Field Adjusted SEER [SEERFA]
Residential Buildings: Technologies, Design, And Performance Analysis

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ABSTRACT

SEER (Seasonal Energy Efficiency Ratio) ratings of central air conditioners and heat pumps are being used increasingly for marketing purposes, accelerating demand for engineering "high SEER ratings." The rating system, based on standardized laboratory tests, is used to compare two similarly sized pieces of equipment for the same application, with the higher SEER-rated piece of equipment offering higher energy efficiency.

Problems arise because equipment is manufactured in discrete pieces while final assembly depends on installation in the customer's home. Further, the fabricated duct system often does not meet standards of the industry and the manufacturer. This can negatively impact the actual efficiency of the completed system. Overemphasis on SEER can lead to programmatic neglect of the training, testing, and inspection needed to achieve field efficiency that approaches the expected potential of the equipment.

This paper examines the impacts of a number of assembly factors on the energy efficiency that the system (not just the equipment) can be expected to deliver by using a "field adjusted" SEER (SEERFA). The paper emphasizes the importance of training, testing, and inspection needed for significant improvement in actual air conditioning efficiency delivered in houses. The paper reviews available literature on laboratory tests and field tests in houses concerning the impacts of sizing, proper charge, proper system airflow, and duct leakage on air conditioning steady state and seasonal efficiency. A series of graphs are included to show the "typical" actual seasonal efficiency (SEERFA) expected under current less-than-specified field assembly quality.

It should be noted that some installed systems with SEER = 12 yield field adjusted SEERFA of 6.4 or lower.

Introduction

The subject for this paper is an estimation of the impacts of improper charge, improper duct airflow volume, leaky ducts, and oversizing on the actual seasonal energy efficiency of central air conditioners and heat pumps [SEERFA = SEER-Field Adjusted]. Three useful things are provided here: (1) a list of references on the general subject of actual central air conditioning efficiency in houses; (2) tables which permit the reader to estimate the actual efficiency expected from a central air conditioner from field tests of correct charge, evaporator airflow, sizing, etc.; and (3) graphs which apply the table factors to a "typical" split system central air conditioner as indicated by a number of field studies cited in reference documents.

While SEER is only for cooling, heat pump heating energy is also affected by improper charge, airflow, sizing, and leaky ducts.

In the process of consulting concerning service and efficiency of electrically operated residential space conditioning equipment, a frequently asked question has been: *"Since many electric utilities are using only SEER as a basis for payments to both HVAC dealers and to retail customers, is there an approximate way to estimate the impact of improper charge or improper airflow on SEER?"*

This paper attempts to provide that estimation.

Market response to SEER data and actual field system efficiency is a valid concern. A possible method to try to lower space conditioning bills might include installing a SEER 14 unit, hoping to get an actual SEER 10 performance. It is believed that the more effective and environmentally friendly approach is to ensure a unit performs to its proper specification. The basic field system performance information is given in this paper upon which an economic analysis of programmatic approaches to reducing space cooling energy could be developed.

Correct Charge

Standard refrigerant flow control devices used on equipment sold in the United States are of two generic types: fixed orifice and TXV. Fixed orifice devices may be designated as capillary tube, accurator, piston, short tube orifice, etc. TXV valves may also be designated as thermal expansion valves or TEV. The refrigerant flow control device is a major determinant factor is how the equipment responds to field conditions.

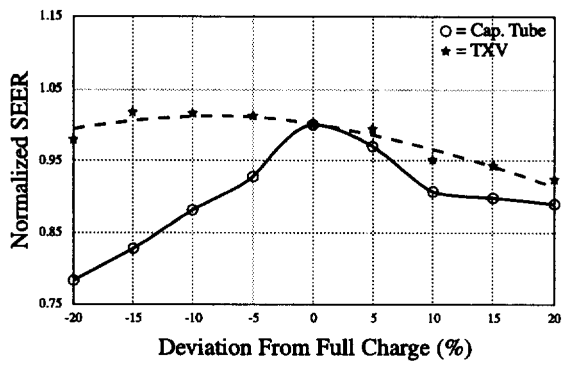

Figure 1 Normalized SEER for the Capillary Tube and TXV Systems at Various Charging Conditions

Fully Charged Condition: 140 oz.

Figure 1 (Farzad & O'Neal 1993) shows the impact of improper charge on the SEER of a capillary tube (a fixed orifice device) and a TXV system. This is only for one specific system - but the impact is likely to be somewhat similar in generic units. The range of charge conditions was only from -20 % to + 20 % (20% undercharged to 20% overcharged) while field studies frequently find real systems with charge outside this range including overcharged by 100% and more. Table 1 – based on Figure 1 - shows the impacts of incorrect charge between 80% and 120% correct charge on fixed orifice and TXV equipment. Figure 6 estimates the impact of improper charge for a "typical" system for fixed orifice equipment at 80% correct charge based on the following field findings as guidelines to a "typical" system:

A. Fixed orifice systems are estimated at approximately 70% of the systems sold nationally. Air Conditioning, Heating & Refrigeration News (6/27/94 p. 20 & 22) states that over 75% of all unitary air conditioning shipments are in the category of SEER just above the minimum i.e. 10 < SEER< 10.9. Units in this efficiency range typically have fixed orifice refrigerant flow control because it is the least cost device and the residential central air conditioning business is primarily driven by "low bid" competition.

B. Field studies by Advanced Energy (Katz, 1997) and Proctor Engineering (Proctor, 1997) & (Proctor & Albright, 1996) have found incorrect charge in 60% - 80% of the tested units. The reference document (Proctor, 1997) shows 78% of the field tested units were undercharged. Of these 78%, those with refrigerant line sets less than 10 feet long were undercharged by an average of 11% while those with longer line sets were undercharged by an average of 33%. (Proctor & Albright, 1996) states "nearly all of those homes had undercharged air conditioners." The worst of these was undercharged by 38%.

Table 1
Impacts Of Incorrect Charge On Rated SEER [SEERFA] [Estimate]

DOE Rated SEER	Fixed Orifice Charge Condition -20%	-10%	Mfg.	+10%	+20%	TXV Charge Condition -20%	-10%	Mfg.	+10%	+20%
14	11	12.4	14	12.7	12.3	13.7	14.1	14	13.3	12.8
13	10.2	11.5	13	11.8	11.4	12.7	13.1	13	12.4	11.9
12	9.4	10.6	12	10.9	10.6	11.7	12.1	12	11.4	11
11	8.6	9.7	11	10	9.7	10.8	11.1	11	10.5	10.1
10	7.9	8.9	10	9.1	8.8	9.8	10.1	10	9.5	9.2

Correct Airflow

(Palani et al. 1992) and (Parker et al. 1997) examined the aspect of reduced evaporator air flow on cooling system performance.

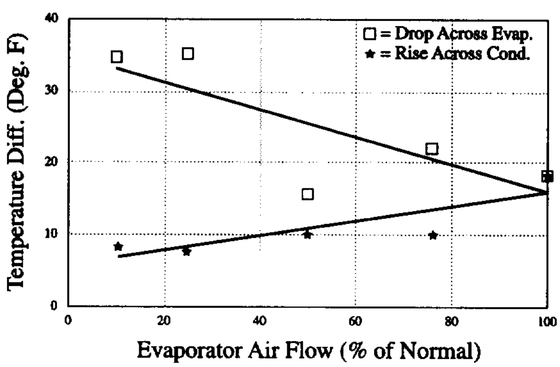

Figure 2 Performance of Evaporator Under Reduced Air Flow
Reduction in Evaporator Air Flow
(Temp. Difference Across Coils)
Source: Palani, et al. 1992

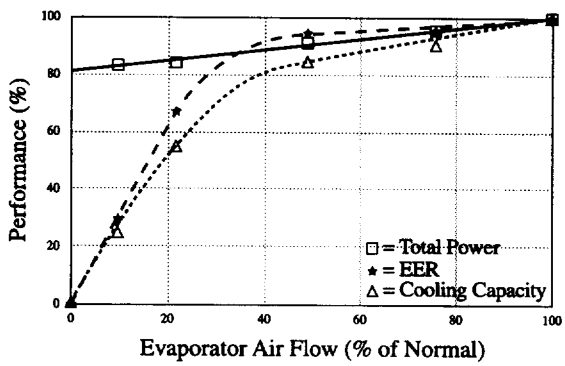

Figure 3 Performance of Evaporator Under Reduced Air Flow
Reduction in Evaporator Air Flow
(Total Power and EER)
Source: Palani, et al. 1992

(Palani it al. 1992) tested a fixed orifice (short tube orifice) system and tests were performed at an outdoor temperature of 75 F/ 60% rh — which is not a standard DOE test condition. Figure 2 (Palani et al. 1992) shows the primary impact of airflow is on the temperature change of the air across the evaporator. Figure 2 shows a temperature drop across the evaporator of about 25° F @ 50% Normal Airflow and only about 15° F @ Normal Airflow) - so customers are likely to note too much airflow ("my unit is not cooling") and significantly deficient airflow will likely cause icing on the evaporator leading to compressor failure. Figure 3 (Palani et al. 1992) shows that the capacity and EER (steady state efficiency) decline only slightly down to 50% airflow [approx. 4.2 % reduction at 25 % airflow deficiency and 6.5% reduction at 50% deficiency]. Thus a reasonable guess on loss steady state efficiency from airflow problems might be approximately a 5% reduction in steady state EER based on these (Palani et al. 1992) tests. If these estimates also holds true for the DOE "B" test condition of 82° F dry bulb outdoors, 80° F_{dry} and 67° F_{wet} indoors, then a reasonable estimate of the impact of low airflow would be a 5% reduction in SEER = [SEERFA].

(Rodriguez, 1995) measured the drop in EER at ARI conditions (95° F outdoor, 80° F dry indoor, 67° F wet indoor) for both TXV and orifice system. The TXV system performed somewhat better with about a 15% drop in EER at 50% airflow while the orifice system EER dropped about 19% at 50% airflow. Thus again a 5% reduction in SEER appears to be a reasonable estimate for common low airflow situations.

Field studies typically find an average evaporator airflow lower than the manufacturer's recommended 400 cfm/ton (wet). (Parker, 1997) found an average 289 cfm/ton [low by 28% which from (Rodriguez, 1995) would equate to a drop in EER of 11% for an orifice system or 5% for a TXV system]. (Proctor et al. 1992) found an average system airflow of 344 cfm/ton [low by 14% which again from (Rodriguez, 1995) would equate to a drop in EER of 9% for an orifice system or 1% for a TXV system].

(Parker et al., 1997) states, "We conclude that improving evaporator airflow to rated values (often 400 cfm/ton) in residential air-conditioning systems has the potential to reduce average residential cooling energy use by approximately 10%."

The first approximation of combined impacts of improper charge and low airflow is that they combine as given in equation 1.

Equation 1

SEERFA = ($SEER_{Rated}$)
X [Impact of Improper Charge – Figure 1 (Farzad & O'Neal 1993)]
X [Impact of Improper Airflow – Figure 3 (Palani et al. 1992)]

Table 2 uses data from Table 1 and applies the estimated 5% reduction due to inefficiencies of incorrect airflow.

Table 2

Combined Incorrect Charge And Incorrect Airflow On Rated SEER [SEERFA] [Estimate]

DOE Rated SEER	Fixed Orifice Charge Condition -20%	-10%	Mfg.	+10%	+20%	TXV Charge Condition -20%	-10%	Mfg.	+10%	+20%
14	10.5	11.8	14	12.1	11.7	13	13.4	14	12.6	12.2
13	9.7	10.9	13	11.2	10.8	12.1	12.4	13	11.8	11.3
12	8.9	10.1	12	10.4	10.1	11.1	11.5	12	10.8	10.5
11	8.2	9.2	11	9.5	9.2	10.3	10.5	11	10	9.6
10	7.5	8.5	10	8.6	8.4	9.3	9.6	10	9	8.7

Figure 7 shows the combined impacts of improper charge and improper airflow on the chosen "typical" system.

Leaky Ducts

Duct leakage has three effects on cooling load and the cooling energy provided by the equipment. First, a supply leak is a direct loss of capacity. Second, a return leak will often bring in hot attic air. Third, the difference between supply leakage and return leakage will cause an additional energy penalty due to resulting house pressure differences.

ASHRAE is currently proposing a Standard 152 P which provides a method to calculate an efficiency for the duct system in a house. The negative impacts of a real leaky duct system can perhaps be related to a loss of SEER i.e. [SEERFA] of the equipment. The field data available to make such an approximation is typically a reduction in energy use when the ductwork is sealed (existing houses). Thus we equate a percent improvement (reduction in the energy use) from the repair to the rated SEER loss from the typical "as found" ductwork.

(Proctor et al. 1995) found an average loss of cooling efficiency of 37% is due to duct leakage and duct heat transfer. Proper sealing and insulation of ducts is estimated to be able to save approximately 50% of these losses (i.e. estimated savings = 26% +/- 5%). Thus an improvement of 21 % is a reasonable, conservative estimate for a "typical" system.

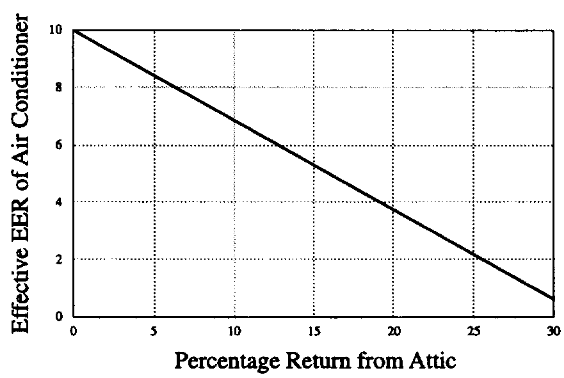

Figure 4 Performance Degradation of Air Conditioner When Attic Air is Drawn into Air Handler

Assuming Room is 78° and Attic Air is 120°F

Source: Cummings, et al. 1990

Figure 4 (Cummings et al. 1990) showed that if 6% of the return air is pulled from a 120 °F attic, the EER is reduced by about 21%. This type of data was responsible for helping Florida pass a building code requiring that air handlers not be located in attic space.

(Rodriguez, 1995) performed tests simulating a leaky return duct in a hot attic and used a TXV air conditioning unit. These test results show that the capacity and efficiency loss is highly dependent on the temperature and relative humidity of the attic and the outdoor operating temperature.

Data developed by (Katz 1997) was examined using the method found in the reference from The Energy Conservatory. The following leakage values were used: 261 CFM_{25} per system (all leakage was assumed to go to "outside" since no house was specifically designed to have interior ducts); average system size = 2.4 tons; and average system volume airflow = 850 CFM (based upon design condition of 400 CFM/ton and field experience that low airflow is the normal situation). Using these data in the approximate method yields an average system loss due to leaky ducts of 23%.

If we assume then that the portion of leaky ducts which can be "fixed" by a competent program is responsible for approximately a 21% loss in EER and the above cited recent field study of new homes with an approximate calculation indicates a 23% loss, then an approximate 21% loss in SEER = [SEERFA] is a reasonable engineering guess for "typical" leaky ducts.

Table 3 shows the impact of this "typical" leaky duct system on the field performance of equipment based on SEER rating.

Table 3

Impacts Of Leaky Ducts On Rated SEER [SEERFA] [Estimate]

DOE Rated SEER	Estimated Effective (Field Adjusted) SEERFA
14	11.1
13	10.3
12	9.5
11	8.7
10	7.9

Figure 8 presents this "typical" leaky duct impacts on SEER.

Again, a first approximation of the combined impacts of the above field factors is a straightforward multiplication (Equation 2).

Equation 2

SEERFA = (SEER Rated)
X [Impact of Improper Charge - Figure 1 (Farzad & O'Neal 1993)]
X [Impact of Improper Airflow - Figure 3 (Palani et al. 1992)]
X [Impact of Leaky Ducts (= 0.79)]

Table 4 indicates the SEERFA which results when the field factors are applied.

Table 4

Combined Incorrect Charge, Incorrect Airflow, & Leaky Ductwork On Rated SEER [SEERFA] [Estimate]

DOE Rated SEER	Fixed Orifice Charge Condition -20%	-10%	Mfg.	+10%	+20%	TXV Charge Condition -20%	-10%	Mfg.	+10%	+20%
14	8.3	9.3	14	9.6	9.2	10.3	10.6	14	10	9.6
13	7.7	8.6	13	8.8	8.5	9.6	9.8	13	9.3	8.9
12	7.0	8.0	12	8.2	8.0	8.8	9.1	12	8.5	8.3
11	6.5	7.3	11	7.5	7.3	8.1	8.3	11	7.9	7.6
10	5.9	6.7	10	6.8	6.6	7.3	7.6	10	7.1	6.9

Using the SEER 14 as an example, Table 4 above shows estimated SEER reductions due to the poor quality field conditions in the range of -25% to - 41% [SEERFA of 8.3 to 10.6 for a SEER 14 unit - depending upon type of refrigerant flow control and incorrect charge].

For comparison to the above estimation, it is interesting that an actual retrofit field project which emphasized quality in the above central air conditioning parameters showed an average cooling savings of 24.4% (Proctor, 1993).

Figure 9 shows the impacts of charge, system airflow, and leaky ducts on the "typical" system.

Design Field Impact: Oversizing

A final "real" field impact on the actual efficiency which a homeowner receives from central air conditioning equipment is the effects of sizing.

The industry standard used to determine the proper equipment size is based on Manual J and S of the Air-Conditioning Contractor of America (ACCA). These procedures use American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) 2 1/2 % design weather conditions and manufacturer's published sensible capacities at these same design conditions. Theoretically, if these design conditions are applied perfectly and the loads are calculated perfectly, the correctly sized unit would run full time for the few hours (2 1/2 % of the summer season) when conditions are above the design weather. Field studies of the impacts of sizing have used other definitions of "correct" sizing [examples - sized to just run full-time on the hottest recorded field test day (Giolma et al. 1985) or examination of run time data for "full run" hours]. This lack of a uniform definition of "correct" sizing makes comparisons of the impacts of sizing on efficiency difficult. However the field study in (James, et al. 1997) does use the ACCA Manual J sizing criteria with some slight deviation as discussed in that reference. (James, et al. 1997) field results with regression analysis indicated that 50% oversizing would increase seasonal energy use by 9.3%.

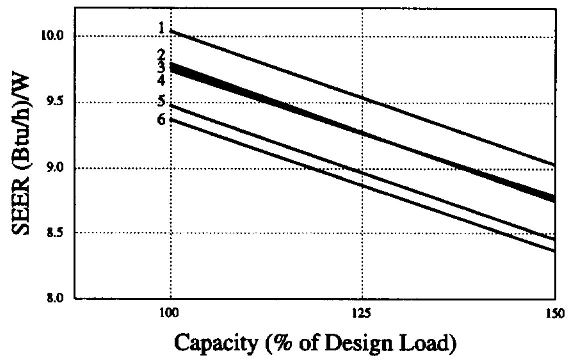

Figure 5 Sensitivity of Varying House Sizes, Internal Loads, and Window Shadings on Air Conditioner Seasonal Energy Efficiency Ratio (SEER)

Source: McLain, et al. 1985

Legend

Curve No.	House Description	Shading Coefficient	Average Internal Equipment Load, kW	% Difference From Base Curve 5
1	Hastings Ranch	0.6	1	6
2	Hastings Two-Story	0.6	2	3
3	Large Ranch	0.6	1	3
4	Hastings Two-Story	0.9	1	3
5 (Base)	Hastings Two-Story	0.6	1	0
6	Hastings Two-Story	0.6	0	-1

(Kuenzi & Wood, 1987) used computer simulations to find an indicated 12% reduction in SEER for a 50% oversizing condition. Figure 5 (McLain, et al. 1985) estimated a saving of 11% for correctly sized air conditioners versus 50% oversized (an approximately 0.2% SEER reduction for each 1% oversizing). (Proctor & Albright 1996) estimate that a 50% oversizing results in a 12% reduction of SEER. The field findings of (James, et al. 1997) are thus very consistent with the computer predictions.

The most dramatic impact of oversizing is to increase the peak demand experienced by the central electric utility (Neal & O'Neal 1992) and (Reddy & Claridge 1995).

It is common for builders and contractors to oversize because they feel that this reduces service calls. Field studies of sizing of central air conditioners have reported average oversizing of central air conditioners ranging from 24% to over 100% (Blasnik et al. 1995); (Giolma et al. 1985);); (Proctor & Albright 1996); (Katz 1997); (Demand-Side Technology Reports 1995); (Wilson et al. 1995). However, oversizing has negative impacts on costs and comfort. Intentional oversizing is poor practice because: (1) it may create comfort problems because of over-capacity the run-times of the system are short and so the blower does not have time to mix the indoor air. This leads to hot spots in places such as kitchens or rooms with large sunlight exposures; (2) it reduces the dehumidification capacity of the system because during short on cycles there is not enough opportunity for the condensed water to be removed at the indoor coil; (3) it causes wear and tear on the equipment. Frequent starting and stopping of electric motors shortens their life; (4) it consumes more energy than a properly sized unit due to frequent cycling. This is because an air conditioner is less efficient during transient start-up than in steady state operation; and (5) the initial cost of the equipment and installation as well as the maintenance costs are higher.

(Katipamula, et al. 1987) uses a TRANSYS simulation to examine the impacts of oversizing on "time outside the comfort zone" on specific days in several climates (does not compute seasonal energy use). Oversizing is shown to increase the time outside of the comfort zone - with the normal reaction to lack of comfort is to decrease the thermostat setting, thus increasing the energy use and cost of cooling.

Based upon the above cited field data and computer studies, it is reasonable to assume an average field oversizing of 50% and thus a conservative "typical" SEER reduction due to oversizing of 9.3%.

It is unlikely that all of these negative impacts would simply multiply, but this provides a first approximation of combined impacts. Equation 3 shows how this could be applied with measured field data.

Equation 3

SEERFA = ($SEER_{Rated}$)
X [Impact of Improper Source -Figure 1 (Farzad & O'Neal 1993)]
X [Impact of Improper Airflow - Figure 3 (Palani et al. 1992)]
X [Impact of Leaky Ducts/Heat Transfer (= 0.79)]
X [Impact of Oversizing (= 0.91)]

The results of the combined impacts of these field factors is given in Table 5.

Table 5

Combined Incorrect Charge, Incorrect Airflow, Leaky Ductwork, And Oversizing On Rated SEER [SEERFA] [Estimate]

DOE Rated SEER	Fixed Orifice Charge Condition					TXV Charge Condition				
	-20%	-10%	Mfg.	+10%	+20%	-20%	-10%	Mfg.	+10%	+20%
14	7.6	8.5	14	8.7	8.4	9.4	9.6	14	9.1	8.7
13	7.0	7.8	13	8.0	7.7	8.7	8.9	13	8.5	8.1
12	6.4	7.3	12	7.5	7.3	8.0	8.3	12	7.7	7.6
11	5.9	6.6	11	6.8	6.6	7.4	7.6	11	7.2	6.9
10	5.4	6.1	10	6.2	6.0	6.6	6.9	10	6.5	6.3

Figures 10 and 11 are graphical presentations of the impacts of these combined "field adjusted" factors on the chosen "typical" system and the beneficial impacts of TXV refrigerant flow control.

Using Figure 11 as summary findings shows that the average customer who experiences the negative impacts of all of the actual installation and maintenance factors of the real world will only receive about 54% of the rated SEER for a fixed orifice device central air conditioner and only about 66% of the rated SEER for a central air conditioner with a TXV metering device. Figure 12 shows the contribution of each of the individual field factors on the resulting field adjusted SEER (SEERFA).

Stated positively, there is an opportunity to reduce some central air conditioner customer's annual energy costs by up to 40% (see savings calculation below) by training and programs which focus on quality in field work associated with residential HVAC. Even larger savings are found through the reduced initial cost of the equipment and the greatly extended equipment life.

Savings calculations:

SEER = Seasonal cooling energy / Watts
For a rated SEER 10 unit, from table 4, on average it is currently producing an actual SEERFA = 5.9.
Thus, watts currently used = 1/5.9 X (cooling energy) = 0.169 X (cooling energy)
If we can achieve in the field the rated SEER and the required cooling energy stays the same, then:
watts required become = 1/10 X (cooling energy) = 0.1 X (cooling energy)

$$\text{thus \% reduction} = \frac{\text{current watts - reduced watts}}{\text{current watts}} = \frac{0.169 - 0.1}{0.169} = \frac{0.069}{0.169}$$

Equals 40 % Reduction
Thus, on average, a customer's current cooling bill with a "typical" central air conditioning system is approximately 70% higher than it could be.

Use Of Appoximations

Any use of the approximations included in this paper to examine financial impacts to either a system owner or to a utility should keep in mind the following information.

The above approximate impacts of various field factors apply only to the predicted annual energy use for cooling. These factors also have impacts on the heating energy for heat pumps and on the life of the equipment for both central air conditioners and heat pumps.

The major impacts to a utility are likely to be on the peak demand as given in (Neal & O'Neal, 1992) and (Reddy & Claridge, 1993).

The owner of a system is likely to see savings as great or greater than the predicted energy savings in the form of extended equipment life. A typical system valued at $4,500 with a predicted life of ten years thus has an annualized cost of $450 for the equipment. Proper sizing, charging, and airflow can easily result in predicted life of 15 or greater years with the resulting annualized equipment cost of only $300 per year, an annual equipment cost savings of $150.

The savings in heating will be dependent upon the climate and the annual heating required.

Conclusion

An analysis method, field adjusted SEER, has examined the impacts of a number of central air conditioning system assembly factors on the delivered energy efficiency of the system. Our results show that refrigerant charge, deficient air flow, duct leakage, and system oversizing can typically reduce delivered cooling efficiency to approximately half of the nominal rating of the equipment. It is recommended that training, field testing, and quality inspection can produce large improvements in field performance.

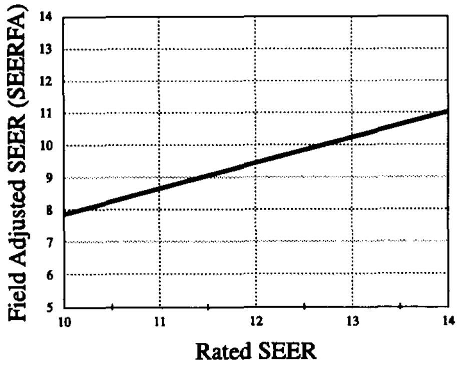

Figure 6 Impact of 20% Undercharge
Fixed Orifice Refrigerant Metering

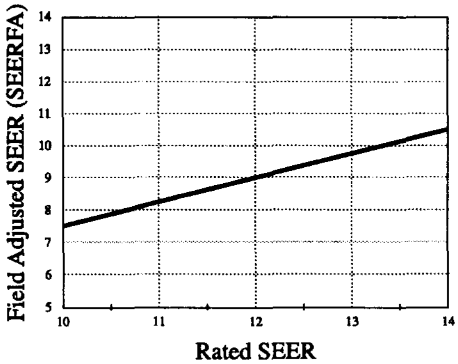

Figure 7 Low Airflow Plus 20% Undercharge
Fixed Orifice Refrigerant Metering

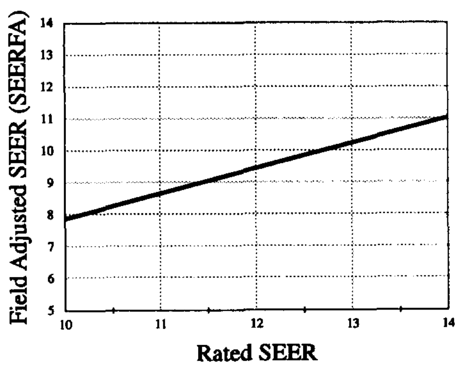

Figure 8 Leaky Ducts (Average)
Average Leaky Ducts =
21% Loss in System Efficiency

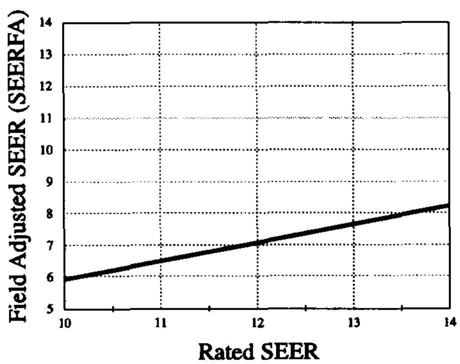

Figure 9 Leaky Ducts, Low Airflow, 20% Undercharged
Fixed Orifice Refrigerant Metering

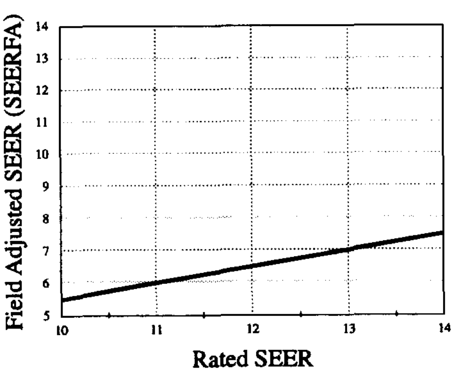

Figure 10 Oversized, Low Airflow, 20% Undercharged, Leaky Ducts
Fixed Orifice Refrigerant Metering

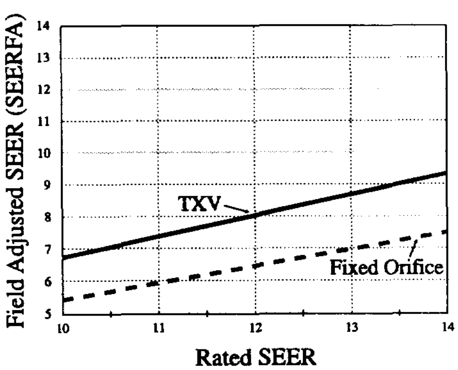

Figure 11 Oversized, Low Airflow, Undercharged, Leaky Ducts
Comparison of TXV and Fixed Orifice
50% Oversized, 20% Undercharged,
Average Low Airflow, Average Leaky Ducts

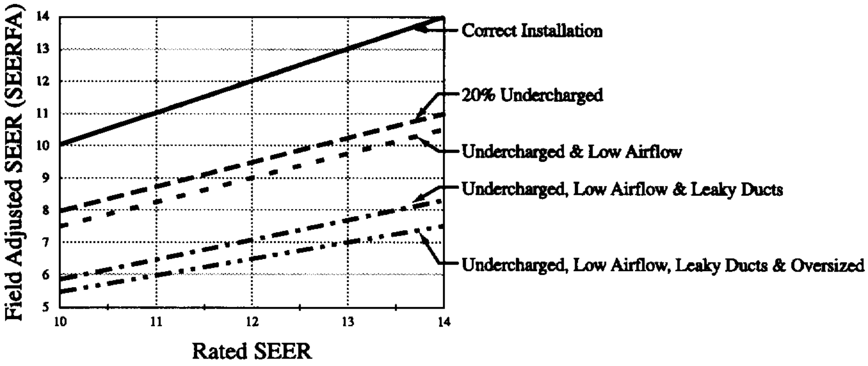

Figure 12 Impact of Installation Factors on a Fixed Orifice Split System Central A/C

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Cummings, J. B., Tooley, J. J., Jr., Moyer, N., and Dunsmore, R., Impacts of Duct Leakage on Infiltration Rates, Space Conditioning Energy Use, and Peak Electrical Demand in Florida Homes, ACEEE 1990 Summer Study, Pacific Grove, California, 9, 9.65-9.76.

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