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Assessment of HVAC Installations in Long Island Lighting Power Authority's Service Territory

Prepared for:
Conservation Services Group

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EXECUTIVE SUMMARY

Conservation Services Group (CSG) contracted with Proctor Engineering Group (PEG) to analyze data collected by CSG field personnel on air conditioner installations in Long Island Lighting Power Authority's (LIPA) service territory.

This investigation involved field testing the air conditioning units, duct systems, and building shells of a sample of homes with recently installed air conditioning systems (within the last 3 years). The sample included the following groups of customers:

1. Customers who received an incentive to install air conditioning sized within 25% of the Manual J estimated load.

2. Customers who received an incentive for a programmable setback thermostat in conjunction with their new air conditioning system(s).

3. Customers contacted by Random Digit Dialing (RDD) who had installed an air conditioner within the last three years.

The investigation found that each of the above groups had substantial deficiencies with the installation of their air conditioners and with the integrity of the building shell. Improvements can be made to provide lower energy usage and reduced demand while improving occupant comfort and satisfaction.

The key findings of this study include:

- There was no significant difference between groups in the sizing of these units with respect to ACCA Manual J. On average, the units receiving an incentive for sizing to Manual J exceeded Manual J by 67%.
  A closed loop system to ensure compliance with program standards needs to be instituted.
- Significant duct leakage and existing duct insulation levels reduce overall cooling efficiency for all groups. Both groups receiving an incentive had lower duct leakage than the random (comparison) group.
- Many of these air conditioners had insufficient air flow across the indoor coil. This is a common problem on oversized air conditioners. The units receiving an incentive averaged 336 cfm per ton compared to a "standard" of 400 cfm per ton. The comparison group has even lower airflow averaging 300 cfm per ton.
- There were significant problems with most of these homes with respect to the building shell. These homes were excessively leaky and poorly insulated.

- The units that received an incentive for sizing to Manual J had an average SEER rating of 14 which is higher than the other two groups (Thermostat Group 13.2, Comparison Group 11.6).
- Some units were installed with existing indoor coils. This practice significantly reduces the efficiency of the new unit below its SEER rating.
- Potential peak reductions from reducing duct leakage, increasing duct insulation, improving coil air flow, ensuring proper charge, and reducing unit oversizing range from 0.10 kW to over 0.50 kW per home. Note that these are the additional reductions possible over the current installation practice in new "high efficiency" air conditioner installations.

The following additional research is recommended:

- A sample of homes and air conditioners should be tested, characterized, and metered. At a minimum, the metering should be hourly. Preferably the air conditioner would be submetered and a data acquisition system used to record the actual capacity delivered to the duct system. The second option is a certain method of establishing the true cooling load of the building.
- New air conditioner installation practices in LIPA's service territory should be observed. The results would allow refinement of future program specifications.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

1
BACKGROUND

Conservation Services Group (CSG) contracted with Proctor Engineering Group (PEG) to analyze data collected by CSG field personnel on air conditioner installations in Long Island Lighting Power Authority's (LIPA) service territory. This assessment involved detailed field testing of a sample of 66 homes (73 HVAC systems) in LIPA service territory to identify problems with current practice HVAC system installations.

This report describes the activities and results of the field testing.

PRIOR RESEARCH

PEG's prior experience, and the findings of other research projects around the country has found that typical air conditioning system installations have numerous problems which adversely impact efficiency, demand, and comfort. The primary problems identified include:

- excessive duct leakage in unconditioned spaces leading to substantial loss of conditioned air, heated return system air, and increased house infiltration;
- insufficient airflow through the indoor coil (many times caused by restrictive duct design, which in turn leads to increased duct leakage effects);
- incorrect refrigerant charge;
- excessive air conditioning system sizing.

In prior studies, these problems were found to be common, not unusual, circumstances. Duct leakage and air conditioner performance has become a significant concern in the recent past. Studies from California, Florida, Nevada, and the Pacific Northwest have consistently found large efficiency losses due to typical levels of duct leakage and duct conduction losses.

2

FIELD INVESTIGATION

Trade practices and housing styles vary throughout the country and so do the relative frequency and severity of different air conditioner installation problems. In addition, other problems or savings opportunities may be as or more important in LIPA's service territory than those previously studied. A field investigation of recently installed (within the last 3 years) air conditioning systems in LIPA's service territory was needed to characterize the local problems and opportunities.

SAMPLE

This study contained 4 distinctive sample groups. The sample groups included:

1. Manual J - Includes customers who applied for and received an incentive from LIPA to have the installing contractor perform an Air Conditioning Contractors of America (ACCA) Manual J heat gain calculation at the time of installation. In order to qualify for the incentive the installed capacity of the air conditioning system(s) needed to be within +/- 25% of the Manual J load.

2. Thermostat - Includes customers who applied for and received an incentive from LIPA to have the installing contractor install a programmable setback thermostat in conjunction with the installation of their new air conditioning system(s).

3. Both - Includes customers who applied for and received both the Manual J and the Thermostat incentives.

4. RDD - Includes customers contacted by Random Digit Dialing (RDD). This group serves as the control group. These customer were randomly contacted and asked if they had installed an air conditioner within the last three years. If they answered yes and had not participated in a LIPA incentive program, they were included in the sample.

Table 2-1 details the number of houses and systems contained within each group.

Table 2-1
Sample Groups

Group	Number of Houses	Number of Systems
Manual J	9	10
Thermostat	25	28
Both	3	3
RDD	29	32
Total	66	73

FIELD DATA COLLECTION PROTOCOL

The field investigation was designed to examine a wide variety of potential HVAC problem areas and to collect information needed to assess summer design cooling loads and overall building shell thermal integrity. The field procedures included many state-of-the-art diagnostic tests (particularly for assessing the duct systems). The field testing protocol is summarized in Table 2-2.

Table 2-2
Summary of Field Test/Data Collection Procedures

Parameter	Tests	Description / Use
Duct Leakage	Duct Blaster™[1] - total leakage	pressurize ducts to 25 pa with the Duct Blaster™ attached to the duct system, registers sealed, measure fan flow
	Duct Blaster™ - exterior leakage	repeat above test while blower door pressurizes house to 25 pa, eliminating pressure difference between ducts and house
Air Handler Flow	Operating Static Pressures	measure static pressures in supply and return plenums - used for reference point when measuring air flow, also used to determine restrictiveness of system
	Energy Conservatory prototype Air Handler Flow Plate (AHFP)	Measure the flow through the indoor coil using the AHFP at the air handler
AC Info	Miscellaneous	collect nameplate information from indoor and outdoor units, assess potential for improvements in installation
Design Cooling Load	Building Dimensions, materials, R-values, shading/exposures,	calculate design cooling loads & proper AC size using enhanced ACCA Manual J[2]
	Same as Above	calculate design cooling loads & proper AC size using standard ACCA Manual J
Building Airtightness	Blower Door Test	measure CFM50 of house, also measure pressures developed in key building zones such as attics

IMPLEMENTATION

Specially trained field technicians were needed to perform the fieldwork. Conservation Services Group (CSG) selected individuals trained in the disciplines required to perform the work. All technicians were trained in data collection by PEG's program manager on the first two days of data collection.

The two person teams required an average of half a day per house. Scheduling began in December and all fieldwork was completed during two trips in January and February of 2001.

[1] Duct Blaster is a trade mark of the Energy Conservatory.

[2] The enhanced Manual J program used in this project used blower door measured leakage rate to estimate Air Changes per Hour (ACH) rather than based on visual observations of the building shell (standard ACCA practice).

FINDINGS - GENERAL CHARACTERISTICS

The typical house in the study was a two story frame house with a conditioned basement, 3 bedrooms, 1785 square foot of living space, a volume of about 14,300 cubic feet, double glazed windows, and R-11 attic insulation. Eight of the houses had two AC systems.

The houses were leaky, with an average air leakage of 4124 Cubic Feet per Minute at 50 Pascals pressure (CFM50) measured with a blower door. This level of air tightness raises the cooling and heating load of the house and wastes energy. This level of leakage is much higher than what has been seen in previous PEG studies.

When the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) standard 62-1989 is applied to modeled ventilation, over 90% of the houses have excessive infiltration. ASHRAE standard 62-1989 specifies that residential structures must have 0.35 natural Air Changes per Hour (ACH) or 15 CFM per person whichever is greater. All but 4 of the houses exceed the ASHRAE standard based on blower door measurements and the Lawrence Berkeley Laboratory (LBL) infiltration model. The distribution of natural Air Changes per Hour is shown in Figure 2-1

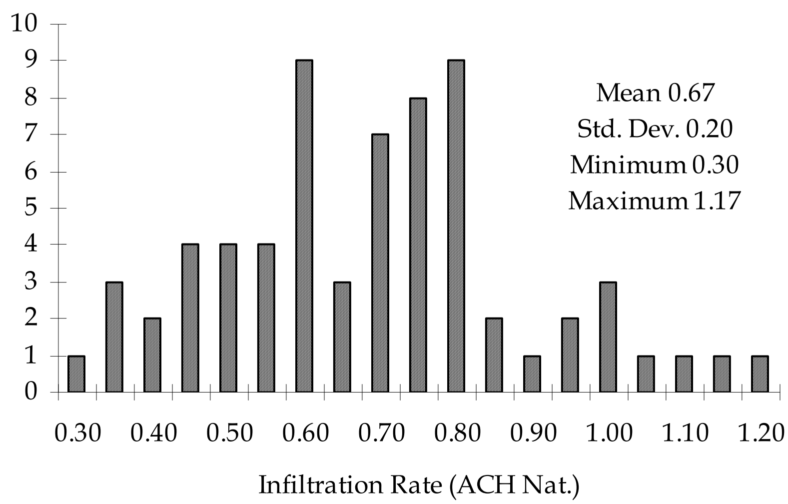

Figure 2-1
Natural Air Changes per Hour

There was not any statistically significant difference between the air leakage rates of the houses participating in the LIPA incentive programs and the random sample.

FINDINGS - DUCT LEAKAGE

Detailed duct leakage measurements were used to quantify the magnitude and impact of the existing leakage problems and the opportunities for improvement. All duct leakage measurements were performed with the Duct Blaster™. Three measures of duct leakage are summarized in this report: total leakage, leakage to outside, and normal operating leakage split between supply and return.

During the testing, the technicians noted that most of the duct systems had obvious and easily eliminated leakage at the plenums, boot connections, and air handler. The systems tested were as tight as they will ever be. They can be expected to leak more over time due to tape failure and disturbances (i.e., disconnections caused by people working around the duct systems).

The total duct leakage test establishes the total amount of leakage out of the ducts when all the registers are sealed and the ducts are pressurized to the test pressure (25 Pascals). This test measures both leakage to inside and outside the house. Total duct leakage is a fast and accurate test method that is easily applied to both existing structures and new construction (even before the drywall is installed). The average total leakage rate was 450 CFM25. The distribution of total duct leakage is shown in Figure 2-2.

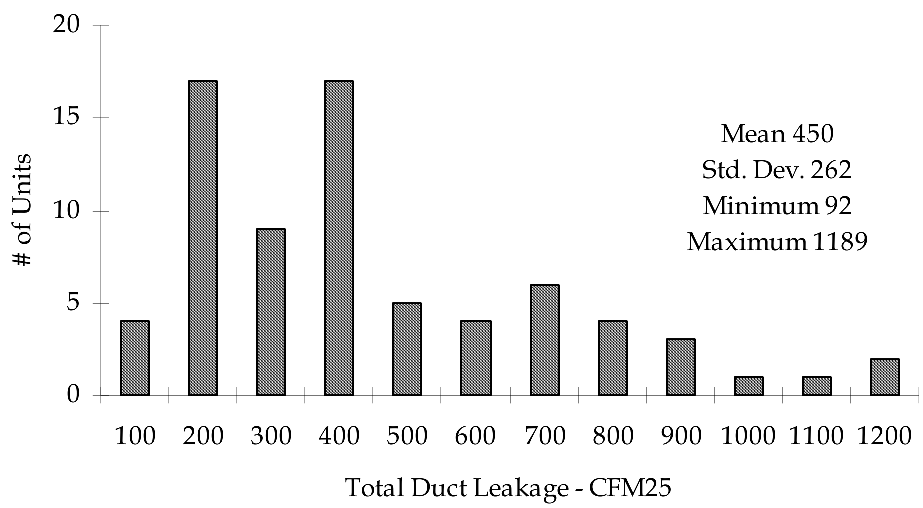

Figure 2-2
Total Duct Leakage

Duct leakage to (and from) the exterior is a better measure of duct leakage problems than the total leakage measurement, but involves more difficult and time-consuming tests. In this study, exterior duct leakage was measured using a blower door and a Duct Blaster™ pressurizing both the building and the ducts simultaneously. Having the house and the ducts at the same pressure reduces the duct leakage to inside to a minimum and thus measures the duct leakage to the exterior. The average leakage to the exterior rate was 245 CFM25. The distribution of exterior duct leakage is shown in Figure 2-3.

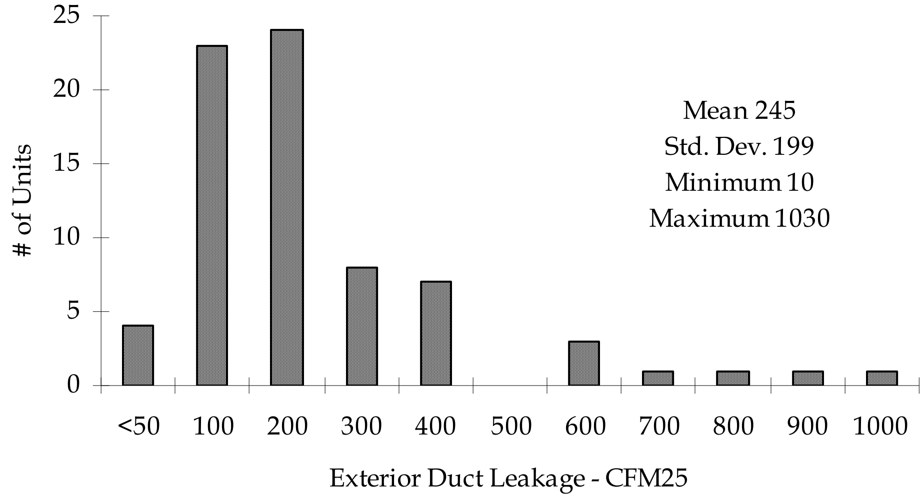

Figure 2-3
Duct Leakage to the Exterior

Both the duct leakage to the exterior test and the total duct leakage test are useful in estimating the size of the holes in the duct system. The key quantities that effect energy usage however are the leakage in the supply and return systems under operating conditions (as a percentage of the airflow through the indoor coil). These key duct leakage quantities were determined in the following manner:

1. A diagnostic test known as the “Half Nelson” was performed to estimate the ratio of total supply leakage area and the total return leakage area.
2. The operating leakage for each side was estimated by adjusting the leakage rate to the average pressure in that side of the duct system[3].
3. The operating leakage estimates were divided by the total operating airflow through the indoor coil.

[3] The flow exponent was assumed to be 0.50. The leakage at operating conditions therefore was calculated as Test Flow * (operating pressure/test pressure)^.50

The operating duct leakage split between supply and return is summarized in Figure 2-4. The flow rates averaged about 16 percent of the air handler flow on the supply side and 13 percent of the airflow on the return side.

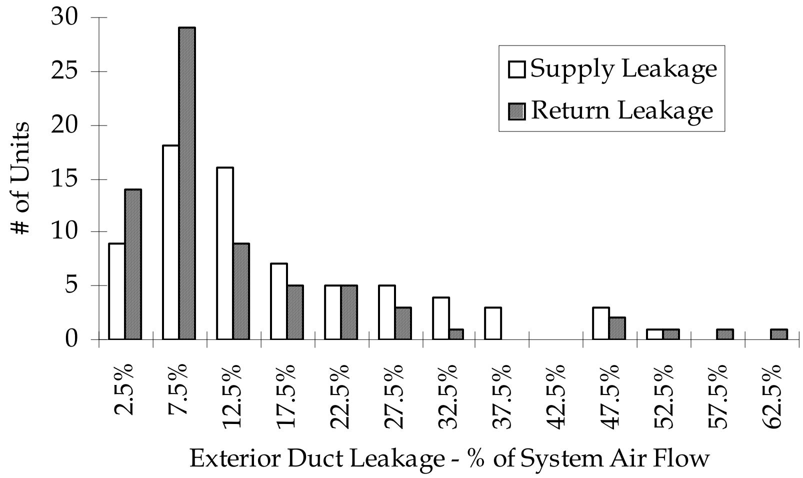

Figure 2-4
Supply and Return Leakage as a Percentage of Flow

The houses participating in the LIPA incentive programs showed a lower occurrence of duct leakage related problems than the random sample. Table 2-3 compares the occurrence of duct leakage problems in the LIPA incentive program participants and the random sample.

Table 2-3
Comparison of duct leakage results for the LIPA program participants and random sample

Group	Total Duct Leakage	Duct Leakage to the Exterior	Supply Leakage as a Percentage of Flow	Return Leakage as a Percentage of Flow
LIPA Manual J	380	188	10%	11%
LIPA Thermostat	401	219	14%	12%
Random Sample	517	285	21%	16%

FINDINGS - AIR CONDITIONING SYSTEMS

The houses had a wide variety of air conditioning system makes and models. The typical air conditioner was a split system. The systems examined had the typical problems seen in retrofit installations, ranging from leaving old indoor coils in place, placing a 4 ton air handler with a two and a half ton condensing unit, and not modifying the duct systems resulting in high operating static pressures.

The average SEER rating of the households participating in the LIPA Manual J program was 14.0. The LIPA Thermostat program participants had an average SEER rating of 13.2 and the random sample had an average SEER rating of 11.6.

Air Handler Flow Rate

The proper operation of an air conditioning system depends upon providing the correct air flow rate through the indoor coil -- usually listed by the manufacturer as 400 CFM per ton of nominal capacity. Low airflow has been a common problem found in other studies of air conditioner performance.

All systems were tested for airflow with a clean filter in place and operating at the cooling mode blower speed. The Energy Conservatory Air Handler Flow Plate (AHFP) airflow test method was used because of its ease of use and reliability (12 of the systems were tested using the Duct Blaster™ airflow test). The AHFP procedure involves these steps:

1. The supply system static pressure is measured during normal operation.
2. The AHFP is inserted in place of the filter at the air handler blower compartment.
3. The supply system static pressure and the pressure drop across the AHFP are measured with the system running at cooling speed.
4. The supply system static pressure measured in step 1 is compared to the pressure measured in step 3. If there is a difference a correction factor is determined.
5. A lookup table is used to determine the flow rate of the system based on the pressure drop across the AHFP.

Figure 2-5 shows the distribution of measured flow rates compared to 400 cfm per ton. The average measured flow rate was 320 CFM per ton, 20% below the target. Sixty four percent of the units were below 350 CFM/ton (often used as a level requiring corrective action). It should be noted that these units have the highest airflow they will ever experience. As the units get older, the blower and indoor coil will become dirty and the airflow will decrease.

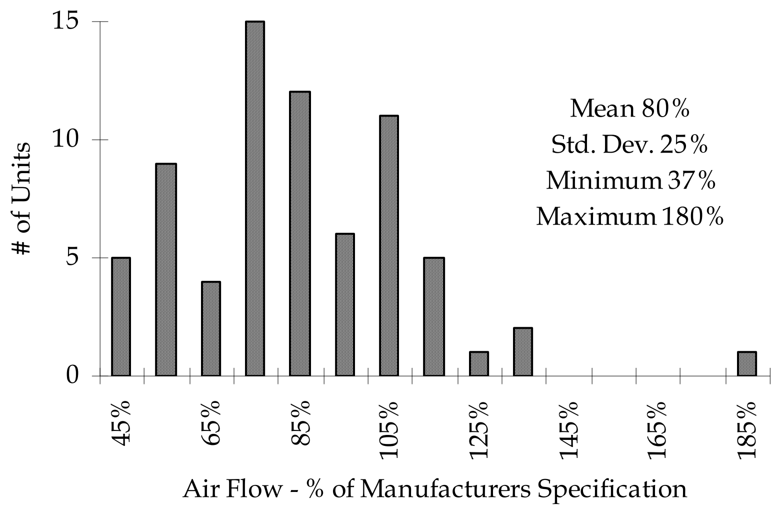

Figure 2-5
Air Handler Flow

The potential causes of the low airflow were investigated. The primary cause of low airflow was high operating static pressure caused by poor duct system design or installation. Average operating pressures were measured at 48 Pascals (0.2 IWC) on the supply side and 62 Pascals (0.35 IWC) on the return side. In many cases the measured static pressure due to the ductwork alone was high enough that adequate flow could not occur. With the filter and coil in place the airflow is decreased even further.

Many of the systems had single returns. Adding sufficient return easily repairs the high return static pressures.

Other causes of low air flow included; old, dirty evaporator coils left in place when the condenser unit was replaced, use of restrictive pleated filters, old undersized air handlers left in place when the condenser unit was replaced.

The systems with very high airflow typically had oversized air handlers. For example the system with 180% of rated airflow had a 4-ton air handler installed with a 2.5-ton condenser. There were several systems that had oversized air handlers. These cause excess energy usage due to the large fan motors running against high static pressures. Another system with a 4-ton air handler and a 2.5-ton condenser had a measured supply plenum pressure of 193 Pascals and a measured return plenum pressure of 94

Pascals. This is equal to 1.15 inches of water column (typical manufacturers' MAXIMUM design is 0.5 IWC – including the pressure drop for the indoor coil and filter, which these measurements don't include).

Refrigerant Charge

Incorrect refrigerant charge is a common problem with air conditioning systems. It is a common expectation that newly installed systems would be properly charged. Unfortunately, new systems appear to suffer from incorrect charge as often as older systems (SOURCE: Hamerlund et al, 1990, Blasnik et al, 1995).

Most installation technicians are under demanding time constraints when installing systems. In order to cut the amount of time necessary to install a system, many technicians rely on shortcuts, rules of thumb and guesswork rather than adhering to the manufacturers installation instructions.

Most air conditioners come from the factory charged with enough refrigerant to accommodate a standard length line set. If the installed line set is less than or more than the standard the charge must be adjusted to compensate for the difference (if the line set is shorter charge must be removed, if longer charge must be added). Most installation technicians consider weighing in the correct charge too time consuming and rely on refrigerant system pressures to indicate if the charge is correct.

There are many rules of thumb for assessing the charge in air conditioners. One of the most common methods used is looking at the refrigerant gauge pressures to see if they are in the "correct" range for the presumed indoor and outdoor conditions. The correct range is often interpreted as: low side pressure is near 70 to 80 psig or condenser saturation temperature approximately 20°F hotter than ambient. If the pressure/temperature is in the "correct" range the system is assumed to be charged properly.

Previous PEG studies found roughly one quarter to one third of the systems overcharged and one quarter to one third undercharged.

Due to the time of year in which the testing took place (middle of winter), air conditioner refrigerant charge could not be checked. Table 2-4 presents data from a previous study in Arizona in which refrigerant charge in new air conditioner installations was checked.

Table 2-4
Air Conditioner Refrigerant Charge

	Arizona 1995	
Charge	**# of Units**	**% of Units**
Within 5% of Correct Charge	5	18%
Undercharged	21	78%
Overcharged	1	4%

Proctor Engineering Group runs a group of programs that include the technician calling data into a toll free line while they are servicing air conditioners. These data are immediately checked and the technician reports the amount of refrigerant adjustment that achieved correct charge. This data is compiled from over 2000 units and is displayed in Table 2-5. Technicians assess the air conditioners charge status based on either the superheat method (for fixed orifice refrigerant metering systems) or subcooling (for thermostatic expansion valve refrigerant metering systems).

Table 2-5
Charge Fractions from CheckMe!® Database

Charge Fraction	Percent of Population
0.16	0.25%
0.24	0.15%
0.34	0.30%
0.42	0.45%
0.54	1.74%
0.66	3.09%
0.74	5.23%
0.84	10.85%
0.92	12.44%
1.00	37.35%
1.08	16.62%
1.16	7.86%
1.26	2.04%
1.36	0.70%
1.46	0.15%
1.55	0.45%
1.76	0.25%
1.89	0.10%

Air Conditioner Sizing

The Air Conditioning Contractors of America (ACCA) Manual J is a standard reference for estimating the design load for residential air conditioning systems.

Two versions of Manual J were used in this study. The standard method estimates the infiltration load by calling the house “Best, Average, or Poor”. The enhanced method uses a blower door test to determine how much leakage the house actually has and bases the infiltration estimate on the measured value. These homes were particularly leaky when measured with the blower door. When the standard version of Manual J was used with “Poor” construction, the total load was increased by 4%. This value is insignificant compared to the 64% oversizing displayed in these units.

The enhanced Manual J calculations performed on the houses in this study found cooling loads at design conditions ranging from 11,949 to 61,181 Btu/hr with an average of 25,055 Btu/hr. The largest single contributor to the load was glazing. Slightly less than one quarter (23%) of the design load came from heat gains through windows and glass doors. The next highest single contributor was the infiltration gain, with 18% of the load coming from the combined sensible and latent infiltration. Attic and wall conduction, were also big contributors with 17% and 15% respectively.

The 97.5% design conditions for Long Island are 89°F dry bulb -- 73°F wet bulb outdoors (about 97 grains of moisture per pound of air or 47% Relative Humidity) and 75°F dry bulb indoors. The capacity of the installed equipment at design conditions was estimated from manufacturers’ data corrected to 89°F outside and 75°F inside. The distribution of installed capacity vs. design load is shown in Figure 2-6.

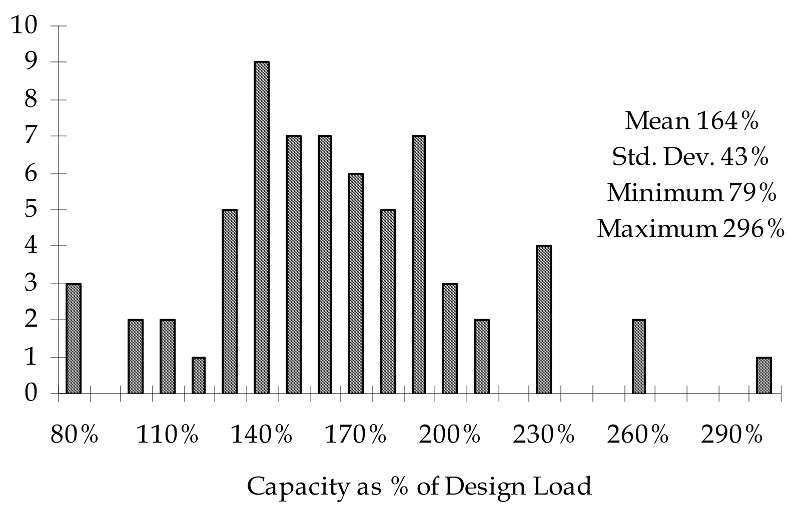

Figure 2-6
Installed Capacity vs. Design Load

The average design capacity of the equipment installed per house is 38,862 Btu/hr. This capacity represents an average 64% oversizing when compared to the calculated design loads.

Two system houses were not sized any closer to design than single system houses. The average two-system house had a Manual J calculated heat gain of 35,486 and was equipped with air conditioners with a total design capacity of 58,853 (83% oversize). The average single system house had a Manual J calculated heat gain of 23,617 and was equipped with an air conditioner with a design capacity of 36,104 (62% oversize). Table 2-6 shows the comparison on single system and two system houses.

Table 2-6
Sizing Comparisons

	Single System Homes	Two System Homes	All Homes
Modeled Capacity @ 89°F out 75/62°F in	36,104	58,853	38,862 Btu/hr
Manual J Estimated Load	23,617	35,486	25,055 Btu/hr
% of Manual J Estimated Load	62%	83%	64%

The houses participating in the LIPA incentive programs were not sized any closer to ACCA Manual J standards than the random sample. Table 2-7 compares sizing of air conditioners in the LIPA incentive program participants and the random sample.

Table 2-7
Comparison of air conditioner sizing for the LIPA program participants and random sample

Group	Total House Heat Gain Load	Total System Capacity for House (at Design)	Capacity as a Percent of Design Load
LIPA Manual J	23,123	37,648	167%
LIPA Thermostat	24,121	36,370	164%
Random Sample	26,815	41,457	163%

SUMMARY OF FIELD FINDINGS

The homes in this sample had high infiltration rates with 94% exceeding the amount needed to meet ASHRAE ventilation standards with the windows closed. The measured supply duct leakage averaged 16% of the air handler flow. Return leakage was very similar at 13%. Significant problems were found with low flow across the inside coil. These findings are consistent with similar investigations. Table 2-8 summarizes the key results from the field investigation.

Table 2-8
Summary of Field Findings

	Shell	**Ducts**		**Air Conditioner**	
	Leakage	Operating Leakage to Outside (% of flow)		AC Sizing (% of load)	Air Flow
	CFM50	Supply	Return		CFM/ton
Unit Mean		16%	13%		320
House Mean	4124			164%	
Std Deviation	1392	13%	13%	43%	100
Median	4000	13%	9%	159%	311
Minimum	1900	1%	0%	79%	148
Maximum	10000	51%	60%	296%	718

3

ESTIMATE OF AC PEAK LOAD AND PEAK REDUCTIONS

The peak day load profile for residential air conditioners in LIPA's service territory was estimated based on prior studies (Proctor et al. 1997, PG&E 1994,.Proctor and deKieffer, 1997). These estimates are based on local weather conditions and are reported in local standard time. An hourly air conditioner energy consumption model developed during the SIGECO project was used as the primary generator for these estimates (Proctor and deKieffer 1997). This was supplemented by data from a New Jersey study (Proctor et al. 1997) and a very comprehensive study for PG&E (PG&E 1994).

HOURLY AIR CONDITIONER ENERGY CONSUMPTION MODEL

These estimates are based on hourly-metered data that have been subjected to extensive validation and analysis.

The original model estimated an overall constant, a shift (occurring above the hourly base temperature), and the coefficients of two independent variables (outdoor temperature and outdoor temperature above the hourly base temperature). The model thus produced constants and coefficients specific to each hour of the day. The form of the equation is:

$$Use_{it} = a_{it} + b1_{it} * Tout + c_{it} + b2_{it} * Tout$$

Where:

Use_{it} = Median whole house electrical use in house i at hour t

a_{it} = Regression constant for house i at hour t

$b1_{it}$ = Regression coefficient of outside temperature for house i at hour t

Tout = Outside temperature at hour t

c_{it} = Value shift when Tout > $Tref_t$ or 0.0 when Tout < $Tref_t$
This allows for a step function change at the reference temperature

$b2_{it}$ = Regression coefficient (slope adjustment) of outside temperature when Tout > $Tref_t$
or 0.0 when Tout < $Tref_t$

$Tref_t$ = Reference temperature for cooling in hour t

AC Peak

The cooling reference temperature (Tref) was estimated for each hour based on best-fit criteria to a random sample of SIGECO homes.

The air conditioner watt draw is estimated as the shift plus the temperature slope adjustment times the outside temperature. That is:

$$ACUse_{it} = c_{it} + b2_{it} * Tout$$

Where:

$ACUse_{it} =$ Air Conditioner electrical use in house i at hour t

This approach captures temperature dependent air conditioner effects and any other electric consumption that correlates with increasing outdoor temperature above the reference temperature. Refrigerators for example show this pattern.

AC PEAK DAY LOAD SHAPE

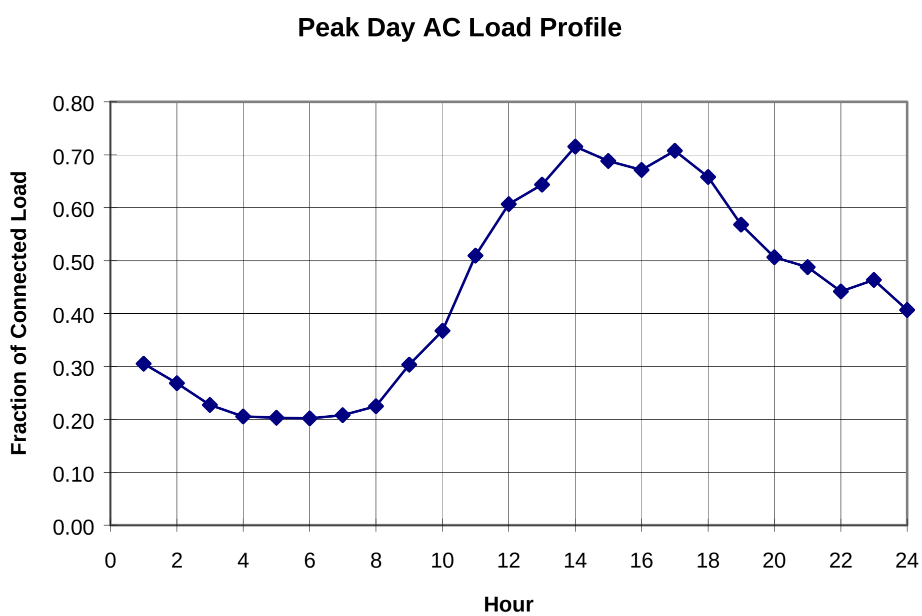

Figure 3-1
Summer Peak Day Diversified[4] Load Profile (Central AC)

[4] Diversified load is the load seen by the utility, which is the average of all the different air conditioners.

AC Peak

Figure 3-2 is based on an operating EER of 11.2 and an average of 39,000 btuh installed air conditioning per home. NOTE: These are watt draws for air conditioned homes with new air conditioners. The watt draws for older air conditioners will be higher.

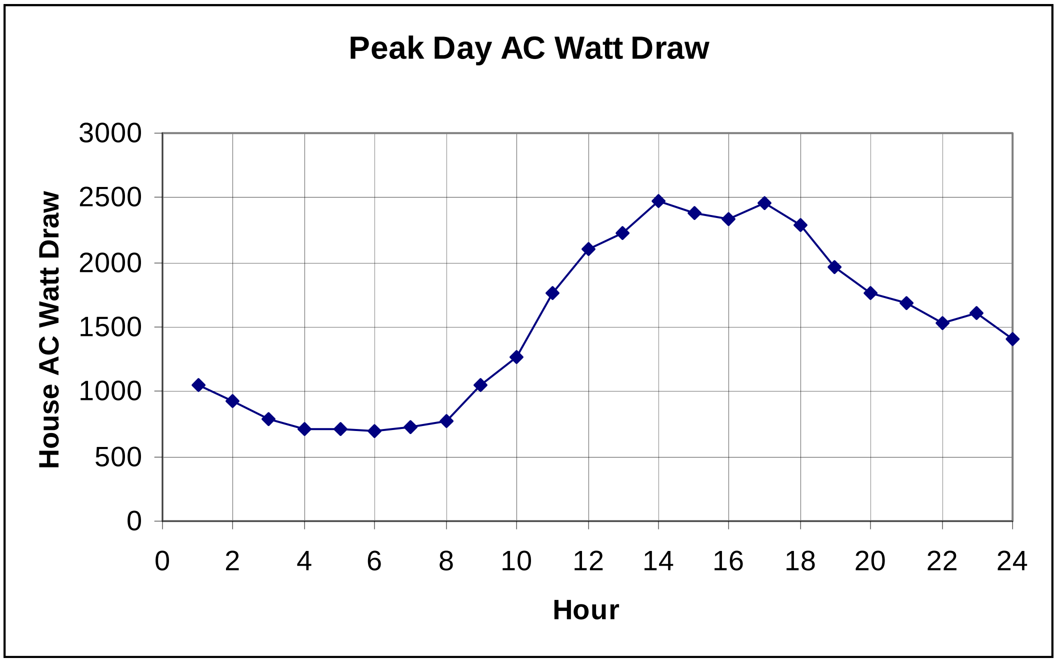

Figure 3-2
Summer Peak Day Diversified Watt Draw (Central AC)

IMPACTS OF EFFICIENCY IMPROVEMENTS ON PEAK.

The impacts of efficiency improvements on peak energy use based on the above load shape are shown in Table 3-1. These impacts are shown for retrofits similar to those in the sample.

Table 3-1. Estimated Peak Demand Reduction for Individual Measures (not interacted)

	without Resizing	with Resizing
Duct Leakage Reduction and Increased Duct Insulation (R-8 in attic)	0.32 kW	0.49 kW
Correct Refrigerant Charge and Airflow	0.10 kW	0.21 kW
Programmable Thermostats	none	none

Duct Sealing

The effect of duct sealing on existing homes has been proven in two metered data programs. The one most similar to this is the SIGECO study (Proctor and deKieffer, 1997). The peak reduction results from that pilot are shown in Figure 3-3.

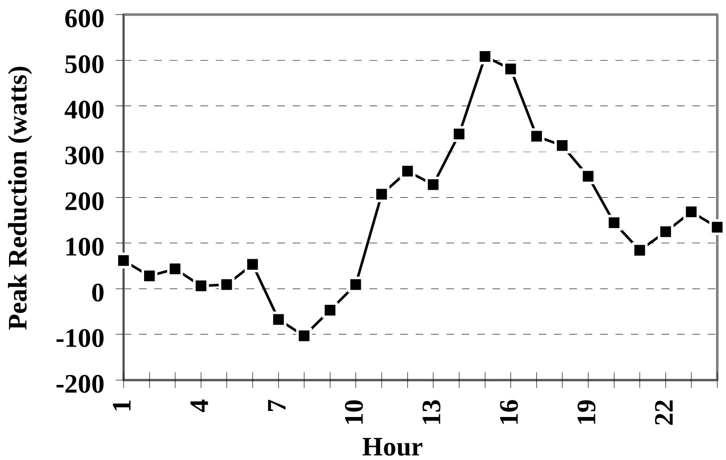

Figure 3-3
Summer Peak Reduction from Duct Sealing (SIGECO data)

Refrigerant Charge and Airflow

The peak reduction effect of correcting refrigerant charge on existing homes is particularly advantageous on undercharged units that are cycling on peak. Given the extreme oversizing seen in the sample, this would be particularly important in this area. Figure 3-4 shows the effect of charge in the efficiency of a standard air conditioner with a short tube orifice metering device.

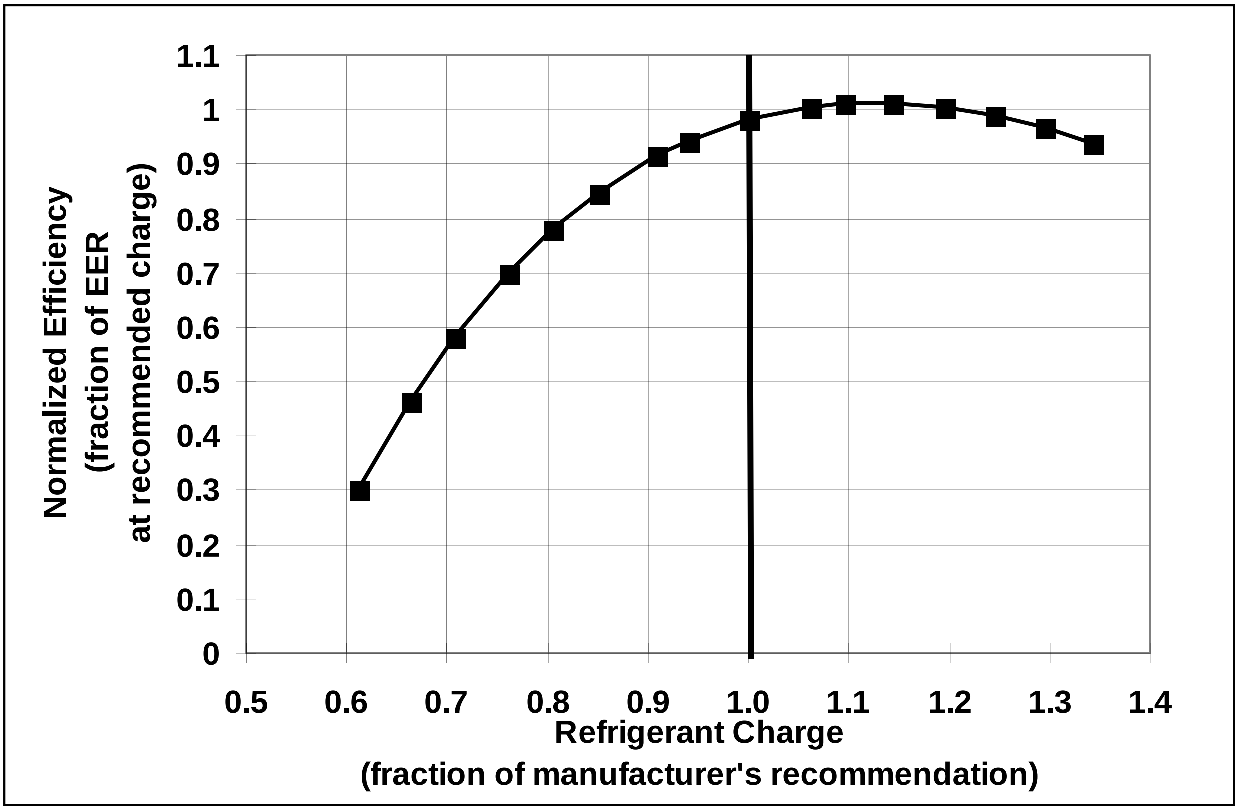

Figure 3-4
Effect of Refrigerant Charge on AC Efficiency (Short tube metering device)

Programmable Thermostat

The effect of a programmable thermostat on peak is estimated as nil. Investigators have found evidence that only individuals who are already prone to use manual setbacks will use automatic setbacks. The people prone to leave their thermostats at constant settings are unlikely to use automatic setbacks. If the people who usually "turn off" the unit while they are gone start using automatic thermostats to cool off the home before they get there, there will be a shift to earlier afternoon usage increasing peak. For a similar hypothesis concerning automatic thermostats with supporting data see Nevius and Pigg, 2000.

4

ESTIMATE OF AC OPERATING HOURS

This section contains an estimate of the operating hours for residential air conditioners in LIPA's service territory. These estimates are based on the measured parameters of the homes in the sample interacted with local weather conditions. They are not based on metered data for the homes.

The operating hours is defined as the cumulative number of run hours over an average summer. As such the energy consumption for cooling is the average kW draw when operating multiplied by the operating hours.

It is often assumed that the operating hours is a constant. It is not. Operating hours are dependent upon the cooling load and the delivered capacity of the air conditioner. Most often, air conditioners are sized to floor area rather than to load. Since newer buildings are more energy efficient this results in increased oversizing of air conditioners. When the amount of oversizing increases, the operating hours figure drops.

METHODOLOGY

PEG triangulated this estimate of the operating hours from metered New Jersey data, from our hourly air conditioner response model (which is based on hourly data), and the relationship between load and capacity found in the sample.

OPERATING HOURS

Annual residential central air conditioner operating hours is estimated to be 338.

This estimate is significantly lower than the 600 plus hours shown in the ARI directory for Long Island. This is not surprising since the estimates in the ARI directory are often high, particularly near oceans. This problem has been brought to the attention of Lawrence Berkley National Laboratory, the institution that originally generated the estimates. The ARI quoted numbers are under review.

5
CONCLUSIONS AND RECOMMENDATIONS

Newly installed air conditioning systems in Island Lighting Power Authority's service territory have substantial deficiencies, similar to those found in studies from other parts of the country. Moderate cost improvements can reduce energy usage and demand while improving occupant comfort and satisfaction.

CONCLUSIONS

- Air infiltration rates for the housing stock examined is very high, leading to excessive infiltration cooling loads.
- Attic and wall insulation levels are low. This adds significantly to the cooling load of the house.
- Duct leakage is reducing the overall cooling efficiency.
- Air conditioners often have insufficient air flow across the indoor coil. Proper installation (following the manufacturers installation instructions) and testing would remedy these problems.
- A program that ensures properly installed air conditioners could reduce cooling usage and peak.
- Air conditioners can be installed with lower connected load (via lower capacity) if the systems are operating properly. Resizing the air conditioner is also a more certain change in peak than relying on the effect of duct tightness (or other program elements) alone.
- The current program of incentives for proper sizing has not effected the size of the air conditioners being installed with respect to ACCA Manual J loads.

LIPA has a variety of potentially worthwhile options for improving cooling efficiency and reducing peak demand. Proper program design, training, and quality assurance are critical issues for actually achieving these improvements. This is illustrated by the failure of the sizing program to reduce sizing.

RECOMMENDATIONS

1) Program implementation should include quality assurance procedures to ensure savings actually occur.
2) In order to ensure peak reduction, improvements on system installation and design should be accompanied with reductions in air conditioner capacity.
3) If air conditioner capacity is reduced, it is recommended that the duct systems remain the same size to reduce static pressures and improve airflow.
4) If recommendation #3 is followed, it is essential that duct insulation be increased.
5) Air handler manufacturers should be enlisted to work with utilities toward the common goal of building tighter air handling units, which are the cause of significant distribution system leaks and are outside the influence of the local installer;

The following additional research is recommended:

- A sample of homes and air conditioners should be tested, characterized, and metered. At a minimum, the metering should be hourly. Preferably the air conditioner would be submetered and a data acquisition system used to record the actual capacity delivered to the duct system. The second option is a certain method of establishing the true cooling load of the building.
- New air conditioner installation practices in LIPA's service territory should be observed. The results would allow refinement of future program specifications.

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APPENDIX A: INDIVIDUAL HOUSE DATA

House #	Group 1=Manual J 2=Therm 3=Both 4=RDD	Living Space Total	Volume	Blower Door CFM50	Natural ACH House	Infiltration Sensible Load	Attic Sensible Load	Floor Sensible Load	Walls Sensible Load	Windows Sensible Load	Doors Sensible Load	Glass Doors Sensible Load
10	1	2126.8	16801.72	3200	0.50	1619	4083	0	2861	3465	220	1843
11	1	1360.2	10337.52	4225	1.08	2138	3721	1048	2603	4159	283	761
12	1	1595.7	12765.6	5000	0.77	1898	2440	0	1952	4764	274	1154
45	3	2212	16590	5075	0.72	2408	3436	0	7003	11818	182	124
48	1	1951	15608	4900	0.68	1940	5023	0	2902	5265	328	412
49	1	1283	10264	3900	0.75	1518	2038	0	2634	5497	225	312
51	1	970	7760	2300	0.58	873	3259	81	1438	1923	167	110
53	3	1743	15251.25	4450	0.57	1689	2665	0	2274	8184	215	1786
56	3	967.5	9675	3400	0.96	1290	2943	94	1379	3777	112	0
59	1	1683	13127.4	4400	0.78	2087	3325	527	2603	2127	171	736
61	1	3485	27880	5660	0.47	2685	3920	0	3180	8606	147	2332
62	1	1405	11240	3450	0.60	1309	1656	60	2454	5202	112	3355
	Mean	1732	13942	4163	0.70	1788	3209	151	2774	5399	203	1077
	Median	1639	12947	4313	0.70	1793	3292	0	2603	4983	198	748
	Min	968	7760	2300	0.47	873	1656	0	1379	1923	112	0
	Max	3485	27880	5660	1.08	2685	5023	1048	7003	11818	328	3355
	Std. Dev.	684	5276	954	0.18	510	936	319	1443	2867	68	1049
	90% CI	325	2505	453	0.08	242	444	152	685	1361	32	498
	Q 25%	1341	10319	3438	0.58	1466	2609	0	2194	3699	162	265
	Q 50%	1639	12947	4313	0.70	1793	3292	0	2603	4983	198	748
	Q 75%	1995	15854	4925	0.77	2100	3770	84	2871	6169	238	1800

House #	Group 1=Manual J 2=Therm 3=Both 4=RDD	People/ Appliances Sensible Load	Duct Gain Sensible Load	Total Sensible Heat Gain	Latent People Load	Latent Infiltration Load	Total Latent Heat Gain	Total Gain (Sensible & Latent)	House Total AC Capacity at Design	House Total AC Capacity at Design / Total Gain
10	1	2700	2519	19309	1150	2359	3509	22818	45919	201%
11	1	2400	2567	19677	920	3115	4035	23712	45437	192%
12	1	2400	2232	17113	920	2765	3685	20799	34463	166%
45	3	2100	4061	31131	690	3508	4198	35329	28206	80%
48	1	2400	2741	21011	920	2827	3747	24757	39276	159%
49	1	2700	2239	17164	1150	2212	3362	20526	29362	143%
51	1	2400	1538	11788	920	1272	2192	13980	23682	169%
53	3	2400	2882	22094	920	2461	3381	25475	45437	178%
56	3	2100	1754	13449	690	1880	2570	16020	33885	212%
59	1	2400	2096	16073	920	3042	3962	20034	35619	178%
61	1	2700	3536	27106	1150	3913	5063	32168	56219	175%
62	1	2400	2482	19030	920	1908	2828	21857	34271	157%
	Mean	2425	2554	19579	939	2605	3544	23123	37648	167%
	Median	2400	2500	19169	920	2613	3597	22338	35041	172%
	Min	2100	1538	11788	690	1272	2192	13980	23682	80%
	Max	2700	4061	31131	1150	3913	5063	35329	56219	212%
	Std. Dev.	201	705	5405	154	743	772	6006	9195	34%
	90% CI	95	335	2566	73	353	367	2852	4366	16%
	Q 25%	2400	2198	16853	920	2136	3228	20403	32754	158%
	Q 50%	2400	2500	19169	920	2613	3597	22338	35041	172%
	Q 75%	2475	2776	21282	978	3060	3980	24937	45437	182%

House #	Group 1=Manual J 2=Therm 3=Both 4=RDD	Living Space Total	Volume	Blower Door CFM50	Natural ACH House	Infiltration Sensible Load	Attic Sensible Load	Floor Sensible Load	Walls Sensible Load	Windows Sensible Load	Doors Sensible Load	Glass Doors Sensible Load
5	2	2,985	25372.5	6480	0.60	3074	12745	0	8025	5494	305	335
7	2	1438	11144.5	3175	0.75	1721	1803	183	6528	2371	112	1464
13	2	2037.1	15176.395	3650	0.56	1732	3061	54	8259	2676	178	1979
14	2	1273.5	9869.625	2600	0.52	987	2854	0	1505	2244	201	867
15	2	1763.5	14108	2150	0.30	816	3953	39	2103	3107	182	113
17	2	955.5	7644	3085	0.79	1171	2973	0	3626	3746	255	0
18	2	1461	11688	3900	0.88	2114	3191	743	2762	3281	112	772
19	2	1053	8950.5	2650	0.58	1006	2454	0	2800	2091	199	684
24	2	2,883	23064	6600	0.67	3131	5960	272	4554	6306	287	228
26	2	2,450	21511	3000	0.33	1423	3262	319	2201	6137	360	0
27	2	2121	16968	3450	0.44	1746	3809	27	4373	3276	185	104
30	2	1342	10601.8	3600	0.67	1366	3280	0	2766	4433	347	571
33	2	1812	14314.8	4800	0.78	2024	3298	256	2483	4515	312	742
37	2	2804	22432	10000	1.04	2372	4094	74	2679	10040	310	863
38	2	1973	15784	5030	0.84	2545	5680	1068	11578	6093	400	639
40	2	2187.5	17959.375	6000	0.66	2277	7735	3733	10643	12049	262	1009
43	2	2357	19091.7	2800	0.34	1328	1297	37	3234	5697	311	118
45	3	2212	16590	5075	0.72	2408	3436	0	7003	11818	182	124
50	2	1288	11205.6	2400	0.42	911	1531	0	1264	2570	310	0
52	2	1704	13461.6	4000	0.69	1898	2486	31	2343	2991	293	1097
53	3	1743	15251.25	4450	0.57	1689	2665	0	2274	8184	215	1786
55	2	1783	13372.5	4000	0.79	2024	4556	222	5986	4469	190	106
56	3	967.5	9675	3400	0.96	1290	2943	94	1379	3777	112	0
57	2	2214	17712	5500	0.72	2609	3739	282	3227	4320	322	1835
60	2	1236	9579	2000	0.41	759	1890	0	1700	1532	166	181
63	2	1166	8453.5	4250	1.17	2016	1957	364	1461	4173	197	931
65	2	1450	11600	1936	0.33	735	2385	0	2511	4732	258	423
66	2	1726	13808	3300	0.56	1566	3551	143	2943	4022	282	0
	Mean	1799	14514	4046	0.65	1741	3664	284	4008	4862	244	606
	Median	1753	13958	3625	0.66	1726	3227	47	2783	4247	257	497
	Min	956	7644	1936	0.30	735	1297	0	1264	1532	112	0
	Max	2985	25373	10000	1.17	3131	12745	3733	11578	12049	400	1979
	Std. Dev.	572	4714	1739	0.22	673	2256	719	2814	2735	79	600
	90% CI	178	1465	541	0.07	209	701	223	875	850	24	186
	Q 25%	1329	11009	2950	0.50	1260	2478	0	2256	3078	184	111
	Q 50%	1753	13958	3625	0.66	1726	3227	47	2783	4247	257	497
	Q 75%	2194	17154	4858	0.78	2155	3845	260	4912	5796	310	883

ouse #	Group 1=Manual J 2=Therm 3=Both 4=RDD	People/ Appliances Sensible Load	Duct Gain Sensible Load	Total Sensible Heat Gain	Latent People Load	Latent Infiltration Load	Total Latent Heat Gain	Total Gain (Sensible & Latent)	House Total AC Capacity at Design	House Total AC Capacity at Design / Total Gain
5	2	2400	4857	37235	920	4479	5399	42635	45437	107%
7	2	2400	2487	19069	920	2508	3428	22497	34078	151%
13	2	2400	3051	23391	920	2523	3443	26834	37831	141%
14	2	2100	1614	12373	690	1438	2128	14501	28398	196%
15	2	2400	1907	14619	920	1189	2109	16728	32344	193%
17	2	2100	2081	15952	690	1706	2396	18348	33115	180%
18	2	2400	2306	17682	920	3081	4001	21683	45437	210%
19	2	2100	1700	13035	690	1465	2155	15190	22333	147%
24	2	3300	3606	27643	1610	4562	6172	33816	56797	168%
26	2	2700	2460	18863	1150	2074	3224	22087	33885	153%
27	2	2700	2433	18653	1150	2544	3694	22347	34078	152%
30	2	2400	2274	17438	920	1991	2911	20348	25508	125%
33	2	2700	2449	18779	1150	2949	4099	22879	34078	149%
37	2	2700	3470	26601	1150	3456	4606	31207	44474	143%
38	2	3000	4650	35652	1380	3709	5089	40741	39758	98%
40	2	3000	6106	46815	1380	3318	4698	51513	40721	79%
43	2	2700	2208	16931	1150	1936	3086	20016	40721	203%
45	3	2100	4061	31131	690	3508	4198	35329	28206	80%
50	2	2400	1348	10333	920	1327	2247	12580	32151	256%
52	2	2400	2031	15569	920	2765	3685	19254	43992	228%
53	3	2400	2882	22094	920	2461	3381	25475	45437	178%
55	2	2700	3038	23291	1150	2949	4099	27390	38794	142%
56	3	2100	1754	13449	690	1880	2570	16020	33885	212%
57	2	2700	2855	21890	1150	3802	4952	26842	49576	185%
60	2	2400	1294	9923	920	1106	2026	11949	28013	234%
63	2	2400	2025	15524	920	2938	3858	19382	28206	146%
65	2	2400	2017	15462	920	1071	1991	17452	32537	186%
66	2	2400	2236	17143	920	2281	3201	20344	28591	141%
	Mean	2496	2686	20591	994	2536	3530	24121	36371	164%
	Median	2400	2370	18168	920	2516	3436	21885	34078	153%
	Min	2100	1294	9923	690	1071	1991	11949	22333	79%
	Max	3300	6106	46815	1610	4562	6172	51513	56797	256%
	Std. Dev.	295	1121	8591	226	981	1124	9481	8049	45%
	90% CI	92	348	2670	70	305	349	2947	2502	14%
	Q 25%	2400	2023	15508	920	1837	2527	18124	31261	141%
	Q 50%	2400	2370	18168	920	2516	3436	21885	34078	153%
	Q 75%	2700	3041	23316	1150	3140	4124	26979	41539	194%

House #	Group 1=Manual J 2=Therm 3=Both 4=RDD	Living Space Total	Volume	Blower Door CFM50	Natural ACH House	Infiltration Sensible Load	Attic Sensible Load	Floor Sensible Load	Walls Sensible Load	Windows Sensible Load	Doors Sensible Load	Glass Doors Sensible Load
1	4	2,698	21584	6050	0.65	2870	3117	0	3168	3573	401	796
2	4	1,785	13836.075	4050	0.77	2196	3309	0	2103	4726	266	108
3	4	2710.8	23312.88	3650	0.37	1732	2701	115	3485	4638	422	381
4	4	2120.3	16962.4	4975	0.68	2360	7264	0	7571	4535	271	729
6	4	1896	15566.16	6469	0.97	3069	20562	0	9341	12377	344	419
8	4	1929	16975.2	2900	0.45	1572	2683	167	2759	2435	246	1535
9	4	1647	13176	3900	0.58	1480	4020	0	5517	4041	335	331
16	4	1720.7	13404.253	4700	0.82	2230	2994	0	5774	3322	232	243
20	4	1806	13797.84	4150	0.79	2250	3871	68	5949	4276	381	112
21	4	1734	13351.8	4500	0.79	2135	10143	0	6378	3144	208	559
22	4	1982.49	15859.92	4950	0.73	2348	32072	0	2343	5671	296	0
23	4	1605	11716.5	4100	0.92	2075	2478	1205	2042	2344	390	1517
25	4	972	7776	1900	0.73	721	2376	0	1450	3186	264	337
28	4	2152	17216	5500	0.75	2609	4334	317	3855	3908	277	98
29	4	1164	9312	4600	0.97	1746	2609	30	5635	3579	274	149
31	4	1606	12687.4	5000	0.64	2372	1237	0	2463	4293	114	0
32	4	1722	13603.8	4000	0.58	1518	5366	0	3276	4947	327	113
34	4	1378	11161.8	3700	0.90	1755	1735	88	1110	5508	212	0
35	4	1788	13946.4	5030	0.78	1909	2817	0	3147	5372	460	402
36	4	1942	15536	5030	0.63	1909	4807	425	2986	12329	309	1566
39	4	3148	25498.8	5030	0.46	3700	5716	4435	3677	14649	395	903
41	4	1364	10571	2600	0.48	1233	3039	48	2279	3042	258	326
42	4	1209	9672	2300	0.47	873	1825	0	1877	9382	216	0
44	4	2193	17105.4	5000	0.57	2108	6814	198	3689	5096	309	356
46	4	1766	14128	2800	0.39	1063	7340	856	2333	7712	284	113
47	4	1079	8739.9	2900	0.72	1223	3651	118	1827	3352	73	1721
54	4	2064	18163.2	3700	0.54	1613	1917	114	2218	5963	206	655
58	4	1375.5	11004	5300	1.12	2609	4425	0	4727	4001	304	838
64	4	996	7719	3100	0.51	1176	1941	0	4040	3449	175	125
	Mean	1778	14255	4203	0.68	1947	5419	282	3690	5340	285	498
	Median	1766	13798	4150	0.68	1909	3309	0	3168	4293	277	337
	Min	972	7719	1900	0.37	721	1237	0	1110	2344	73	0
	Max	3148	25499	6469	1.12	3700	32072	4435	9341	14649	460	1721
	Std. Dev.	508	4317	1125	0.19	674	6320	844	1956	3088	89	514
	90% CI	155	1319	344	0.06	206	1930	258	597	943	27	157
	Q 25%	1378	11162	3650	0.54	1518	2609	0	2279	3449	232	113
	Q 50%	1766	13798	4150	0.68	1909	3309	0	3168	4293	277	337
	Q 75%	1982	16962	5000	0.79	2348	5366	118	4727	5508	335	729

ouse #	Group 1=Manual J 2=Therm 3=Both 4=RDD	People/ Appliances Sensible Load	Duct Gain Sensible Load	Total Sensible Heat Gain	Latent People Load	Latent Infiltration Load	Total Latent Heat Gain	Total Gain (Sensible & Latent)	House Total AC Capacity at Design	House Total AC Capacity at Design / Total Gain
1	4	3000	2539	19462	1380	4182	5562	25025	64114	256%
2	4	2700	2311	17719	1150	3200	4350	22068	39758	180%
3	4	2700	2426	18601	1150	2523	3673	22274	65940	296%
4	4	2400	3770	28900	920	3439	4359	33259	54870	165%
6	4	2400	7277	55789	920	4472	5392	61181	65073	106%
8	4	2700	2115	16213	1150	2291	3441	19654	45437	231%
9	4	2400	2719	20842	920	2157	3077	23919	38313	160%
16	4	2400	2579	19775	920	3249	4169	23944	37349	156%
20	4	2700	2941	22547	1150	3279	4429	26975	34078	126%
21	4	2700	3790	29058	1150	3111	4261	33319	34078	102%
22	4	2400	6770	51900	920	3422	4342	56242	44956	80%
23	4	2400	2167	16617	920	3023	3943	20560	32151	156%
25	4	2100	1565	11999	690	1051	1741	13740	17039	124%
28	4	2400	2670	20468	920	3802	4722	25190	43992	175%
29	4	2400	2463	18885	920	2544	3464	22349	37349	167%
31	4	2700	1977	15156	1150	3456	4606	19762	46401	235%
32	4	2400	2692	20640	920	2212	3132	23772	45437	191%
34	4	2100	1876	14385	690	2558	3248	17633	32729	186%
35	4	2700	2521	19329	1150	2782	3932	23261	32151	138%
36	4	2400	4010	30742	920	2782	3702	34443	48034	139%
39	4	2700	5426	41601	1150	5392	6542	48143	65073	135%
41	4	2700	1939	14864	1150	1797	2947	17812	34078	191%
42	4	2400	2486	19059	920	1272	2192	21251	34656	163%
44	4	2700	3191	24462	1150	3072	4222	28685	38794	135%
46	4	2400	3315	25417	920	1548	2468	27886	53044	190%
47	4	2700	2200	16866	1150	1782	2932	19798	26664	135%
54	4	2700	2308	17694	1150	2350	3500	21195	28206	133%
58	4	2400	2896	22201	920	3802	4722	26923	39758	148%
64	4	2100	1951	14958	690	1714	2404	17362	22719	131%
	Mean	2514	2996	22971	1007	2837	3844	26815	41457	163%
	Median	2400	2539	19462	920	2782	3932	23772	38794	156%
	Min	2100	1565	11999	690	1051	1741	13740	17039	80%
	Max	3000	7277	55789	1380	5392	6542	61181	65940	296%
	Std. Dev.	218	1366	10470	167	983	1052	11074	12702	47%
	90% CI	67	417	3198	51	300	321	3382	3880	14%
	Q 25%	2400	2200	16866	920	2212	3132	20560	34078	135%
	Q 50%	2400	2539	19462	920	2782	3932	23772	38794	156%
	Q 75%	2700	3191	24462	1150	3422	4359	27886	46401	186%

House #	Group 1=Manual J 2=Therm 3=Both 4=RDD	MJ AC/HR Poor	MJ Summer Infiltration CFM	MJ Summer Infiltration Btuh	MJ Summer Infiltration Latent	MJ Sens Infil / PEG Sens Infil	MJ Latent Infil / PEG Latent Infil	MJ Total Infil / PEG Total Infil
17	2	0.7	89.35836	1376.1187	2005.2016	1.175359	1.175359	1.175359
56	3	0.7	113.10075	1741.7516	2537.9808	1.349824	1.349824	1.349824
51	1	0.7	90.7144	1397.0018	2035.6311	1.600439	1.600439	1.600439
25	4	0.7	90.90144	1399.8822	2039.8283	1.941368	1.941368	1.941368
64	4	0.7	90.23511	1389.6207	2024.8759	1.181148	1.181148	1.181148
19	2	0.7	104.631345	1611.3227	2347.9274	1.602163	1.602163	1.602163
47	4	0.7	102.169431	1573.4092	2292.682	1.28663	1.28663	1.28663
29	4	0.7	108.85728	1676.4021	2442.7574	0.960263	0.960263	0.960263
63	2	0.7	98.821415	1521.8498	2217.5526	0.75481	0.75481	0.75481
42	4	0.7	113.06568	1741.2115	2537.1939	1.994774	1.994774	1.994774
60	2	0.7	111.97851	1724.4691	2512.7978	2.271932	2.271932	2.271932
14	2	0.7	115.375916	1776.7891	2589.0356	1.800663	1.800663	1.800663
49	1	0.7	119.98616	1847.7869	2692.4894	1.2172	1.2172	1.2172
50	2	0.7	130.993464	2017.2993	2939.4933	2.214772	2.214772	2.214772
30	2	0.7	123.935042	1908.5996	2781.1023	1.396954	1.396954	1.396954
11	1	0.7	120.845609	1861.0224	2711.7755	0.870489	0.870489	0.870489
41	4	0.7	123.57499	1903.0548	2773.0228	1.542881	1.542881	1.542881
58	4	0.7	128.63676	1981.0061	2886.6089	0.759238	0.759238	0.759238
34	4	0.7	130.481442	2009.4142	2928.0036	1.144781	1.144781	1.144781
62	1	0.7	131.3956	2023.4922	2948.5173	1.545441	1.545441	1.545441
7	2	0.7	130.279205	2006.2998	2923.4654	1.165537	1.165537	1.165537
65	2	0.7	135.604	2088.3016	3042.9538	2.842221	2.842221	2.842221
18	2	0.7	136.63272	2104.1439	3066.0382	0.995142	0.995142	0.995142
12	1	0.6	127.911312	1969.8342	2870.3298	1.038077	1.038077	1.038077
23	4	0.6	117.39933	1807.9497	2634.441	0.871447	0.871447	0.871447
31	4	0.6	127.127748	1957.7673	2852.7467	0.825364	0.825364	0.825364
9	4	0.6	132.02352	2033.1622	2962.6078	1.373654	1.373654	1.373654
59	1	0.6	131.536548	2025.6628	2951.6801	0.970441	0.970441	0.970441
52	2	0.6	134.885232	2077.2326	3026.8246	1.094661	1.094661	1.094661
16	4	0.6	134.310615	2068.3835	3013.9302	0.927658	0.927658	0.927658
32	4	0.6	136.310076	2099.1752	3058.7981	1.382798	1.382798	1.382798
66	2	0.6	138.35616	2130.6849	3104.7122	1.361005	1.361005	1.361005
21	4	0.6	133.785036	2060.2896	3002.1362	0.965096	0.965096	0.965096
53	3	0.6	152.817525	2353.3899	3429.2253	1.39349	1.39349	1.39349
15	2	0.6	141.36216	2176.9773	3172.1669	2.667997	2.667997	2.667997
46	4	0.6	141.56256	2180.0634	3176.6638	2.051545	2.051545	2.051545
55	2	0.6	133.99245	2063.4837	3006.7906	1.019482	1.019482	1.019482
2	4	0.6	138.637472	2135.0171	3111.0249	0.972345	0.972345	0.972345
35	4	0.6	139.742928	2152.0411	3135.8313	1.127334	1.127334	1.127334
20	4	0.6	138.254357	2129.1171	3102.4278	0.946293	0.946293	0.946293
33	2	0.6	143.434296	2208.8882	3218.6656	1.091296	1.091296	1.091296
6	4	0.6	155.972923	2401.983	3500.0324	0.782686	0.782686	0.782686
8	4	0.6	170.091504	2619.4092	3816.8533	1.666017	1.666017	1.666017
36	4	0.6	155.67072	2397.3291	3493.251	1.255826	1.255826	1.255826
48	1	0.6	156.39216	2408.4393	3509.4401	1.241618	1.241618	1.241618
38	2	0.6	158.15568	2435.5975	3549.0135	0.95692	0.95692	0.95692

22	4	0.6	158.916398	2447.3125	3566.084	1.042171	1.042171	1.042171
13	2	0.6	152.067478	2341.8392	3412.3942	1.352442	1.352442	1.352442
54	4	0.6	181.995264	2802.7271	4083.9737	1.737627	1.737627	1.737627
4	4	0.5	141.63604	2181.195	3178.3127	0.924179	0.924179	0.924179
27	2	0.5	141.6828	2181.9151	3179.362	1.249848	1.249848	1.249848
10	1	0.5	140.294362	2160.5332	3148.2055	1.334287	1.334287	1.334287
28	4	0.5	143.7536	2213.8054	3225.8308	0.84846	0.84846	0.84846
40	2	0.5	149.960781	2309.396	3365.1199	1.014185	1.014185	1.014185
44	4	0.5	142.83009	2199.5834	3205.1072	1.043231	1.043231	1.043231
45	3	0.5	138.5265	2133.3081	3108.5347	0.886078	0.886078	0.886078
57	2	0.5	147.8952	2277.5861	3318.7683	0.872904	0.872904	0.872904
43	2	0.5	159.415695	2455.0017	3577.2882	1.848197	1.848197	1.848197
26	2	0.5	179.61685	2766.0995	4030.6021	1.943574	1.943574	1.943574
1	4	0.5	180.2264	2775.4866	4044.2804	0.967026	0.967026	0.967026
3	4	0.5	194.662548	2997.8032	4368.2276	1.73127	1.73127	1.73127
37	2	0.5	187.3072	2884.5309	4203.1736	1.216073	1.216073	1.216073
24	2	0.5	192.5844	2965.7998	4321.5939	0.947223	0.947223	0.947223
5	2	0.5	211.860375	3262.6498	4754.1468	1.061329	1.061329	1.061329
39	4	0.5	212.91498	3278.8907	4777.8122	0.886108	0.886108	0.886108
61	1	0.5	232.798	3585.0892	5223.9871	1.335175	1.335175	1.335175
N		66	66	66	66	66	66	66
Mean		1	140	2164	3153	1.30	1.30	1.30
Median		1	137	2117	3084	1.18	1.18	1.18
Min		1	89	1376	2005	0.75	0.75	0.75
Max		1	233	3585	5224	2.84	2.84	2.84
Std. Dev.		0	29	453	660	0.45	0.45	0.45
90% CI		0	6	92	134	0.09	0.09	0.09
Q 25%		1	125	1921	2799	0.97	0.97	0.97
Q 50%		1	137	2117	3084	1.18	1.18	1.18
Q 75%		1	153	2351	3425	1.51	1.51	1.51

APPENDIX B: INDIVIDUAL SYSTEM DATA

System #	Group 1=Manual J 2=Therm 3=Both 4=RDD	ARI Rated Capacity	Air Conditioner Rated Nominal Tonnage	Air Conditioner Capacity @ Design	SEER	Airflow Across Indoor Coil (CFM)	CFM per Nominal Ton	Measured Airflow / Rated Airflow
13	1	48500	4.0	45,919	14.25	1149	287	72%
14	1	48000	4.0	45,437	12.5	827	207	52%
15	1	36400	3.0	34,463	13.25	1007	336	84%
50	3	29800	2.5	28,206	15.5	970	388	97%
53	1	41500	3.5	39,276	14	736	210	53%
54	1	31000	2.5	29,362	14.1	983	393	98%
56	1	25000	2.0	23,682	14	769	385	96%
58	3	48000	4.0	45,437	14	959	240	60%
61	3	35800	3.0	33,885	15	841	280	70%
65	1	37600	3.0	35,619	14.3	1169	390	97%
67	1	35000	3.0	33,115	14.5	1351	450	113%
68	1	24400	2.0	23,104	14.05	1015	508	127%
69	1	36200	3.0	34,271	13.05	946	315	79%
	Mean	36708	3.0	34752	14.0	979	338	84%
	Median	36200	3.0	34271	14.1	970	336	84%
	Min	24400	2.0	23104	12.5	736	207	52%
	Max	48500	4.0	45919	15.5	1351	508	127%
	Std. Dev.	8118	0.7	7682	0.8	171	92	23%
	90% CI	3703	0.3	3505	0.4	78	42	10%
	Q 25%	31000	2.5	29362	14.0	841	280	70%
	Q 50%	36200	3.0	34271	14.1	970	336	84%
	Q 75%	41500	3.5	39276	14.3	1015	390	97%

ouse #	System #	Group 1=Manual J 2=Therm 3=Both 4=RDD	Supply Plenum Opperating Pressure (Pascals)	Return Plenum Opperating Pressure (Pascals)	Total Duct Leakage (CFM25)	Duct Leakage to Outside (CFM25)	Area of Supply leakage	Area of Return Leakage	Total Leakage % Supply Operating Leakage	Total Leakage % Return Operating Leakage	Outside Leakage % Supply Operating Leakage	Outside Leakage % Return Operating Leakage	Supply % Accessible
5	7	2	91	74	767	196	43%	57%	30%	35%	8%	9%	100%
7	10	2	91	92	376	212	56%	44%	52%	42%	29%	23%	55%
13	16	2	40	61	195	110	65%	35%	10%	7%	6%	4%	35%
14	17	2	76	121	144	81	57%	43%	11%	10%	6%	6%	60%
15	18	2	27	59	343	193	80%	20%	24%	9%	14%	5%	50%
17	20	2	45	26	154	87	56%	44%	11%	6%	6%	4%	30%
18	21	2	90	121	376	174	65%	35%	29%	18%	14%	8%	30%
19	22	2	109	131	660	660	50%	50%	49%	53%	49%	53%	65%
24	27	2	64	103	385	385	57%	43%	22%	21%	22%	21%	90%
24	28	2	30	144	230	123	65%	35%	9%	11%	5%	6%	90%
26	30	2	45	140	748	384	73%	27%	42%	28%	21%	14%	100%
27	31	2	168	34	423	101	45%	55%	42%	23%	10%	5%	50%
30	34	2	53	66	233	211	62%	38%	14%	10%	13%	9%	90%
33	37	2	64	78	227	154	47%	53%	10%	12%	6%	8%	90%
37	42	2	52	57	418	208	63%	37%	20%	13%	10%	6%	n
38	43	2	30	26	316	178	62%	38%	23%	13%	13%	7%	90%
39	44	2	23	63	1189	1030	57%	43%	46%	56%	40%	49%	90%
40	45	2	79	36	522	209	49%	51%	44%	31%	18%	12%	n
43	48	2	31	36	312	158	57%	43%	18%	14%	9%	7%	90%
45	50	3	58	138	351	198	39%	61%	15%	37%	8%	21%	80%
50	55	2	92	60	316	197	62%	38%	30%	15%	19%	9%	90%
52	57	2	80	66	408	201	67%	33%	29%	13%	14%	6%	75%
53	58	3	10	65	415	160	59%	41%	11%	20%	4%	8%	75%
55	60	2	91	40	395	135	79%	21%	42%	7%	14%	2%	90%
56	61	3	36	61	302	145	73%	27%	22%	11%	11%	5%	90%
57	62	2	23	99	409	237	48%	52%	12%	26%	7%	15%	90%
57	63	2	22	100	136	62	39%	61%	6%	21%	3%	10%	90%
60	66	2	48	75	225	193	56%	44%	12%	12%	10%	10%	100%
63	70	2	81	50	874	66	68%	32%	83%	31%	6%	2%	15%
65	72	2	42	50	224	130	53%	47%	12%	11%	7%	7%	100%
66	73	2	193	94	368	225	72%	28%	57%	15%	35%	9%	80%
		Mean	64	76	401	219	59%	41%	27%	20%	14%	12%	75%
		Median	53	66	368	193	57%	43%	22%	15%	10%	8%	90%
		Min	10	26	136	62	39%	20%	6%	6%	3%	2%	15%
		Max	193	144	1189	1030	80%	61%	83%	56%	49%	53%	100%
		Std. Dev.	41	35	232	189	11%	11%	18%	13%	11%	12%	24%
		90% CI	12	10	68	56	3%	3%	5%	4%	3%	3%	7%
		Q 25%	34	54	232	133	52%	35%	12%	11%	7%	6%	60%
		Q 50%	53	66	368	193	57%	43%	22%	15%	10%	8%	90%
		Q 75%	86	100	417	210	65%	48%	42%	27%	16%	11%	90%

House #	System #	Group 1=Manual J 2=Therm 3=Both 4=RDD	Return % Accessible	ARI Rated Capacity	Air Conditioner Rated Nominal Tonnage	Air Conditioner Capacity @ Design	SEER	Airflow Across Indoor Coil (CFM)	CFM per Nominal Ton	Measured Airflow / Rated Airflow
5	7	2	100%	48,000	4.0	45,437	n	1518	379	95%
7	10	2	70%	36,000	3.0	34,078	14	543	181	45%
13	16	2	45%	40,000	3.5	37,831	14.3	1117	319	80%
14	17	2	65%	30,000	2.5	28,398	12.3	934	374	93%
15	18	2	60%	34,200	3.0	32,344	12	827	276	69%
17	20	2	40%	35,000	3.0	33,115	13.5	768	256	64%
18	21	2	45%	48,000	4.0	45,437	13	1117	279	70%
19	22	2	70%	23,600	2.0	22,333	12.2	1008	504	126%
24	27	2	100%	30,000	2.5	28,398	14	1128	451	113%
24	28	2	100%	30,000	2.5	28,398	14	1228	491	123%
26	30	2	100%	35,800	3.0	33,885	13	1239	413	103%
27	31	2	50%	36,000	3.0	34,078	14	841	280	70%
30	34	2	90%	27,000	2.5	25,508	12	1030	412	103%
33	37	2	90%	36,000	3.0	34,078	13	1252	417	104%
37	42	2	n	47,000	4.0	44,474	14	1320	330	83%
38	43	2	90%	42,000	3.5	39,758	15.1	668	191	48%
39	44	2	90%	34,400	3.0	32,537	12.1	1006	335	84%
40	45	2	n	43,000	3.5	40,721	13	728	208	52%
43	48	2	90%	43,000	3.5	40,721	13	784	224	56%
45	50	3	90%	29,800	2.5	28,206	15.5	970	388	97%
50	55	2	90%	34,000	3.0	32,151	12.4	896	299	75%
52	57	2	90%	46,500	4.0	43,992	12.4	1195	299	75%
53	58	3	100%	48,000	4.0	45,437	14	959	240	60%
55	60	2	90%	41,000	3.5	38,794	12	1018	291	73%
56	61	3	90%	35,800	3.0	33,885	15	841	280	70%
57	62	2	90%	29,800	2.5	28,206	12.4	1138	455	114%
57	63	2	90%	22,600	2.0	21,370	12.4	556	278	70%
60	66	2	100%	29,600	2.5	28,013	12	1027	411	103%
63	70	2	5%	29,800	2.5	28,206	12.4	908	363	91%
65	72	2	100%	34,400	3.0	32,537	12.4	925	308	77%
66	73	2	90%	30,200	2.5	28,591	14	908	363	91%
		Mean	80%	35823	3.0	33901	13.2	981	332	83%
		Median	90%	35000	3.0	33115	13.0	970	319	80%
		Min	5%	22600	2.0	21370	12.0	543	181	45%
		Max	100%	48000	4.0	45437	15.5	1518	504	126%
		Std. Dev.	24%	7218	0.6	6836	1.0	220	86	22%
		90% CI	7%	2132	0.2	2019	0.3	65	25	6%
		Q 25%	70%	30000	2.5	28398	12.4	841	279	70%
		Q 50%	90%	35000	3.0	33115	13.0	970	319	80%
		Q 75%	90%	41500	3.5	39276	14.0	1123	399	100%

House #	System #	Group 1=Manual J 2=Therm 3=Both 4=RDD	Supply Plenum Opperating Pressure (Pascals)	Return Plenum Opperating Pressure (Pascals)	Total Duct Leakage (CFM25)	Duct Leakage to Outside (CFM25)	Area of Supply leakage	Area of Return Leakage	Total Leakage % Supply Operating Leakage	Total Leakage % Return Operating Leakage	Outside Leakage % Supply Operating Leakage	Outside Leakage % Return Operating Leakage	Supply % Accessible
1	1	4	11	53	902	894	54%	46%	33%	60%	32%	60%	40%
1	2	4	36	63	521	401	73%	27%	41%	21%	32%	16%	45%
2	3	4	16	176	245	203	83%	17%	19%	13%	16%	10%	50%
3	4	4	n	n	92	39	28%	72%	n	n	n	n	40%
3	5	4	n	n	189	42	16%	84%	n	n	n	n	75%
4	6	4	101	110	485	343	27%	73%	23%	64%	16%	45%	55%
6	8	4	40	136	485	29	75%	25%	36%	23%	2%	1%	15%
6	9	4	85	127	376	319	80%	20%	60%	19%	51%	16%	60%
8	11	4	74	116	420	126	67%	33%	30%	19%	9%	6%	80%
9	12	4	58	43	420	348	64%	36%	35%	17%	29%	14%	50%
16	19	4	51	151	687	77	78%	22%	51%	24%	6%	3%	20%
20	23	4	88	141	406	304	42%	58%	21%	35%	15%	27%	30%
21	24	4	75	75	278	248	72%	28%	28%	11%	25%	10%	35%
22	25	4	20	10	712	183	64%	36%	49%	19%	12%	5%	40%
23	26	4	81	123	790	443	68%	32%	60%	34%	34%	19%	45%
25	29	4	91	25	163	113	75%	25%	25%	4%	17%	3%	100%
28	32	4	47	88	590	551	74%	26%	32%	15%	30%	14%	75%
29	33	4	118	38	361	280	60%	40%	31%	12%	24%	9%	90%
31	35	4	80	109	695	202	60%	40%	41%	32%	12%	9%	75%
32	36	4	130	58	140	82	54%	46%	11%	6%	7%	4%	100%
34	38	4	12	42	771	114	47%	53%	22%	47%	3%	7%	90%
35	39	4	102	119	303	254	49%	51%	33%	37%	28%	31%	90%
36	40	4	52	60	645	363	71%	29%	60%	26%	34%	15%	25%
36	41	4	22	53	1106	622	60%	40%	50%	52%	28%	29%	25%
41	46	4	51	43	463	10	83%	17%	67%	13%	1%	0%	10%
42	47	4	28	70	221	124	75%	25%	25%	13%	14%	7%	100%
44	49	4	135	113	242	186	43%	57%	15%	18%	12%	14%	90%
46	51	4	40	129	896	442	77%	23%	44%	24%	22%	12%	80%
47	52	4	32	65	1018	641	69%	31%	75%	47%	47%	30%	50%
54	59	4	31	67	556	128	79%	21%	19%	7%	4%	2%	90%
58	64	4	44	17	202	176	52%	48%	17%	10%	15%	8%	70%
64	71	4	32	91	1173	820	52%	48%	55%	86%	38%	60%	25%
		Mean	59	84	517	285	62%	38%	37%	27%	21%	16%	58%
		Median	51	72	474	225	65%	35%	33%	20%	17%	11%	53%
		Min	11	10	92	10	16%	17%	11%	4%	1%	0%	10%
		Max	135	176	1173	894	83%	84%	75%	86%	51%	60%	100%
		Std. Dev.	35	43	293	225	17%	17%	17%	19%	13%	16%	28%
		90% CI	11	13	85	66	5%	5%	5%	6%	4%	5%	8%
		Q 25%	32	53	270	122	52%	25%	24%	13%	12%	6%	39%
		Q 50%	51	72	474	225	65%	35%	33%	20%	17%	11%	53%
		Q 75%	84	118	699	372	75%	48%	50%	35%	29%	18%	83%

House #	System #	Group 1=Manual J 2=Therm 3=Both 4=RDD	Supply Plenum Opperating Pressure (Pascals)	Return Plenum Opperating Pressure (Pascals)	Total Duct Leakage (CFM25)	Duct Leakage to Outside (CFM25)	Area of Supply leakage	Area of Return Leakage	Total Leakage % Supply Operating Leakage	Total Leakage % Return Operating Leakage	Outside Leakage % Supply Operating Leakage	Outside Leakage % Return Operating Leakage	Supply % Accessible
1	1	4	11	53	902	894	54%	46%	33%	60%	32%	60%	40%
1	2	4	36	63	521	401	73%	27%	41%	21%	32%	16%	45%
2	3	4	16	176	245	203	83%	17%	19%	13%	16%	10%	50%
3	4	4	n	n	92	39	28%	72%	n	n	n	n	40%
3	5	4	n	n	189	42	16%	84%	n	n	n	n	75%
4	6	4	101	110	485	343	27%	73%	23%	64%	16%	45%	55%
6	8	4	40	136	485	29	75%	25%	36%	23%	2%	1%	15%
6	9	4	85	127	376	319	80%	20%	60%	19%	51%	16%	60%
8	11	4	74	116	420	126	67%	33%	30%	19%	9%	6%	80%
9	12	4	58	43	420	348	64%	36%	35%	17%	29%	14%	50%
16	19	4	51	151	687	77	78%	22%	51%	24%	6%	3%	20%
20	23	4	88	141	406	304	42%	58%	21%	35%	15%	27%	30%
21	24	4	75	75	278	248	72%	28%	28%	11%	25%	10%	35%
22	25	4	20	10	712	183	64%	36%	49%	19%	12%	5%	40%
23	26	4	81	123	790	443	68%	32%	60%	34%	34%	19%	45%
25	29	4	91	25	163	113	75%	25%	25%	4%	17%	3%	100%
28	32	4	47	88	590	551	74%	26%	32%	15%	30%	14%	75%
29	33	4	118	38	361	280	60%	40%	31%	12%	24%	9%	90%
31	35	4	80	109	695	202	60%	40%	41%	32%	12%	9%	75%
32	36	4	130	58	140	82	54%	46%	11%	6%	7%	4%	100%
34	38	4	12	42	771	114	47%	53%	22%	47%	3%	7%	90%
35	39	4	102	119	303	254	49%	51%	33%	37%	28%	31%	90%
36	40	4	52	60	645	363	71%	29%	60%	26%	34%	15%	25%
36	41	4	22	53	1106	622	60%	40%	50%	52%	28%	29%	25%
41	46	4	51	43	463	10	83%	17%	67%	13%	1%	0%	10%
42	47	4	28	70	221	124	75%	25%	25%	13%	14%	7%	100%
44	49	4	135	113	242	186	43%	57%	15%	18%	12%	14%	90%
46	51	4	40	129	896	442	77%	23%	44%	24%	22%	12%	80%
47	52	4	32	65	1018	641	69%	31%	75%	47%	47%	30%	50%
54	59	4	31	67	556	128	79%	21%	19%	7%	4%	2%	90%
58	64	4	44	17	202	176	52%	48%	17%	10%	15%	8%	70%
64	71	4	32	91	1173	820	52%	48%	55%	86%	38%	60%	25%
		Mean	59	84	517	285	62%	38%	37%	27%	21%	16%	58%
		Median	51	72	474	225	65%	35%	33%	20%	17%	11%	53%
		Min	11	10	92	10	16%	17%	11%	4%	1%	0%	10%
		Max	135	176	1173	894	83%	84%	75%	86%	51%	60%	100%
		Std. Dev.	35	43	293	225	17%	17%	17%	19%	13%	16%	28%
		90% CI	11	13	85	66	5%	5%	5%	6%	4%	5%	8%
		Q 25%	32	53	270	122	52%	25%	24%	13%	12%	6%	39%
		Q 50%	51	72	474	225	65%	35%	33%	20%	17%	11%	53%
		Q 75%	84	118	699	372	75%	48%	50%	35%	29%	18%	83%