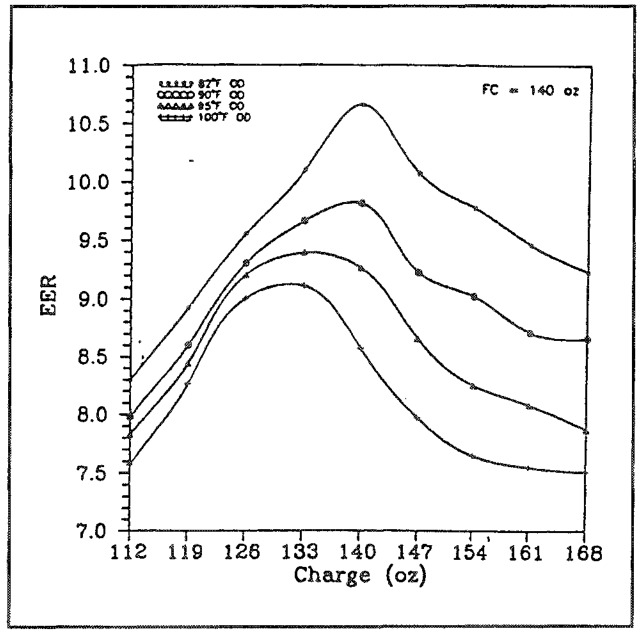

Figure 3. Variation of Steady State Energy Efficiency Ratio (EER) With Refrigerant Charge and Temperature

graph reading. This addition power demand is assumed to be 0.7 kW This figure shows that the undercharged unit has a lower demand than the correctly charged unit at all outdoor temperatures while the overcharged units always has a higher kilowatt demand than the correctly charged unit.

The steady-state efficiency of an air conditioner is typically expressed as the energy efficiency ratio (EER) and is found by dividing the capacity by the power input. As shown in Figure 3, the EER is highest at 82°F for the properly charged (140 oz) unit. The efficiency at all charges decreases with increasing outdoor temperatures. However, the peak efficiency shifts to 5% undercharging at 100°F.

Manufacturer's Data

To assess the potential impact of sizing on the utility peak, steady-state data on similar capillary tube expansion units were obtained from the manufacturer of the unit tested. Figure 4 shows the electric demand variation with capacity at the 95°F outdoor temperature design temperature condition for a number of units available from the manufacturer. A straight line was fit through the data to obtain a relationship between the power demand versus capacity. All units had SEERs between 10.0 and 10.8. We are interested in the total electrical demand of the air conditioner system. These curves indicate that for a manufacturer's "series" of equipment there is a trend

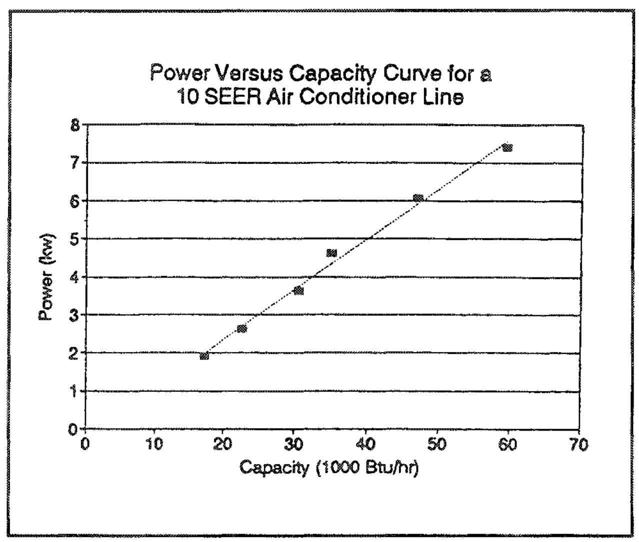

Figure 4. Power Demand as a Function of Capacity for a Line of SEER 10 Air Conditoners

toward lower EER at higher capacity for a temperature of 95°F. For instance, the 60,000 Btu/hr unit had an EER of 7.9 btu/w-h while the 18,000 Btu/hr unit had an EER of 8.4 btu/w-h. A similar line of units with nominal SEERs of 12.0 showed a similar trend.

Analysis of Peak Load Effects

These four figures provide much of the required data necessary to study the impacts of the following variables on the utility peak hourly demand of central air conditioning:

(a) Sizing

(b) Efficiency (EER)

(c) Proper charge.

Before analyzing the potential impact of these factors on peak demand, several important assumptions need to be stated and discussed. These include:

(1) The utility peak load occurs at 100°F. This value was chosen because the maximum temperature data for the laboratory tests was at this temperature. This value for outdoor temperature is probably reasonable for many utilities around the country. It underestimates the temperatures during peak air conditioning for utilities in the Southwest but may overestimate temperatures for utilities in the Northeast.

(2) A properly sized air conditioner will exactly match the cooling load at 95°F outdoor temperature. This assumption in critical. The 95°F temperature is the Air Conditioning Contractor Association (ACCA) Manual J design temperature for southern cities such as Houston, TX, Montgomery, AL, and Augusta, GA [8]. Note that a perfect Manual J calculation would yield design loads about 25% higher than the true load due to conservative values built into the heat gain factors. Note also that the assumed utility peak occurs at an outdoor temperature 5°F above the design temperature and thus the air conditioner would not be able to keep up with the cooling load if it were perfectly sized for 95°F.

(3) The cooling load increases linearly as the outdoor temperature increases. The cooling load is assumed to be zero at an outdoor temperature of 70°F. This would assume an internal heat gain equal to approximately 8°F if the thermostat setting is at 78°F. The house load is also assumed to be equal to the test unit's capacity at 95°F and proper charge, which is 34,000 btu/hr. While a more complicated model that included humidity and internal load schedules could have been utilized, the simple model for a house load provides significant insight into the effect of sizing, charging, and efficiency. Potentially, a more complicated model could provide better quantitative estimates of the effects of these variables. The cooling loads required by the house for temperatures between 80 and 100°F are shown in Table 1.

Table 1. Cooling Loads for the House as a Function Outdoor Temperature

Temperature (F)	Cooling Load (Btu/h)
80	13600
85	20400
90	27200
95	34000
100	40800

The capacities and kW draws are read from Figures 1 and 2 at the four temperatures and for the conditions of 20% undercharged, properly charged, and 20% overcharged. When the house load exceeds the capacity, the equipment will run for the full hour. When the capacity exceeds the load, the fraction of the hour which the equipment must run to satisfy the load is calculated. For a full run hour the utility demand is simply the equipment demand. For a fractional hour operation, the utility demand is the hourly fraction of the equipment demand at that operating condition.

(4) No attempt is made to account for the effect of cycling on the air conditioner's performance. When an air conditioner cycles, it typically requires six to ten minutes to reach steady-state conditions and starting power requirements are higher than during normal running operation. If cycling were included, it would be expected to increase the estimates of both the energy and power.

(5) The fraction of time the unit is on for the peak hour is assumed to be equal to the capacity of the unit divided by the cooling load of the house. When the cooling load is greater than the capacity, the unit is assumed to run continuously.

(6) Residential air conditioning occurs during the coincident peak demand of electric utilities. This

assumption will only be true for summer peaking utilities whose peak occurs during the hottest part of the summer.

(7) The trends observed in the unit (Figures 1, 2 and 3) in the psychrometric tests are typical of other capillary expansion systems in the field. One danger of using data from a single unit to extrapolate to the population of the field units was that it is not known how unique the unit tested was. The unit was an "off-the-shelf" system with no special modifications made for the psychrometric room tests. While it would have been preferable to test a large number of units to get a large cross-section of systems with respect to size and manufacturer, the costs for testing them would be prohibitive.

To examine the effects of sizing of the equipment relative to the load, additional equipment was selected in sizes ranging from 36000 Btu/h to 68000 Btu/h. Power draw for SEER 10 units was developed from the data presented in Figure 4. Power demand ranged from 3.70 kw for a 36,000 Btu/h unit to 6.85 kw at 68,000 Btu/h. To estimate the performance of these units at under and overcharged conditions, it was assumed that the percentage change in capacity and power measured in the test system in the laboratory could be directly applied to the published steady-state data of the systems in Figure 4. For instance, at 100°F, the capacity for the 20% undercharged system was 18.1% less than the properly charged system. This percentage would be applied to all the capacities of the larger systems to determine the degradation in capacity for 20% undercharging at those sizes for 100°F outdoor temperature. Similar corrections in the power demand were also made. Because all are capillary tube designs of the same series by the same manufacturer, this is a reasonable engineering assumption. Table 2 lists results for system sizes of four capacities.

The capacities and power draws for all off-design conditions are read from Figures 1 and 2 as ratios to the design performance (i.e. 95°F, properly charged). These off-design performance ratios are then applied to the design performance for the different SEER-rated and variously sized air conditioners. The values for selected SEER 10 units are tabulated in Table 2 as an example. The simplified utility diversified one hour demand is simply the unit demand for a full hour run (when the load exceeds the capacity) and is the fraction of the hour multiplied by the unit power demand when the unit more than meets the load. For example, from Table 1, at the utility peak hour of 100°F the minimum run time of the 60,000 Btu/h air conditioner to meet the load is about 47 minutes (i.e. 0.78 hour).

Using the actual house load at 95°F as 34,000 Btu/h, a 40,000 Btu/h unit is oversized by 18%, a 54,000 Btu/h unit is oversized by 59%, and a 60,000 Btu/h unit is oversized by 75%.

Results

Figure 5 shows the utility peak hour demand (at 100°F) in kilowatts versus oversizing percentage for different refrigerant charges. The oversizing percentage is defined as:

$$\%\ True\ Oversizing = \frac{(Properly\ Charged\ Equipment\ Capacity\ @\ 95°F-1)*100}{Cooling\ Load\ @95°F}$$

The cooling load at 95°F is that of the house, which for this paper is 34,000 Btu/h. The air conditioner will have zero percent true oversizing if it is sized to exactly meet the load at 95°F for properly charged conditions. Because the system just meets the load at 95°F, it will remain on continuously (or near continuously) when the outdoor temperature is 100°F. Thus, the peak demand of the unit is the same as the steady-state electrical demand of the unit. For no oversizing, a unit with a 20% undercharge would have an approximately 0.3 kW smaller demand at 100°F. However, it would also have approximately 18.1% less capacity at 100°F. Moving to the right in Figure 5 implies larger capacity (and larger power demand) systems are used in the house. A 10% oversizing would correspond to a properly charged unit with a capacity of 37,400 Btu/h. This same unit would only have 33,670 Btu/h if it were 20% overcharged and 30,640 Btu/h if the unit were 20% undercharged.

As the size is increased, the power demand increases linearly with the same slope found in Figure 4 because the system will run continuously as long as it has a capacity that is smaller than the cooling load of the house. If the size of the properly charged unit is increased until it is capable of providing all the cooling load at 100°F, it will have to provide 40,800 Btu/h, which corresponds to 26% oversizing. Any further size increase makes the capacity of the unit larger than the cooling load on the house. Therefore, it will cycle on and off. Under cycling conditions, the unit is assumed to be on only enough to meet the load of the residence and that there are no cycling losses. Thus, its average demand during the hour flattens, as shown in Figure 5. If the system were 20% undercharged, it would have to be 54% oversized to just meet the cooling load at 100°F. For 20% overcharged, it would have to be 41% oversized.

Table 2. Effect of Sizing, Refrigerant Charge and Outdoor Temperature on the Electrical Demand of an Air Conditioner with Capillary Tube Expansion

Case I. 34,000 Btu/hr capacity and SEER 10

		20% Undercharged				Proper Charged				20% Overcharged			
Outdoor Temperature F	House Load KBTUH	Capacity KBTUH	% Run	kW	Utility kW 1 Hr	Capacity KBTUH	% Run	kW	Utility kW 1 Hr	Capacity KBTUH	% Run	kW	Utility kW 1 Hr
82	16.3	24.6	66	3.44	2.28	35.3	46	3.82	1.76	33.1	49	4.12	2.02
90	27.2	25.6	100+	3.70	3.70	34.6	79	4.03	3.18	32.0	85	4.24	2.70
95	34.0	26.0	100+	3.86	3.86	34.0	100	4.2	4.20	29.7	100+	4.33	4.33
100	40.8	26.3	100+	3.99	3.99	32.1	100+	4.33	4.33	28.9	100+	4.41	4.41

Case II. 42,000 Btu/h capacity and SEER 10 [oversized by 24%]

		20% Undercharged				Proper Charged				20% Overcharged			
Outdoor Temperature F	House Load KBTUH	Capacity KBTUH	% Run	kW	Utility kW 1 Hr	Capacity KBTUH	% Run	kW	Utility kW 1 Hr	Capacity KBTUH	% Run	kW	Utility kW 1 Hr
82	16.3	28.9	56	4.31	2.41	43.6	37	4.78	1.79	40.9	40	5.14	2.05
90	27.2	31.6	86	4.62	3.97	42.7	64	5.04	3.21	39.5	69	5.30	3.65
95	34.0	32.1	100+	4.83	4.83	42.0	81	5.25	4.25	36.7	93	5.41	5.03
100	40.8	32.5	100+	4.99	4.99	39.7	100+	5.41	5.41	35.7	100+	5.51	5.51

Case III. 54,000 Btu/h capacity and SEER 10, oversized by 60%)

		20% Undercharged				Proper Charged				20% Overcharged			
Outdoor Temperature F	House Load KBTUH	Capacity KBTUH	% Run	kW	Utility kW 1 Hr	Capacity KBTUH	% Run	kW	Utility kW 1 Hr	Capacity KBTUH	% Run	kW	Utility kW 1 Hr
82	16.3	39.4	41	5.62	2.33	56.6	29	6.23	1.79	52.9	31	6.71	2.08
90	27.2	41.0	66	6.03	4.00	55.4	49	6.58	3.23	51.2	53	6.92	3.67
95	34.0	41.7	82	6.30	5.17	54.4	62	6.85	4.28	47.6	71	7.06	5.01
100	40.8	42.2	97	6.51	6.29	51.5	79	7.06	5.59	46.2	88	7.19	6.34

Case IV. 60,000 Btu/h capacity and SEER 10 (oversized by 75%)

		20% Undercharged				Proper Charged				20% Overcharged			
Outdoor Temperature F	House Load KBTUH	Capacity KBTUH	% Run	kW	Utility kW 1 Hr	Capacity KBTUH	% Run	kW	Utility kW 1 Hr	Capacity KBTUH	% Run	kW	Utility kW 1 Hr
82	16.3	43.4	38	6.23	2.33	62.3	26	6.92	1.81	58.4	28	7.45	2.08
90	27.2	45.2	60	6.69	4.03	61.1	45	7.30	3.25	56.5	48	7.68	3.70
95	34.0	45.9	74	6.99	5.17	60.0	57	7.60	4.33	52.4	65	7.83	5.09
100	40.8	46.4	88	7.22	6.37	56.6	78	7.83	5.64	51	80	7.98	6.37

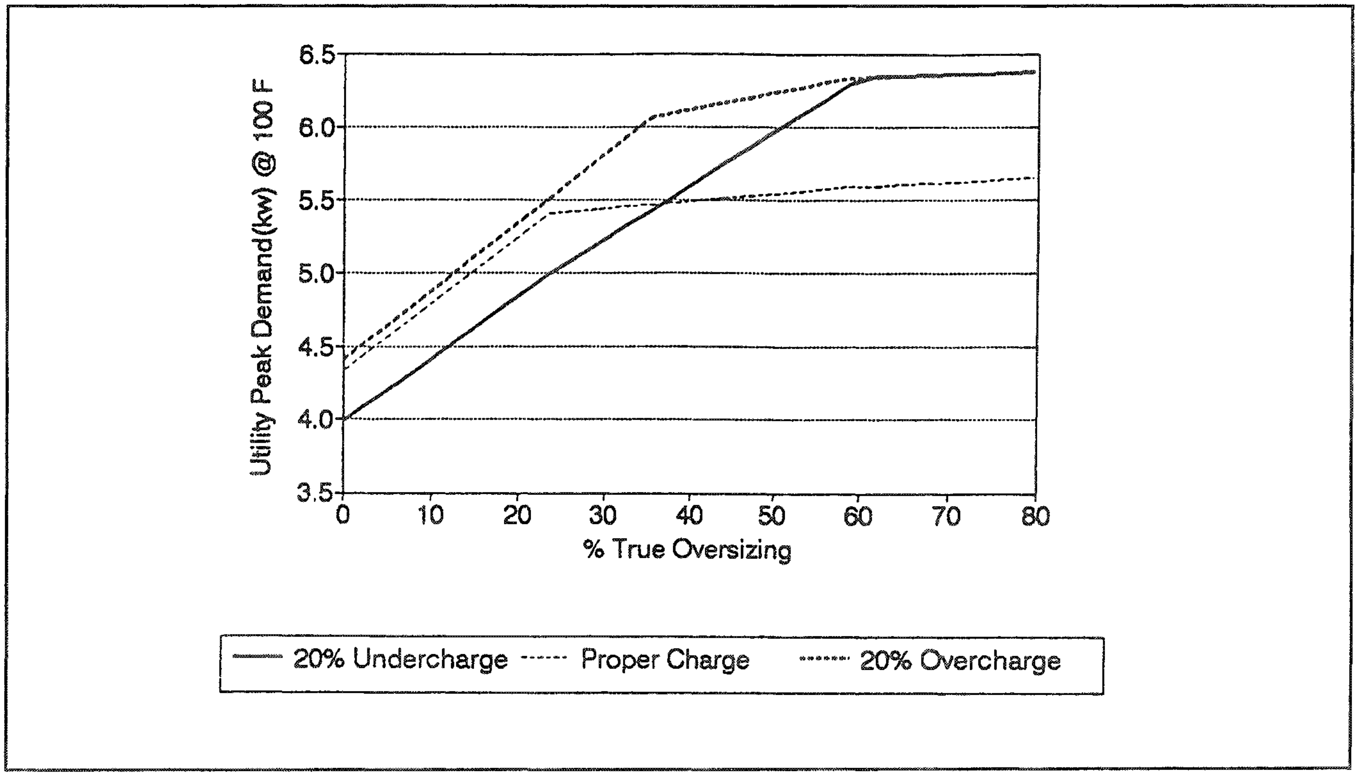

Figure 5. Variation of Utility Peak Demand at 100°F Outdoor Temperature with Percent Oversizing and Refrigerant Charge

Another way to approach Figure 5 is from the perspective of oversizing. As mentioned previously, following design guidelines such as those found in the ACCA manual will provide for a system that is oversized. If the amount of oversizing is 30%, then the undercharged system will provide the lowest peak demand for the utility and the customer. The savings in peak compared to proper charging and overcharging by 20% is 0.2 and 0.6 kw, respectively. If the unit is oversized by 60%, the properly charged unit provides the lowest peak demand at 100°F.

The impact of changes in power demand as a function of sizing was shown in Figure 4. Figure 6 presents results that can be used as an aid to evaluate various utility programs designed to reduce summer peak demand with high efficiency air conditioners. Variations in power are presented for units with SEERs of 10 and 12 and 20% overcharging. Many utilities offer incentives for higher SEER equipment. The SEER 12 unit provides a savings in demand of 0.8 kw over the SEER 10 unit. However, if the SEER 12 unit is 20% overcharged, it will only save 0.3 kw over a properly charged SEER 10 unit when both are oversized by 60%. Figure 6 shows the utility peak demand versus the oversizing percentage. The discontinuity in the curves occurs when the air conditioner meets the house load at 100 °F in the one hour time period. All data for this paper is based on steady-state measurements and thus the curves to the left of the discontinuity are correct. To the right of the discontinuity the equipment will cycle (although very infrequently) and the transient behavior of both power and capacity would raise this portion of the curves if these effects were included in the analysis. To the left, the equipment runs continuously and indoor temperature may increase above the set point.

It is important to know that studies which attempt to determine the true oversizing of central air conditioners indicate that typical oversizing is in the range of 60% to 80% oversized (References 2,3,5). A part of this oversizing results from the natural conservation factors built into ASHRAE and ACCA loads calculations (about 20% - 25%). The bigger portion of normal oversizing results from installers who do no loads calculations but simply use outdated, overly conservative, "rules-of-thumb" (such as 400 sq.ft. per ton) and then go up in equipment size "just to be sure". For our discussion of results below, a normal (standard) existing true oversize of 75% is assumed [2,3,6].

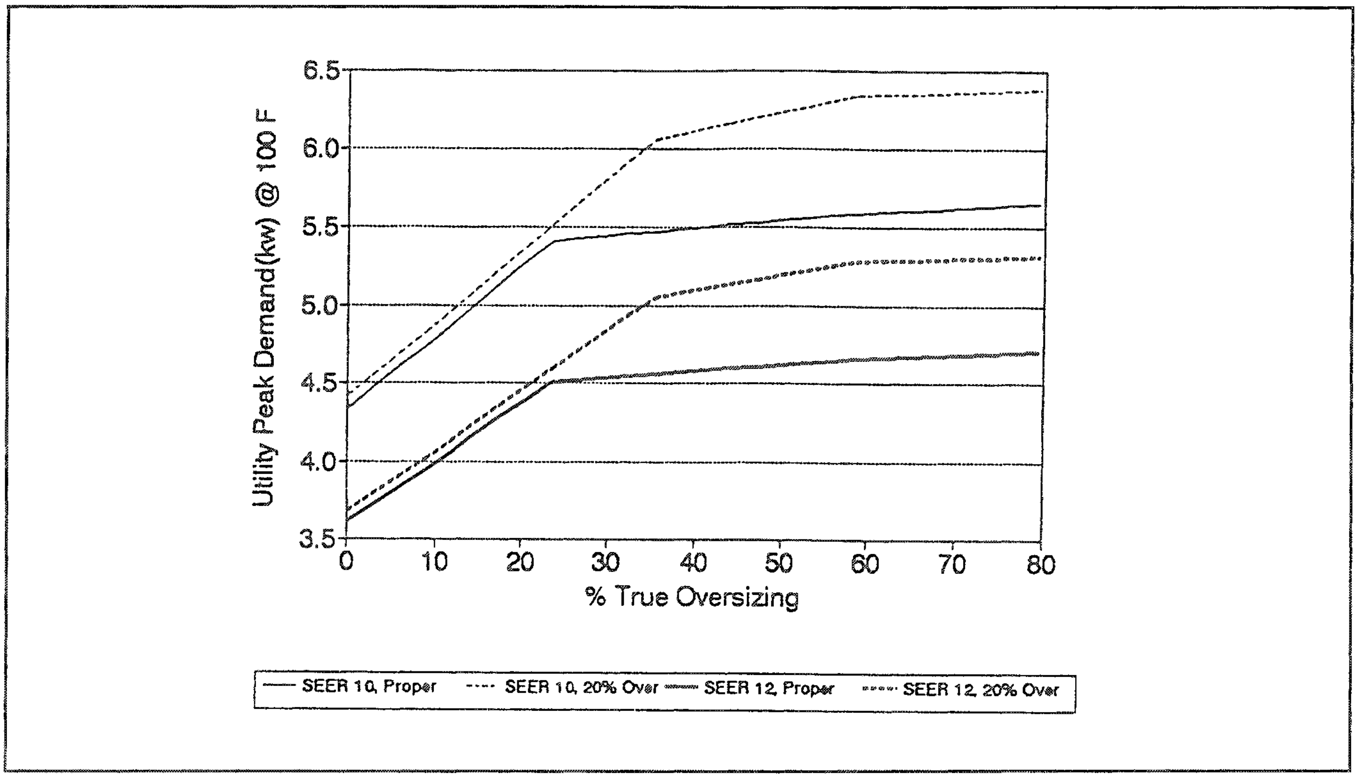

Figure 6. Variation of Utility Peak Demand with Oversizing, SEER, and Refrigerant Charge

Based upon the preceding discussion, the following results of program influenceable parameters on the utility peak demand from residential central air conditioning are noted from Figures 5 and 6.

Sizing Impacts

1. The potential impacts of proper sizing is the largest factor. For example, the utility peak demand for an SEER 10 air conditioner can be reduced from 5.25 kw at 75% oversized to 4.33 kw if sized perfectly. This is a reduction of 1.31 kw or 23%.

2. Very little is gained by size reduction until the size of the equipment is reduced below 26% above the true proper size. Because ACCA/ASHRAE calculations produce results about 25% conservative, this range of sizing can only be reached by never allowing a dealer to exceed Manual J results and encouraging the selection of the next smaller capacity unit.

3. A properly sized unit will provide the homeowner with more indications of service and maintenahce problems. The correction of the problem should provide significantly longer service life for the equipment.

Proper Charge Impacts

1. At the typical oversizing range of 75%, either undercharging or overcharging has a large negative impact on the electric utility peak demand. For an EER 10 air conditioner which is 75% oversized, a 20% over- or under-charged system will require 5.90 kw versus a properly charged unit requiring only 5.25 kw. This is an unnecessary demand of 0.65 kw.

2. The potential negative impacts of undercharge and overcharge for the utility are much reduced for true oversizing below 36%.

SEER Impacts

1. The impacts of SEER changes in the utility peak demand are virtually independent of oversizing (steady-state), but the kw impact depends on the SEER value of the equipment. A change of raising SEER by 2 (i.e. from an SEER of 8 to a SEER of 10) provides a nearly constant 16% reduction in peak demand.

2. A change in SEER of 2 (i.e. from an SEER of 10 to an SEER of 12) can reduce the utility peak by about

0.8 kw. This is taken from a properly charged, 75% oversized condition where the SEER 10 equipment requires 5.64 kw.

Comparison to Previous Studies

In References 2 and 3 for the Austin Electric Utility Department, Austin, Texas, the authors used a modified NBSLD computer program to study various utility load reduction strategy impacts on the residential air conditioning coincident peak demand. The computer program was modified to account for cycling impacts of air conditioning on the utility demand. The strategies examined included:

1. Reduction in building envelopes load

    a. Thermostat set points
    b. Infiltration rate
    c. Insulation levels
    d. Window glazings
    e. Ceiling fans
    f. Temporary discomfort

2. Reduction in air conditioner demand

    a. Higher EER ratings
    b. Down sizing

Comparisons to the present discussion can only be done for sizing and higher efficiency equipment. The Austin study defined "correct" or "proper" sizing as the air conditioning just meeting the peak cooling load for the extreme weather day of August 31, 1983. They studied units sized both larger and smaller than "proper". They also studied air conditioners rated at EER equal to 8.0 and EER equal to 10.5.

Because of the difference in sizing philosophy, the Austin "proper" size is apparently the same size as 26% oversized in the present paper (i.e. the capacity of the air conditioner just equals the peak hour load). Thus the Austin study "downsized" units which are approximately 20% smaller than proper sized would fall at about 5% oversized in the present paper. The Austin study found that current units were 60% oversized to their "proper" size definition and thus would be about 100% oversized of those used in the present paper. The Austin study found about a 30% reduction in peak demand in moving from the existing sizing to a "downsized" case for equipment with EER = 8.

A critical point which the simplified curves of this study show but which is not addressed by the Austin study is that downsizing from 100% oversized to 26% oversized does not reduce the utility peak demand. The reduced utility peak demand results from sizing below the Austin study "proper" size - in practical terms - if the residential air conditioner meets the seasonal peak cooling load of the house then its utility peak demand is higher than it could be and still provide "comfort".

Reference 8 uses simulations with DOE.2.1A to examine the benefits of sizing and EER rating to the homeowner but does not address the utility demand impacts of these changes. (Please note that this reference uses EER as a variable parameter. They calculate an annual energy use and an annual energy load. These quantities are divided for a <u>DOE 2 Seasonal Energy Efficiency Ratio (SEER) which is totally different than the government test SEER</u>. The report computed SEER depends on the location (climate) and the sizing unit.) This study further uses a trial and error method to find "proper" size. This is defined as an air conditioning unit which did not allow the indoor temperature to exceed 80°F for more than 1% of the cooling season with an indoor set temperature of 78°F.

For the specific results of Atlanta, Georgia, this study indicates that at an EER of 8, a reduction to proper size from 59% oversize will save 539 kWh for a season. A 50% reduction in oversizing saves 14% of the energy. A change from EER of 8 to EER of 10 will save 1041 kWh or 24% of the seasonal energy.

If we assume that "proper" size for Reference 8 is somewhere close to "proper" size defined in this paper, what Reference 8 says is that downsizing to proper size saves energy and that the energy savings from changes in EER are about the same magnitude as the percentage change in EER.

Reference 9 is specifically concerned with comfort provided by central air conditioners; the paper examines the impact of sensible heat ratios, sizing, thermostat set temperatures, and mild/humid days as well as design days. The authors of the reference conclude that sizing of central air conditioners to 80% of the design load could improve occupant comfort. Note that the 80% design load sizing should be very close to the "proper" size chosen in this paper.

Application of Results

For proper application of these results to the evaluation of potential utility programs, it must first be remembered that this study has very definite limitations. The analysis is only for steady-state operation of capillary tube refrigerant metering central air conditioning/heat pumps. The steady-state limitation does not impact any results to the left of the discontinuity lines of Figures 4, 5, and 6 because the system in this region must operate continuously for the full hour. For the regions to the right of the discontinuity lines the transient impact would simply reduce the capacity and increase the electric demand, thus raising the curve. This impact should be very small however, because the shortest run time of any of the equipment sized up to 175% oversized is greater than 45 minutes and thus there is at most one transient period during the peak hour. A second discontinuity line is shown at 175% oversized for a properly charged system. Beyond this discontinuity the reduction in run time matches the increased demand to produce the capacity (this area of the curves would begin to be significantly impacted by transient effects).

The limit to capillary tube metered refrigerant equipment is also less restrictive than it may at first appear. It is estimated that well over 80% of the residential central air conditioners ever sold are of this generic type. Even with the modern push for high SEER equipment, the percentage of orifice metered equipment sold continues to stay above 75% of the equipment sold. There is no definitive source for the estimates of the fraction of residential systems that use capillary tubes. Studies conducted on systems using orifice and TXV expansion devices showed different characteristics to that of a capillary tube system[10].

In addition to the impact of these program influenceable variables on the electric utility peak demand, the electric utility manager must also assess the impact of these factors on the energy sales for residential air conditioning to calculate program cost effectiveness. It should be noted that reducing oversizing can save energy by reducing cycling losses on design days but may increase energy use on mild/humid days while providing more comfort. This means that beneficial utility impacts due to downsizing of central air conditioners can also potentially increase the load factor of residential air conditioning.

The percentage of potential impact of proper charging on efficiency (energy consumption) is that proper charging will increase efficiency (EER) in the range of 17% to 22% over the range of outdoor temperatures from 80°F to 100°F. This efficiency increase percentage is approximately the same percentage range of the utility peak demand reduction.

The impact of increasing EER is a definite reduction in energy sales. The example of an EER change from 10 to an EER of 12 discussed above reduces the utility peak demand by about 17%. If the EER change is done properly, it would result in an energy sales reduction of 20% and thus the load factor of this residential air conditioner would be reduced.

The conclusion of the above analysis is that for equally effective expenditures of program money, the utility system would benefit most by promotion of proper sizing (within the range below 26% oversized). Programs to promote proper charging or higher efficiency equipment appear to have about equal potential benefits to electric utilities.

Analysis to Customer Economics

The analysis of the impact of each of these factors on customer economics is beyond the scope of this paper and, in fact, requires data not currently available. However, a general qualitative discussion of the logical results of this analysis on customer costs can be provided.

A quick assumption that higher efficiency (i.e. EER) equipment will provide the best cost benefit to air conditioning customers is not a valid assumption. Improved efficiency numbers at the expense of reduced latent heat capacity may actually reduce customer comfort and increase the annual energy cost of air conditioning (Reference 9). However, EER - even if it is an indicator of seasonal energy use - only impacts the annual energy operating costs. The true customer costs for air conditioning comfort include: (a) initial system costs prorated over the equipment life; (b) annual maintenance costs; and finally, (c) annual energy costs. If the actual equipment life is only ten or twelve years rather than the design twenty to twenty-five years, the prorated equipment cost can easily exceed the annual energy cost. Thus the impact of utility programs on customer air conditioning costs must address initial equipment costs, system lifetime impacts, and annual maintenance cost in addition to the annual energy costs.

Summary

Tables 3 and 4 provide a potential guide for utility executives who wish to assess the impact of their programs to affect customer choices/cost/service of central air conditioning on the utility peak demand, the utility energy sales for residential air conditioning, and the individual customer costs. The utility peak demand impact is given quantitatively. The energy sales and customer cost impacts are only qualitative.

Table 3. Electric Utility Impacts of Residential Air Conditioner Sizing, Proper Charge, and Rated Seer

Program Factor	Utility Factor Peak Impact* (Quantitative)	Energy Impact (Quantitative)	Load Factor Impact (Qualitative)
Sizing	-1.35 kW = -26%	Very Small (< -2%)	Increases
Charge	-0.65 kW = -12%	Approx. Same range as Peak Red. (Up to -20%)	Nominal Change
SEER	-0.80 kW = -15%	Proportional to EER? (20%)	Decreases

* Taken from "Results" section for the specified conditions of the analysis. The base condition for all per cent impact is 75% oversized, EER = 10, properly charged system with a demand of 5.25 kW.

Table 4. Customer Cost Impacts of Residential Air Conditioning Sizing, Proper Charge, Rated SEER (Qualitative Only)

Program Factor	Utility Factor Initial System Cost	Lifetime Impact	Annual Maintenance Costs	Annual Energy Cost
Sizing	Reduces	Increases	Increases	No impact
Charge	No change	Increases	Increases	Reduces (up to 20%)
SEER	Increases (Possible large increase)	no impact	Increases	Reduces (Proportion to SEER?)

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