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An Analysis of Efficiency Improvements in Residential Sized Heat Pumps And Central Air Conditioners

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GLOSSARY OF TERMS

APF	ANNUAL PERFORMANCE FACTOR
ARI	AIR CONDITIONING AND REFRIGERATION INSTITUTE
BTU	BRITISH THERMAL UNIT
CD	DEGRADATION COEFFICIENT
CFM	CUBIC FEET PER MINUTE
CL	COOLING
COP	COEFFICIENT OF PERFORMANCE
DOE	DEPARTMENT OF ENERGY
EER	ENERGY EFFICIENCY RATIO
FPI	FINS PER INCH
HSPF	HEATING SEASONAL PERFORMANCE FACTOR
HR	HOUR
HT	HEATING
LBL	LAWRENCE BERKELEY LABORATORY
NBS	NATIONAL BUREAU OF STANDARDS
NECPA	NATIONAL ENERGY CONSERVATION POLICY ACT
OEM	ORIGINAL EQUIPMENT MANUFACTURERS
ORNL	OAK RIDGE NATIONAL LABORATORY
PLF	PART LOAD FACTOR
SAI	SCIENCE APPLICATION INCORPORATED
SEER	SEASONAL ENERGY EFFICIENCY RATIO
SF	SQUARE FEET
SHF	SENSIBLE HEATING FACTOR
TDB	DRY BULB TEMPERATURE
TON	12000 BTU/HR
TXV	THERMAL EXPANSION VALVE
TWB	WET BULB TEMPERATURE

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CHAPTER 1

INTRODUCTION

The National Energy Conservation Policy Act (NECPA) P.L. 95-619, requires the imposition of minimum efficiency standards on major appliances used in the residential sector[1]. The law requires proposed standards that are both technologically feasible and economically justifiable. Two appliances for standards consideration are the residential sized (65000 Btu/hr and under) air source heat pump and air conditioner. The law requires that the maximum improvements in energy efficiency that are technologically feasible be evaluated for each appliance[1]. Thus, efficiency levels that may be above those currently offered on the market must be considered if they are technologically feasible.

This report summarizes: (1) the performance improvements possible for central air conditioners and heat pumps using conventional design improvements, (2) the development of a methodology for estimating the seasonal performance of variable speed heat pumps and air conditioners, and (3) the estimated maximum efficiency levels that are technically feasible for variable speed heat pumps and air conditioners. This report builds on the work summarized in an earlier report from the Energy Systems Laboratory[2].

The Department of Energy (DOE) is required to divide types of appliances (air conditioners, refrigerators, etc.) into classes for equitable application of efficiency standards. Chapter 2 summarizes the recommended classes of air conditioners and heat pumps.

Before considering application of variable speed compressors and other "advanced" technologies for improving heat pumps, many manufacturers will turn to some of the conventional options. Chapter 3 summarizes the major conventional design changes that can be made in residential sized heat pumps and air conditiners. Chapter 4 provides the estimated heating and cooling performances with the conventional design changes. This material is an update to that found in reference 2. Recommendations are made to use the same cooling efficiency levels for rating each class of central heat pumps and air conditioners.

Chapter 5 provides a brief description of the major advanced technology options for improving the performance of residential heat pumps and central air conditioners. Many of these options will soon be utilized in U.S. manufactured products.

In Chapter 6, the seasonal performance model and methodology used to estimate heating and cooling performance of variable speed units is discussed. The methodology includes: (1) making multiple runs of the Oak Ridge National Laboratory (ORNL) steady-state heat pump model, (2) making reasonable assumptions on the degradation factors, and (3) using a draft version of the Department of Energy (DOE)/ National Bureau of

Standards (NBS) test procedure for variable speed heat pumps and air conditioners to obtain the seasonal heating and cooling performance[3].

Chapter 7 summarizes the final designs of variable speed air conditioners and heat pumps. Designs are included for 3 and 5 ton split and single-package heat pumps and air conditioners.

Major conclusions from this study and recommendations for further study are provided in Chapter 8.

References

1. National Energy Conservation Policy Act, Public Law 950-619.

2. D. L. O'Neal, et. al., "An Analysis of Efficiency Improvements in Residential Sized Heat Pumps", ESL/85-24, Energy Systems Laboratory, Texas A & M University, May 1986.

3. "Energy Conservation Program for Consumer Products; Proposed Rulemaking and Public Hearing Regarding Test Procedures for Central Air Conditioners, Including Heat Pumps", Docket. No. CAS-RM-79-102, Department of Energy, May 1986.

CHAPTER 2

CENTRAL AIR CONDITIONER AND HEAT PUMP CLASSES

This chapter summarizes the recommended classes for central air conditioners and heat pumps. A more detailed discussion of the justification for classes of heat pumps is provided in reference 1.

Central Air Conditioners

The Department of Energy currently specifies four classes of air conditioners[2]:

(1) Split system, 39000 Btu/hr or under,
(2) Split system, greater than 39000 Btu/hr,
(3) Package system, 39000 Btu/hr or under, and
(4) Package system, greater than 39000 Btu/hr.

These four classes were analyzed earlier for imposition of standards[3,4]. To create any new classes, a particular air conditioner would have to satisfy one of the following criteria [3]:

(1) have a different primary energy source, i.e., oil or gas,
(2) have a different capacity or other performance related feature which affects efficiency and utility, or
(3) have features providing utility that also affect the efficiency of the model.

From the above criteria, it would be possible to develop at least two new classes of air conditioners. These would be gas(or fossil fuel) driven and multi-zone air conditioners. Gas driven air conditioners currently include gas absorption and gas desiccant units. Residential sized (under 65000 Btu/hr) units of both kinds are currently being marketed in the United States. Multi-zone air conditioners for residential applications are beginning to be marketed by at least one U.S. manufacturer (Carrier). A multi-zone air conditioning systems provides utility to consumers, in that he can control the temperature of each room of his house separately. While we advise separate classes for both gas and multi-zone air conditioners, DOE must develop a test procedure for measuring the performance of these units. Only the original four classes are considered in this report.

Heat Pumps

For heat pumps, our earlier report[1] recommended nine classes (Table 2.1). Of the nine classes, only the first four are explicitly covered in this report. The results from this report could be used for estimating the performance requirements for the fifth (split, heating only) and sixth (package, heating only) classes.

Table 2.1 - Heat pump class recommendations

Heat Source/Sink	Type	Capacity (Btu/hr)
air	split	less than 39,000
air	split	39,000 to 65,000
air	package	less than 39,000
air	package	39,000 to 65,000
air	split, heating only	less than 65,000
air	package, heating only	less than 65,000
air	multi-zone	less than 65,000
Water		less than 39,000
Water		39,000 to 65,000

References

1. D. L. O'Neal, et al, "An Analysis of Efficiency Improvements in Residential Sized Heat Pumps", ESL/85-24, Energy Systems Laboratory, Texas A & M University, May 1986.

2. "Energy Conservation Program for Consumer Products", Federal Register, pp. 43976-44087, June 30, 1980.

3. "Engineering Analysis", DOE/CS-0166, U.S. Department of Energy, June 1980.

4. "Engineering Analysis", DOE/CE-0030, U.S. Department of Energy, March 1982.

CHAPTER 3

CONVENTIONAL DESIGN OPTIONS FOR IMPROVING EFFICIENCY

This chapter summarizes the design options using conventional technology that can be used to improve the performance of the central air conditioners and heat pumps. More detailed information on the design options is provided in our earlier report[1]. The conventional design options considered included: (1) Increased condenser and evaporator heat exchanger performance, (2) Decreased compressor size, (3) Increased combined fan and motor efficiency, (4) Demand defrost control systems (heat pumps only), (5) High efficiency compressors, and (6) Two speed compressors. The conventional design options are similar to some of those previously used to evaluate efficiency improvements for central air conditioners[2,3]. All "advanced" technology options (i.e., those not widely used in U.S. heat pumps and air conditioners) are considered in a later chapter.

1) Condenser and Evaporator Heat Exchanger Performance.

One of the easiest methods of increasing a heat pump's efficiency is to improve the heat transfer of the heat exchangers. Improving the heat transfer is accomplished either by increasing the heat exchanger surface area, the overall heat transfer coefficent, or the number of circuits.

Increasing the surface area in a heat exchanger can be accomplished by adding more frontal area, adding tube rows, or increasing the fin density. Each is discussed below.

1A) Increased heat exchanger frontal area.

Adding more frontal area increases the area for air to contact the fins and tubes of the heat exchanger. Limits were imposed on the maximum size of both the indoor and outdoor coils. The limits either equalled or slightly exceeded the maximum coil sizes for systems on the market. The principal reasons for the limitations were the effect of coil size on latent cooling capacity and physical constraints of the ductwork in residential applications.

1B) Increased tube rows.

Increasing tube rows allows a manufacturer to increase heat transfer surface area while maintaining the same frontal cross sectional area in an heat exchanger. The amount of copper tubing and fin material increases, but the overall dimensions of the heat pump chasis remain approximately the same. Many manufacturers have chosen this option to improve performance in single package systems because of space constraints. The incremental improvement of each new tube row is smaller than the improvement provided by the previous tube row. Four or five tube rows are not uncommon for the indoor coil while the outdoor coil is seldom more than three or four rows.

1C) <u>Increased fin density</u>

Fin density is the number of fins per tube length. Lower efficiency units typically have as few as 15 fins per inch (fpi) in the outdoor heat exchanger while the higher efficiency units have as many as 21 fpi. For the indoor heat exchanger, most units have 12 to 14 fpi.

1D) <u>Increased heat transfer coefficient</u>

The overall heat transfer coefficient can be improved by using higher performance heat transfer surfaces for the fins. One example of this application was the switch by the HVAC industry from straight to wavy fin designs several years ago. All the baseline designs used in this report start with wavy fins. Newer heat transfer surfaces include perforated fins, spine fins, and internal fins in the refrigerant tubes.

1E) <u>Increased Parallel Circuits</u>

In the evaporator of a heat exchanger, refrigerant typically enters as a two phase "wet" vapor, having a low quality and low specific volume. As the refrigerant is evaporated, its specific volume increases. If the flow area remains constant from the inlet to the outlet of the heat exchanger, the refrigerant can accelerate to unacceptably large velocities. To maintain acceptable velocities on the refrigerant side of the heat exchanger, the flow is typically split in the heat exchanger, creating parallel flow circuits. Proper circuiting will keep the refrigerant pressure drop down at acceptable levels, which will reduce the power required by the compressor.

2) Decreased Compressor Size

In conjunction with Design Option #1 (increased heat exchanger performance), the compressor size must be reduced to maintain the rated capacity. This is accomplished by installing a lower capacity compressor into the unit. Using a smaller compressor provides a decrease in power consumption and a boost in efficiency.

3) Increased Combined Fan and Motor Efficiency

The indoor units now being manufactured typically use a permanent split capacitor motor and a centrifugal forward curved fan with a combined efficiency of 20% to 30%. A combined fan and fan motor efficiency of 34% has been used in other studies and is possibly attainable for the future [4].

Permanent split capacitor motors are also used on the outdoor unit in combination with a propeller fan. The combined fan/motor efficiencies typically range from 10% to 20%. All baseline units used a combined efficiency of 10% on the outdoor section. A combined efficiency of 20% was used on the high efficiency line.

4) Demand Defrost Control Systems (Heat Pumps Only)

Demand defrost control systems can now be found on many of the high performance heat pump units. These units defrost only when enough frost buildup is detected to degrade the heat pump performance. In the DOE test procedure, units with demand defrost receive a boost in capacity of 7% for the 35 F rating point[5]. Because the COP is defined as the capacity divided by the power, a 7% improvement in capacity at 35 F also means a 7% improvement in COP at 35 F. This procedure is followed in the analysis.

5) High Efficiency Compressors

Most residential sized central air conditioners and heat pumps manufactured in the United States use reciprocating compressors. At least one U.S. and several of the Japanese manufacturers also use rotary compressors in their heat pumps. Recent improvements in compressor efficiency have centered on better valving and higher efficiency compressor motors.

For lower capacity air conditioners and heat pumps (under 2 tons), the most immediate promise for better performing compressors are the higher efficiency rotary compressors. They offer EERs of approximately 5% better than reciprocating compressors of the same capacity.

The efficiency of the better compressor motors being used by the manufacturers are as high as 87%. It should be possible to improve the combined motor/compressor efficiency another 5% with current technology.

6) Two Speed Compressors

The two speed compressor operates at low speed when the building load is low, resulting in a substantially reduced power requirement and improved efficiency. The two speed unit also reduces cycling losses since it better matches the load on the building. When the building load is high, the compressor is switched over to high speed mode and the capacity is increased.

References

1. D. L. O'Neal, et al, "An Analysis of Efficiency Improvements in Residential Sized Heat Pumps", ESL/85-24, Energy Systems Laboratory, Texas A & M University, May 1986.

2. "Engineering Analysis", DOE/CS-0166, U.S. Department of Energy, June 1980.

3. "Engineering Analysis", DOE/CE-0030, U.S. Department of Energy, March 1982.

4. "Design Optimization and the Limits of Steady-State Heating Efficiency for Conventional Single-Speed Air-Source Heat Pumps", ORNL/CON-63, Oak Ridge National Laboratory, Oak Ridge, TN.

5. "Test Procedure for Central Air Conditioners, Including Heat Pumps", Federal Register, Dec. 27, 1979, pp. 76700-76723.

Chapter 4

CONVENTIONAL DESIGN IMPROVEMENTS: RESULTS

The final heat pump and central air conditioner designs and the methodology to arrive at the final designs for each class is discussed below. Heat pumps are discussed first then air conditioners.

Heat Pumps

The final heat pump designs for the conventional design options are only slight modifications from those published in our earlier study[1]. The general design approach consisted of developing a line of heat pumps for each class similar to what a larger manufacturer might do. Each line included the efficiency spectrum from the lowest efficiency in the class to a unit having an efficiency near the maximum technology feasible with advanced technology. Each line included enough heat pump designs to provide DOE with the data to evaluate, in small efficiency increments, the imposition of standards over a wide range of efficiencies. A detailed explanation of the design procedure was provided in reference 1. The only change in the analysis over what was previously used is a correction in the fan power calculated in the ORNL heat pump model. The correction typically resulted in an increase in total heat pump power of about 5% for most designs over what had been calculated previously.

The major design restrictions used in the analysis are shown in Table 4.1. These restrictions limit the maximum efficiency that can be obtained with a heat pump. However, the restrictions are necessary to maintain comfort (SHR $\leq$ 0.8) or have a unit that can fit within size constraints typically encountered in the evaporator.

Table 4.1 - Restrictions used for the heat pump designs.

Item	Value
Sensible Heating Factor	≤0.80
Indoor Coil Size	
3 ton	≤5 sf
5 ton	≤8 sf
Outdoor Coil Size	
3 ton	≤25 sf
5 ton	≤30 sf
Fin Density	
Indoor Coil	≤13 fpi
Outdoor Coil	≤19 fpi
Cooling CD	≥0.15
Heating CD	≥0.20

Baseline Units

Baseline units were selected for the four heat pump classes. The baseline units are typical of the lower efficiency and lower priced units sold in 1985. These units are constructed using the less costly and less efficient compressors and fan motors along with smaller indoor and outdoor coils. A detailed description of the components and performance of the heat pumps is provided in Tables 4.2 and 4.3. Key features of the units included:

* Capacity is based on the standard 95 deg outdoor test.

* Unit SEER and HSPF are calculated using the DOE test procedure.

* The compressors are currently available from compressor manufacturers.

* Evaporator and condenser size are specified by the frontal area and number of tube rows. All coils are of a wavy fin construction with a thickness of 0.0052 inches.

* The fans are assumed to use permanent split capacitor motors with efficiencies of 55%. The efficiency is the ratio of shaft output to the electrical input.

* A propeller fan is used in the outdoor unit and a centrifugal forward curved fan in the indoor unit.

Table 4.2 - Hardware on baseline heatpump systems

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** Baseline Systems **
****

MODEL	3 Ton Units Split	3 Ton Units Package	5 Ton Units Split	5 Ton Units Package
SUPERHEAT	25 CL/5 HT	25 CL/5 HT	25 CL/5 HT	25 CL/5 HT
SUBCOOL	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT
COMPRESSOR	AD 4.800	AD 3.799	BG 9.538	BG 9.213
EER	10.0	10.0	9.2	9.2
OUTDOOR COIL				
Face Area (ft^2)	10.0000	6.0000	15.0000	14.0000
# of Rows	1.0000	4.0000	2.0000	5.0000
# of Parallel Ckts	2.0000	3.0000	4.0000	4.0000
Fins/Inch	15.0000	15.0000	15.0000	15.0000
Fin Thickness	0.0052	0.0052	0.0052	0.0052
O.D. of Tubes	0.3880	0.3880	0.3880	0.3880
I.D. of Tubes	0.3620	0.3620	0.3620	0.3620
Vert Space (in)	1.2500	1.2500	1.2500	1.2500
Hor Space (in)	1.0830	1.0830	1.0830	1.0830
# of Return Bends	26.0000	104.0000	52.0000	130.0000
Refrig. Control	TXV	TXV	TXV	TXV
Fin Design	WAVY	WAVY	WAVY	WAVY
INDOOR COIL				
Face Area (ft^2)	3.8000	3.5000	5.0000	5.0000
# of Rows	4.0000	4.0000	4.0000	4.0000
# of Parallel Ckts	4.0000	4.0000	6.0000	6.0000
Fins/Inch	13.0000	13.0000	13.0000	13.0000
Fin Thickness	0.0052	0.0052	0.0052	0.0052
O.D. of Tubes	0.3250	0.3250	0.3250	0.3250
I.D. of Tubes	0.3030	0.3030	0.3030	0.3030
Vert Space (in)	1.0000	1.0000	1.0000	1.0000
Hor Space (in)	0.6250	0.6250	0.6250	0.6250
# of Return Bends	72.0000	72.0000	72.0000	72.0000
Refrig. Control	TXV	TXV	TXV	TXV
Fin Design	WAVY	WAVY	WAVY	WAVY
OUTDOOR FAN				
CFM	2800.00	2800.00	4000.00	3500.00
Fan & Motor eff.	0.10	0.09	0.10	0.09
INDOOR FAN				
CFM	1100.00	1100.00	1400.00	1200.00
Fan & Motor eff.	0.20	0.17	0.20	0.17
Ref. Lines (feet)	30.00	6.00	30.00	6.00
Liquid Line O.D.	3/8	3/8	3/8	3/8
Suction Line O.D.	5/8	5/8	7/8	7/8

Table 4.3 - Performance data on baseline heatpump systems

****
** Baseline Systems **
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	3 Ton Units		5 Ton Units	
	Split	Package	Split	Package
SYSTEM RATINGS				
CO Cooling/Heating	0.25/0.25	0.25/0.25	0.25/0.25	0.25/0.25
SEER	6.78	6.88	6.49	6.63
HSPF	6.19	5.60	5.98	5.80
SHF 95 deg	0.74	0.73	0.67	0.65
SHF 82 deg	0.72	0.71	0.66	0.64
95 deg F COP	2.00	2.05	1.94	1.98
CAPACITY	35500.00	35600.00	59300.00	59800.00
EER	6.83	7.01	6.62	6.76
82 deg F COP	2.27	2.30	2.17	2.22
CAPACITY	38000.00	37900.00	63000.00	63700.00
EER	7.75	7.86	7.42	7.58
47 deg F COP	2.49	2.19	2.27	2.26
CAPACITY	36300.00	37300.00	65400.00	60300.00
35 deg F COP	2.31	2.13	2.23	2.23
CAPACITY	29600.00	31300.00	54300.00	54500.00
17 deg F COP	1.91	1.74	1.97	2.04
CAPACITY	22200.00	23300.00	41900.00	42400.00

* An additional penalty due to the heat pump cabinet was included for the package systems. This penalty was in the form of a reduced efficiency for fans in package systems. For example, the efficiency of the indoor fan/motor combination was 20% for split sytems versus 17% for the package systems.

The first two items in Table 4.2 are the superheat in the evaporator and subcooling in the condenser, specified in degrees F. For example, all the units had 25 F superheat at the outlet of the evaporator and 15 F subcooling at the outlet of the condenser in the cooling mode. In the heating mode, the units had 5 F superheat at the outlet of the evaporator and 10 F subcooling at the outlet of the condenser. It was assumed that all the heat pumps used a thermal expansion valve.

The next items in Table 4.2 provide a description of the compressor: model designation of the compressor, its displacement, and its rated energy efficiency ratio. The first letter in the model designation of the compressor is a code for the compressor manufacturer. The second letter is a code for the manufacturer's own model number (or line). The numbers in the model designation provide the displacement in cubic inches. The compressors for both the three and five ton units were on the market in 1985. The EERs of the compressors are at the rating conditions shown in Table 4.4. The rated EER provides one measure of the performance improvement that can be expected in compressors. However, the actual efficiency improvement in heat pump performance from installing a compressor with a higher EER will differ from the simple percentage improvement of the compressor at the rating conditions shown in Table 4.4. The SEER and HSPF are calculated at different temperatures from those shown in Table 4.4. Thus, a compressor that is 10% more efficient (compared to some base) at the rating conditions in Table 4.4 may be only 5% more efficient at conditions used to calculate the SEER or HSPF.

Table 4.4 - Rating conditions for compressor EER and capacity.

Condition	Value
Evaporator Temp. (F)	45
Gas Leaving Temp. (F)	45
Gas Entering Temp. (F)	95
Condensing Temp. (F)	130
Liquid Entering Temp. (F)	115
Ambient (F)	95

The next two major sections in Table 4.2 include descriptions of the indoor and outdoor heat exchangers. Major items include: the face area of the heat exchangers, fin thickness and spacing, and tube descriptions. The base three ton split and package systems had outdoor face areas of 10.0 and 6.0 sf, respectively. The base five ton units had larger outdoor face areas: 15 and 14 sf for the split and package system, respectively. Indoor heat exchanger areas were 3.8 and 3.5 sf for the three ton split and package systems, respectively, and 5 sf for both five ton systems. Fin spacing on all baseline units was 15 fpi and 13 fpi for the outdoor and indoor heat exchangers, respectively. These heat exchanger areas and fin spacings are comparable to those in lower efficiency systems found on the market.

The next two items in Table 4.2 provide information on the indoor and outdoor fans. Both fan flow rate in cubic feet per minute (cfm) and combined fan/motor efficiency are given. As stated earlier, the fan/motor efficiencies for the package systems are slightly lower than those for the split systems to account for added losses in the package system cabinets.

The first items in Table 4.3 are the degradation coefficients for both heating and cooling. For the baseline units, the degradation coefficients were assumed to be 0.25, which is the default value in the DOE test procedure[2].

The next items in Table 4.3 are the SEER, HSPF, and sensible heating factor (SHF) for the baseline units. The HSPF is calculated at the minimum design heating load specified in the DOE test procedure for region IV[2]. The HSPF values in the ARI Directory are based on the HSPF for the minimum design heating load[3]. The SHF is the ratio of sensible cooling to total cooling for the unit.

The lowest efficiency three ton package and split heat pumps listed in the ARI Directory in 1985 had SEERs of 6.55 and 6.75, and HSPFs of 5.85 and 6.10, respectively[3]. For five ton systems, the lowest package unit had a SEER of 6.95 and HSPF of 6.05, while the lowest split unit had a SEER of 6.80 and HSPF of 6.10[3]. The baseline systems listed in Tables 4.2 and 4.3 had comparable (or slightly poorer) performance. The object of the baseline system was not to match exactly the performance of the lowest efficiency system on the market, but to provide a starting point for the analysis that was close to the poorest performers on the market.

The last five items in Table 4.3 are the steady state capacity, and energy efficiency ratio(or coefficient of performance) for the units at five rating points (17 F, 35 F, 47 F, 82 F, and 95 F outdoor temperature). These were produced using the ORNL heat pump model[4].

Final Conventional Designs

A line of heat pumps for each heat pump class was developed. Twelve heat pump designs are in each line. The large number of designs provides small incremental improvements in efficiency from the bottom of the line to the top. Each class is discussed seperately.

3 Ton Split Systems

Tables 4.5 and 4.6 provide the detailed data on the 3 ton split system line. Each unit has an alpha-numeric designation. The first two numbers in the designation specify the capacity of the unit(36 is 3 ton and 60 is 5 ton). For the split sytems, the letter following the two numbers is used to specify the model within the line. The baseline unit has the letter "A" for its model specification. The next model in the line would have "B", etc. For package systems, the two numbers are followed by two letters. The first letter is a "P", indicating it is a package unit. The second letter serves the same purpose as the letter designation on the split sytems (i.e., it indicates the model).

The models are arranged in increasing SEER from left to right in the tables. Thus, unit 36F has a higher SEER than unit 36C.

Below the model designation are the list of design options used on the unit. These options are all relative to the baseline system. The list of design options is in a code that corresponds with the list in Chapter 6. For instance, unit 36D has design options 1A, 1B, 1C, 2, 3, and 4. It has a larger heat exchanger frontal area (option 1A), more tube rows (option 1B), higher fin density (option 1C), smaller compressor (option 2), and higher fan/motor efficiency (option 3) than the baseline unit. It also has a demand defrost system (option 4).

The rest of the data in Tables 4.5 and 4.6 is the same data provided in the same order for the baseline units in Tables 4.2 and 4.3. Thus, all the details on the superheat, subcooling, coils, fans, refrigerant lines, steady state performance, etc., is available on each unit.

The best conventionally designed three ton split system heat pump (unit 36L) had a SEER and HSPF of 14.68 and 8.88, respectively. This is a unit whose airflow, fin density, tube rows, etc., have been optimized given the constraints discussed earlier[1]. In 1986, the best 3 ton split sytem listed in the ARI directory had a SEER of 12.5 and HSPF of 8.00[3]. Thus, unit 36L is 11 to 17% more efficient than the best unit in this class in 1986.

Table 4.5 - Hardware data on 3 ton split heatpump systems

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******************
** 3 Ton Systems **
**  Split Units  **
******************
```

MODEL	36A	36B	36C	36D	36E	36F	36G
DESIGN OPTIONS		1B,2	1A,1C,2,3	1A,1B,1C,2 3,4	1A,1B,1C,2 3,4	1A,1B,1C,2 3,4,5	1A,1C,1D,2 3,4,5
SUPERHEAT	25 CL/5 HT	25 CL/5 HT	15 CL/5 HT	15 CL/5 HT	15 CL/5 HT	10 CL/5 HT	10 CL/5 HT
SUBCOOL	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT
COMPRESSOR	AD 4.800	AD 4.010	AD 3.770	AD 3.480	AD 3.410	BH 3.270	BH 3.300
EER	10.0	10.0	10.0	10.0	10.0	10.5	10.5
OUTDOOR COIL							
Face Area (ft^2)	10.0000	10.0000	15.0000	15.0000	15.0000	15.0000	20.0000
# of Rows	1.0000	2.0000	1.0000	2.0000	2.0000	2.0000	1.0000
# of Parallel Ckts	2.0000	2.0000	2.0000	2.0000	2.0000	2.0000	2.0000
Fins/Inch	15.0000	15.0000	17.0000	17.0000	17.0000	17.0000	19.0000
Fin Thickness	0.0052	0.0052	0.0045	0.0045	0.0045	0.0045	0.0045
O.D. of Tubes	0.3880	0.3880	0.3880	0.3880	0.3880	0.3880	0.3880
I.D. of Tubes	0.3620	0.3620	0.3620	0.3620	0.3620	0.3620	0.3620
Vert Space (in)	1.2500	1.2500	1.2500	1.2500	1.2500	1.2500	1.2500
Hor Space (in)	1.0830	1.0830	1.0830	1.0830	1.0830	1.0830	1.0830
# of Return Bends	26.0000	52.0000	26.0000	52.0000	52.0000	52.0000	26.0000
Refrig. Control	TXV	TXV	TXV	TXV	TXV	TXV	TXV
Fin Design	WAVY	WAVY	WAVY	WAVY	WAVY	WAVY	LOUVERED
INDOOR COIL							
Face Area (ft^2)	3.8000	3.8000	3.8000	3.8000	4.5000	4.5000	4.5000
# of Rows	4.0000	4.0000	4.0000	4.0000	4.0000	4.0000	4.0000
# of Parallel Ckts	4.0000	4.0000	4.0000	4.0000	4.0000	6.0000	6.0000
Fins/Inch	13.0000	13.0000	13.0000	13.0000	13.0000	13.0000	13.0000
Fin Thickness	0.0052	0.0052	0.0052	0.0052	0.0052	0.0052	0.0052
O.D. of Tubes	0.3250	0.3250	0.3250	0.3250	0.3250	0.3250	0.3250
I.D. of Tubes	0.3030	0.3030	0.3030	0.3030	0.3030	0.3030	0.3030
Vert Space (in)	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Hor Space (in)	0.6250	0.6250	0.6250	0.6250	0.6250	0.6250	0.6250
# of Return Bends	72.0000	72.0000	72.0000	72.0000	72.0000	72.0000	72.0000
Refrig. Control	TXV	TXV	TXV	TXV	TXV	TXV	TXV
Fin Design	WAVY	WAVY	WAVY	WAVY	WAVY	WAVY	WAVY
OUTDOOR FAN							
CFM	2800.00	2800.00	3000.00	3000.00	3000.00	3000.00	3300.00
Fan & Motor eff.	0.10	0.10	0.15	0.15	0.20	0.20	0.20
INDOOR FAN							
CFM	1100.00	1100.00	1100.00	1100.00	1100.00	1100.00	1100.00
Fan & Motor eff.	0.20	0.20	0.25	0.25	0.30	0.30	0.30
Ref. Lines (30 ft)							
Liquid Line O.D.	3/8	3/8	3/8	3/8	3/8	3/8	3/8
Suction Line O.D.	5/8	5/8	7/8	7/8	7/8	7/8	7/8

Table 4.5 (con't) - Hardware data on 3 ton split heatpump systems

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******************
** 3 Ton Systems **
**  Split Units  **
******************
```

MODEL	36H	36I	36J	36K	36L
DESIGN OPTIONS	1A,1B,1C,1D 2,3,4,5	1A,1C,1D 2,3,4,5	1A,1B,1C,1D 2,3,4,5	1A,1B,1C,1D 2,3,4,5	1A,1B,1C,1D 2,3,4,6
SUPERHEAT	10 CL/5 HT	10 CL/5 HT	10 CL/5 HT	10 CL/5 HT	10 CL/5 HT
SUBCOOL	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT
COMPRESSOR	BH 3.330	BH 3.130	BH 3.060	BI	CF 3.160
EER	10.5	10.5	10.5	11.0	9.8
OUTDOOR COIL					
Face Area (ft^2)	20.0000	25.0000	25.0000	25.0000	25.0000
# of Rows	2.0000	1.0000	2.0000	2.0000	2.0000
# of Parallel Ckts	2.0000	3 CL/5 HT	3 CL/5 HT	3 CL/5 HT	3 CL/5 HT
Fins/Inch	19.0000	19.0000	19.0000	19.0000	19.0000
Fin Thickness	0.0045	0.0045	0.0045	0.0045	0.0045
O.D. of Tubes	0.3880	0.3880	0.3880	0.3880	0.3880
I.D. of Tubes	0.3620	0.3620	0.3620	0.3620	0.3620
Vert Space (in)	1.2500	1.2500	1.2500	1.2500	1.2500
Hor Space (in)	1.0830	1.0830	1.0830	1.0830	1.0830
# of Return Bends	52.0000	26.0000	52.0000	52.0000	52.0000
Refrig. Control	TXV	TXV	TXV	TXV	TXV
Fin Design	LOUVERED	LOUVERED	LOUVERED	LOUVERED	LOUVERED
INDOOR COIL					
Face Area (ft^2)	4.5000	5.5000	5.5000	5.5000	5.5000
# of Rows	4.0000	4.0000	4.0000	4.0000	4.0000
# of Parallel Ckts	6.0000	7 CL/ 3 HT	7 CL/ 3 HT	7 CL/ 3 HT	7 CL/ 3 HT
Fins/Inch	13.0000	13.0000	13.0000	13.0000	13.0000
Fin Thickness	0.0052	0.0052	0.0052	0.0052	0.0052
O.D. of Tubes	0.3250	0.3250	0.3250	0.3250	0.3250
I.D. of Tubes	0.3030	0.3030	0.3030	0.3030	0.3030
Vert Space (in)	1.0000	1.0000	1.0000	1.0000	1.0000
Hor Space (in)	0.6250	0.6250	0.6250	0.6250	0.6250
# of Return Bends	72.0000	72.0000	72.0000	72.0000	72.0000
Refrig. Control	TXV	TXV	TXV	TXV	TXV
Fin Design	WAVY	WAVY	WAVY	WAVY	WAVY
OUTDOOR FAN					
CFM	3300.00	3500.00	3500.00	3500.00	3500.00
Fan & Motor eff.	0.20	0.25	0.25	0.25	0.25
INDOOR FAN					
CFM	1100.00	1100.00	1100.00	1100.00	1100.00
Fan & Motor eff.	0.30	0.35	0.35	0.35	0.35
Ref. Lines (30 ft)					
Liquid Line O.D.	3/8	3/8	3/8	3/8	3/8
Suction Line O.D.	7/8	7/8	7/8	7/8	7/8

Table 4.6 - Performance data on 3 ton split heatpump systems

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*******************
** 3 Ton Systems **
**  Split Units  **
*******************
```

	36A	36B	36C	36D	36E	36F	36G
SYSTEM RATINGS							
CD Cooling	0.25	0.25	0.20	0.20	0.20	0.20	0.15
CD Heating	0.25	0.25	0.20	0.20	0.20	0.20	0.20
SEER	6.78	8.06	8.89	9.65	10.13	11.88	12.11
HSPF	6.19	6.35	7.11	7.16	7.49	7.63	7.94
SHF 95 deg	0.74	0.74	0.75	0.75	0.75	0.75	0.75
SHF 82 deg	0.72	0.72	0.73	0.73	0.73	0.73	0.73
95 deg F COP	2.00	2.39	2.54	2.76	2.88	3.29	3.26
CAPACITY	35500.00	35400.00	35600.00	35400.00	35700.00	35700.00	35600.00
EER	6.83	8.16	8.65	9.43	9.84	11.22	11.11
82 deg F COP	2.27	2.70	2.89	3.14	3.30	3.87	3.84
CAPACITY	38000.00	35300.00	38000.00	37900.00	38000.00	38300.00	38200.00
EER	7.75	9.22	9.88	10.73	11.26	13.20	13.09
47 deg F COP	2.49	2.56	2.88	2.88	2.99	3.17	3.29
CAPACITY	36300.00	32500.00	32600.00	29900.00	29600.00	28200.00	29700.00
35 deg F COP	2.31	2.38	2.65	2.60	2.71	2.84	2.95
CAPACITY	29600.00	27000.00	26900.00	24800.00	24500.00	23200.00	24400.00
17 deg F COP	1.91	1.96	2.21	2.14	2.21	2.29	2.39
CAPACITY	22200.00	19800.00	19700.00	17900.00	17600.00	16500.00	17300.00

Table 4.6 (con't) - Performance data on 3 ton split heatpump systems

****
** 3 Ton Systems **
** Split Units **
****

	36H	36I	36J	36K	36L 2 Speed Compressor High Spd	36L 2 Speed Compressor Low Spd
SYSTEM RATINGS						
CD Cooling	0.15	0.15	0.15	0.15	0.15	
CD Heating	0.20	0.20	0.20	0.20	0.20	
SEER	12.42	13.25	13.70	14.46	14.68	
HSPF	7.61	8.81	8.94	9.27	8.88	
SHF 95 deg	0.75	0.76	0.76	0.76	0.76	0.97
SHF 82 deg	0.73	0.73	0.73	0.73	0.73	0.93
95 deg F COP	3.36	3.52	3.64	3.84	3.55	3.79
CAPACITY	35700.00	35600.00	35600.00	36000.00	35600.00	20800.00
EER	11.45	12.01	12.41	13.11	12.10	12.94
82 deg F COP	3.93	4.20	4.34	4.58	4.06	4.57
CAPACITY	38200.00	38200.00	38100.00	38500.00	38200.00	22600.00
EER	13.42	14.33	14.81	15.63	13.84	15.59
47 deg F COP	3.16	3.76	3.81	3.94	3.67	4.05
CAPACITY	27500.00	33700.00	33200.00	33300.00	33100.00	18800.00
35 deg F COP	2.80	3.36	3.41	3.51	3.23	3.26
CAPACITY	22500.00	27170.00	27600.00	27200.00	26700.00	14600.00
17 deg F COP	2.26	2.70	2.74	2.80	2.57	2.18
CAPACITY	15900.00	19100.00	19300.00	18900.00	18700.00	9100.00

3 Ton Package Systems

Tables 4.7 and 4.8 list the units in the line of 3 ton package sytems. Unit 36PA is the baseline unit, while unit 36PL is the best conventionally designed unit. Other data about the systems are in the same order as that for the 3 ton split systems. The best SEER and HSPFs are 14.43 and 9.46, respectively. These are slightly lower than the best values for split systems because of assumptions about fan losses due to the cabinets in package sytems. The highest listing for this class in the ARI Directory had a a SEER of 10.2 and HSPF of 7.00[3]. Thus, optimizing with conventional options offers large improvements over the best available unit on the market.

5 Ton Split Systems

Tables 4.9 and 4.10 list the units in the 5 ton split system line. Unit 60A is the baseline unit and 60N is the maximum technologically feasible unit. The best performance for the 5 ton split systems using conventional technology is a SEER of 13.41 and HSPF of 8.60. The best 5 ton split system listed in the ARI directory had a SEER of 12.55 and HSPF of 8.00[3].

The maximum efficiencies achievable for the 5 ton systems were ABOUT 10% smaller than 3 ton systems. The primary reason for this lower efficiency was the constraints on the coil sizes for the 5 ton system. The efficiencies of the 5 ton systems could have been higher with larger coils, but this would have led to unacceptably large cabinet sizes. Another contributing factor to the smaller efficiencies for the 5 ton systems was that the compressors available for this size system were slightly less efficient than those for the 3 ton systems.

5 Ton Package Systems

Tables 4.11 and 4.12 list the units in the 5 ton package line. Unit 60PA is the baseline system and 60PN is the maximum technologically feasible unit. The best performances for the 5 ton package system are a SEER of 13.70 and HSPF of 9.11. The best unit in the ARI directory had a SEER of 9.0 and HSPF of 6.8[3].

Table 4.7 - Hardware data on 3 ton package heatpump systems

** 3 Ton Systems **
** Packaged Units **

MODEL	36PA	36PB	36PC	36PD	36PE	36PF	36PG
DESIGN OPTIONS		1A,2	1A	1A,1B,2	1A,1C,2,3	1A,1B,1C,2,3	1A,1C,2,3,4
SUPERHEAT	25 CL/5 HT	25 CL/5 HT	15 CL/5 HT	15 CL/5 HT	15 CL/5 HT	15 CL/5 HT	10 CL/5 HT
SUBCOOL	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT
COMPRESSOR	AD 3.799	AD 3.715	AD 3.809	AD 3.606	AD 3.473	AD 3.390	AD 3.404
EER	10.0	10.0	10.0	10.0	10.0	10.0	10.0
OUTDOOR COIL							
Face Area (ft^2)	6.0000	8.0000	10.0000	10.0000	14.0000	14.0000	17.0000
# of Rows	4.0000	4.0000	2.0000	4.0000	2.0000	4.0000	2.0000
# of Parallel Ckts	3.0000	3.0000	3.0000	3.0000	3.0000	3.0000	3.0000
Fins/Inch	15.0000	15.0000	15.0000	15.0000	17.0000	17.0000	19.0000
Fin Thickness	0.0052	0.0052	0.0052	0.0052	0.0045	0.0045	0.0045
O.D. of Tubes	0.3880	0.3880	0.3880	0.3880	0.3880	0.3880	0.3880
I.D. of Tubes	0.3620	0.3620	0.3620	0.3620	0.3620	0.3620	0.3620
Vert Space (in)	1.2500	1.2500	1.2500	1.2500	1.2500	1.2500	1.2500
Hor Space (in)	1.0830	1.0830	1.0830	1.0830	1.0830	1.0830	1.0830
# of Return Bends	104.0000	104.0000	52.0000	104.0000	52.0000	104.0000	104.0000
Refrig. Control	TXV	TXV	TXV	TXV	TXV	TXV	TXV
Fin Design	WAVY	WAVY	WAVY	WAVY	WAVY	WAVY	WAVY
INDOOR COIL							
Face Area (ft^2)	3.5000	3.5000	3.5000	3.5000	4.5000	4.5000	4.5000
# of Rows	4.0000	4.0000	4.0000	4.0000	4.0000	4.0000	4.0000
# of Parallel Ckts	4.0000	4.0000	4.0000	4.0000	4.0000	4.0000	4.0000
Fins/Inch	13.0000	13.0000	13.0000	13.0000	13.0000	13.0000	13.0000
Fin Thickness	0.0052	0.0052	0.0052	0.0052	0.0052	0.0052	0.0052
O.D. of Tubes	0.3250	0.3250	0.3250	0.3250	0.3250	0.3250	0.3250
I.D. of Tubes	0.3030	0.3030	0.3030	0.3030	0.3030	0.3030	0.3030
Vert Space (in)	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Hor Space (in)	0.6250	0.6250	0.6250	0.6250	0.6250	0.6250	0.6250
# of Return Bends	72.0000	72.0000	72.0000	72.0000	72.0000	72.0000	72.0000
Refrig. Control	TXV	TXV	TXV	TXV	TXV	TXV	TXV
Fin Design	WAVY	WAVY	WAVY	WAVY	WAVY	WAVY	WAVY
OUTDOOR FAN							
CFM	2800.00	2800.00	3000.00	2800.00	3000.00	2800.00	3000.00
Fan & Motor eff.	0.17	0.17	0.17	0.17	0.24	0.24	0.26
INDOOR FAN							
CFM	1100.00	1100.00	1100.00	1100.00	1100.00	1100.00	1100.00
Fan & Motor eff.	0.09	0.09	0.09	0.09	0.14	0.14	0.18
Ref. Lines (6 ft)							
Liquid Line O.D.	3/8	3/8	3/8	3/8	3/8	3/8	3/8
Suction Line O.D.	7/8	7/8	7/8	7/8	7/8	7/8	7/8

Table 4.7 (con't) - Hardware data on 3 ton package heatpump systems

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********************
** 3 Ton Systems **
** Packaged Units **
********************
```

MODEL	36PH	36PI	36PJ	36PK	36PL
DESIGN OPTIONS	1A,1C,2,3,4 5	1A,1C,2,3,4 5	1A,1D,1C 2,3,4,5	1A,1D,1C 2,3,4,5	1A,1D,1C 2,3,4,6
SUPERHEAT	10 CL/5 HT	10 CL/5 HT	10 CL/5 HT	10 CL/5 HT	10 CL/5 HT
SUBCOOL	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT
COMPRESSOR	BH 3.348	BH 3.412	BH 3.094	BH 3.058	BH 3.127
EER	10.5	10.5	10.5	10.5	9.8
OUTDOOR COIL					
Face Area (ft^2)	17.0000	17.0000	20.0000	25.0000	25.0000
# of Rows	2.0000	2.0000	2.0000	2.0000	2.0000
# of Parallel Ckts	3.0000	3.0000	4.0000	4.0000	4.0000
Fins/Inch	19.0000	19.0000	19.0000	19.0000	19.0000
Fin Thickness	0.0045	0.0045	0.0045	0.0045	0.0045
O.D. of Tubes	0.3880	0.3880	0.3880	0.3880	0.3880
I.D. of Tubes	0.3620	0.3620	0.3620	0.3620	0.3620
Vert Space (in)	1.2500	1.2500	1.2500	1.2500	1.2500
Hor Space (in)	1.0830	1.0830	1.0830	1.0830	1.0830
# of Return Bends	52.0000	52.0000	52.0000	52.0000	52.0000
Refrig. Control	TXV	TXV	TXV	TXV	TXV
Fin Design	WAVY	WAVY	LOUVERED	LOUVERED	LOUVERED
INDOOR COIL					
Face Area (ft^2)	5.5000	4.5000	5.5000	5.5000	5.5000
# of Rows	4.0000	4.0000	4.0000	4.0000	4.0000
# of Parallel Ckts	4.0000	4.0000	4.0000	6.0000	6.0000
Fins/Inch	13.0000	13.0000	13.0000	13.0000	13.0000
Fin Thickness	0.0052	0.0052	0.0052	0.0052	0.0052
O.D. of Tubes	0.3250	0.3250	0.3250	0.3250	0.3250
I.D. of Tubes	0.3030	0.3030	0.3030	0.3030	0.3030
Vert Space (in)	1.0000	1.0000	1.0000	1.0000	1.0000
Hor Space (in)	0.6250	0.6250	0.6250	0.6250	0.6250
# of Return Bends	72.0000	72.0000	72.0000	72.0000	72.0000
Refrig. Control	TXV	TXV	TXV	TXV	TXV
Fin Design	WAVY	WAVY	WAVY	WAVY	WAVY
OUTDOOR FAN					
CFM	3000.00	3000.00	3300.00	3600.00	3600.00
Fan & Motor eff.	0.31	0.26	0.31	0.31	0.31
INDOOR FAN					
CFM	1100.00	1100.00	1100.00	1000.00	1000.00
Fan & Motor eff.	0.23	0.18	0.23	0.23	0.23
Ref. Lines (6 ft)					
Liquid Line O.D.	3/8	3/8	3/8	3/8	3/8
Suction Line O.D.	7/8	7/8	7/8	7/8	7/8

Table 4.8 - Performance data on 3 ton package heatpump systems

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*******************
** 3 Ton Systems **
** Package Units **
*******************
```

	36PA	36PB	36PC	36PD	36PE	36PF	36PG
SYSTEM RATINGS							
CD Cooling	0.25	0.25	0.25	0.25	0.20	0.20	0.15
CD Heating	0.25	0.25	0.25	0.25	0.20	0.20	0.20
SEER	6.88	7.65	7.86	8.27	9.77	9.98	10.61
HSPF	5.60	6.22	6.80	6.63	7.87	7.60	8.30
SHF 95 deg	0.73	0.73	0.74	0.74	0.75	0.75	0.75
SHF 82 deg	0.71	0.71	0.72	0.72	0.73	0.73	0.73
95 deg F COP	2.05	2.27	2.32	2.42	2.76	2.83	2.88
CAPACITY	35600.00	35600.00	35600.00	35600.00	35700.00	35700.00	35700.00
EER	7.01	7.75	7.92	8.26	9.41	9.65	9.84
82 deg F COP	2.30	2.56	2.63	2.74	3.16	3.22	3.32
CAPACITY	37900.00	37900.00	38000.00	38000.00	38000.00	38000.00	38200.00
EER	7.86	8.74	8.98	9.37	10.77	11.00	11.34
47 deg F COP	2.19	2.52	2.70	2.74	3.18	3.12	3.28
CAPACITY	37300.00	36600.00	37500.00	35700.00	35600.00	33900.00	35200.00
35 deg F COP	2.13	2.36	2.58	2.50	2.94	2.85	3.02
CAPACITY	31300.00	33800.00	31400.00	29900.00	29700.00	28200.00	29400.00
17 deg F COP	1.74	1.96	2.18	2.09	2.47	2.38	2.54
CAPACITY	23300.00	22900.00	23400.00	22200.00	21900.00	20800.00	21500.00

Table 4.8 (con't) - Performance data on 3 ton package heatpump systems

****
** 3 Ton Systems **
** Package Units **
****

	36PH	36PI	36PJ	36PK	2 Speed Compressor High Spd 36PL	2 Speed Compressor Low Spd 36PL
SYSTEM RATINGS						
CD Cooling	0.15	0.15	0.15	0.15	0.15	
CD Heating	0.20	0.20	0.20	0.20	0.15	
SEER	12.06	12.56	13.51	13.92	14.43	
HSPF	8.69	8.90	9.03	9.12	9.46	
SHF 95 deg	0.75	0.76	0.75	0.76	0.75	0.97
SHF 82 deg	0.73	0.73	0.73	0.73	0.73	0.94
95 deg F COP	3.20	3.32	3.55	3.63	3.55	3.73
CAPACITY	35700.00	35700.00	35700.00	35600.00	35600.00	20700.00
EER	10.91	11.35	12.11	12.38	12.10	12.74
82 deg F COP	3.78	3.95	4.25	4.35	4.06	4.48
CAPACITY	38300.00	38500.00	38300.00	38200.00	38200.00	22400.00
EER	12.91	13.48	14.49	14.83	13.85	15.27
47 deg F COP	3.49	3.64	3.76	3.80	3.79	4.23
CAPACITY	34500.00	34300.00	34100.00	34100.00	34400.00	20100.00
35 deg F COP	3.18	3.31	3.39	3.42	3.37	3.49
CAPACITY	28700.00	28400.00	28300.00	28200.00	28000.00	15900.00
17 deg F COP	2.65	2.74	2.78	2.80	2.74	2.47
CAPACITY	20800.00	20500.00	20300.00	20200.00	20100.00	10500.00

Table 4.9 - Hardware data on 5 ton split heatpump systems

** 5 Ton Systems **
** Split Units **

MODEL	60A	60B	60C	60D	60E	60F	60G
DESIGN OPTIONS		1C	1A,1C,2,3	1A,1C,2,3 4	1A,1C,2,3 4,5	1A,1C,1D,2 3,4,5	1A,1C,1D,2 3,4,5
SUPERHEAT	25 CL/5 HT	25 CL/5 HT	25 CL/5 HT	15 CL/5 HT	15 CL/5 HT	15 CL/5 HT	15 CL/5 HT
SUBCOOL	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT
COMPRESSOR	BG 9.538	BG 9.538	BG 8.746	BG 7.909	BJ 7.840	BJ 7.357	BJ 7.168
EER	9.21	9.21	9.21	9.21	9.51	9.51	9.51
OUTDOOR COIL							
Face Area (ft^2)	15.0000	15.0000	20.0000	20.0000	20.0000	25.0000	25.0000
# of Rows	2.0000	2.0000	2.0000	2.0000	2.0000	2.0000	2.0000
# of Parallel Ckts	4.0000	4.0000	4.0000	4.0000	4.0000	4.0000	4.0000
Fins/Inch	15.0000	17.0000	17.0000	17.0000	17.0000	19.0000	19.0000
Fin Thickness	0.0052	0.0045	0.0045	0.0045	0.0045	0.0045	0.0045
O.D. of Tubes	0.3880	0.3880	0.3880	0.3880	0.3880	0.3880	0.3880
I.D. of Tubes	0.3620	0.3620	0.3620	0.3620	0.3620	0.3620	0.3620
Vert Space (in)	1.2500	1.2500	1.2500	1.2500	1.2500	1.2500	1.2500
Hor Space (in)	1.0830	1.0830	1.0830	1.0830	1.0830	1.0830	1.0830
# of Return Bends	52.0000	52.0000	52.0000	52.0000	52.0000	52.0000	52.0000
Refrig. Control	TXV	TXV	TXV	TXV	TXV	TXV	TXV
Fin Design	WAVY	WAVY	WAVY	WAVY	WAVY	LOUVERED	LOUVERED
INDOOR COIL							
Face Area (ft^2)	5.0000	5.0000	5.0000	6.0000	6.0000	6.0000	7.0000
# of Rows	4.0000	4.0000	4.0000	4.0000	4.0000	4.0000	4.0000
# of Parallel Ckts	6.0000	6.0000	6.0000	6.0000	6.0000	6.0000	6.0000
Fins/Inch	13.0000	13.0000	13.0000	13.0000	13.0000	13.0000	13.0000
Fin Thickness	0.0052	0.0052	0.0052	0.0052	0.0052	0.0052	0.0052
O.D. of Tubes	0.3250	0.3250	0.3250	0.3250	0.3250	0.3250	0.3250
I.D. of Tubes	0.3030	0.3030	0.3030	0.3030	0.3030	0.3030	0.3030
Vert Space (in)	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Hor Space (in)	0.6250	0.6250	0.6250	0.6250	0.6250	0.6250	0.6250
# of Return Bends	72.0000	72.0000	72.0000	72.0000	72.0000	72.0000	72.0000
Refrig. Control	TXV	TXV	TXV	TXV	TXV	TXV	TXV
Fin Design	WAVY	WAVY	WAVY	WAVY	WAVY	WAVY	WAVY
OUTDOOR FAN							
CFM	4000.00	4000.00	4300.00	4300.00	4300.00	5000.00	5500.00
Fan & Motor eff.	0.10	0.10	0.15	0.15	0.15	0.20	0.20
INDOOR FAN							
CFM	1400.00	1400.00	1400.00	1400.00	1400.00	1400.00	1400.00
Fan & Motor eff.	0.20	0.20	0.25	0.25	0.25	0.30	0.30
Ref. Lines (30 ft)							
Liquid Line O.D.	3/8	3/8	3/8	3/8	3/8	3/8	3/8
Suction Line O.D.	7/8	7/8	7/8	1 1/8	1 1/8	1 1/8	1 1/8

Table 4.9 (con't) - Hardware data on 5 ton split heatpump systems

```
******************
** 5 Ton Systems **
**  Split Units  **
******************
```

MODEL	60H	60I	60J	60K	60L
DESIGN OPTIONS	1A,1C,1D,2 3,4,5	1A,1C,1D,2 3,4,5	1A,1C,1D,2 3,4,5	1A,1C,1D 2,3,4,5	1A,1C,1D,2 3,4,6
SUPERHEAT	10 CL/5 HT	10 CL/5 HT	10 CL/5 HT	10 CL/5 HT	10 CL/5 HT
SUBCOOL	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT
COMPRESSOR	BJ 7.037	BJ 6.883	BJ 6.510	BI	CF 6.134
EER	9.51	9.51	9.51	11.00	9.80
OUTDOOR COIL					
Face Area (ft^2)	30.0000	30.0000	30.0000	30.0000	30.0000
# of Rows	2.0000	2.0000	1.0000	1.0000	2.0000
# of Parallel Ckts	4.0000	4.0000	4 CL/6 HT	4 CL/6 HT	4 CL/6 HT
Fins/Inch	19.0000	19.0000	19.0000	19.0000	19.0000
Fin Thickness	0.0045	0.0045	0.0045	0.0045	0.0045
O.D. of Tubes	0.3880	0.3880	0.3880	0.3880	0.3880
I.D. of Tubes	0.3620	0.3620	0.3620	0.3620	0.3620
Vert Space (in)	1.2500	1.2500	1.2500	1.2500	1.2500
Hor Space (in)	1.0830	1.0830	1.0830	1.0830	1.0830
# of Return Bends	52.0000	52.0000	26.0000	26.0000	26.0000
Refrig. Control	TXV	TXV	TXV	TXV	TXV
Fin Design	LOUVERED	LOUVERED	LOUVERED	LOUVERED	LOUVERED
INDOOR COIL					
Face Area (ft^2)	7.0000	8.0000	8.0000	8.0000	8.0000
# of Rows	4.0000	4.0000	4.0000	4.0000	4.0000
# of Parallel Ckts	6.0000	6.0000	8 CL/4 HT	8 CL/4 HT	8 CL/4 HT
Fins/Inch	13.0000	13.0000	13.0000	13.0000	13.0000
Fin Thickness	0.0052	0.0052	0.0052	0.0052	0.0052
O.D. of Tubes	0.3250	0.3250	0.3250	0.3250	0.3250
I.D. of Tubes	0.3030	0.3030	0.3030	0.3030	0.3030
Vert Space (in)	1.0000	1.0000	1.0000	1.0000	1.0000
Hor Space (in)	0.6250	0.6250	0.6250	0.6250	0.6250
# of Return Bends	72.0000	72.0000	72.0000	72.0000	72.0000
Refrig. Control	TXV	TXV	TXV	TXV	TXV
Fin Design	WAVY	WAVY	WAVY	WAVY	WAVY
OUTDOOR FAN					
CFM	6000.00	6000.00	6500.00	6500.00	6000.00
Fan & Motor eff.	0.20	0.25	0.25	0.25	0.25
INDOOR FAN					
CFM	1400.00	1400.00	1400.00	1400.00	1400.00
Fan & Motor eff.	0.30	0.35	0.35	0.35	0.35
Ref. Lines (30 ft)					
Liquid Line O.D.	3/8	3/8	3/8	3/8	3/8
Suction Line O.D.	1 1/8	1 1/8	1 1/8	1 1/8	1 1/8

Table 4.10 - Performance data on 5 ton split heatpump systems

```
*******************
** 5 Ton Systems **
**  Split Units  **
*******************
```

	60A	60B	60C	60D	60E	60F	60G
SYSTEM RATINGS							
CD Cooling	0.25	0.25	0.25	0.20	0.20	0.20	0.20
CD Heating	0.25	0.25	0.25	0.20	0.20	0.20	0.20
SEER	6.49	6.49	7.23	7.96	8.76	9.44	9.59
HSPF	5.98	6.00	6.35	6.96	7.25	7.33	7.45
SHF 95 deg	0.67	0.67	0.68	0.68	0.68	0.68	0.68
SHF 82 deg	0.66	0.67	0.67	0.67	0.67	0.67	0.67
95 deg F COP	1.94	1.94	2.16	2.30	2.51	2.71	2.74
CAPACITY	59300.00	59500.00	59200.00	59800.00	59500.00	59200.00	59400.00
EER	6.62	6.63	7.37	7.86	8.57	9.24	9.36
82 deg F COP	2.17	2.17	2.42	2.59	2.85	3.07	3.12
CAPACITY	63000.00	62900.00	62600.00	63300.00	63500.00	63100.00	63100.00
EER	7.42	7.41	8.26	8.84	9.73	10.49	10.66
47 deg F COP	2.27	2.26	2.45	2.57	2.72	2.84	2.88
CAPACITY	65400.00	65600.00	62100.00	59900.00	58200.00	56500.00	56600.00
35 deg F COP	2.23	2.22	2.34	2.44	2.58	2.65	2.68
CAPACITY	54300.00	54600.00	52000.00	49800.00	48300.00	46600.00	46900.00
17 deg F COP	1.97	1.98	2.10	2.17	2.27	2.31	2.32
CAPACITY	41900.00	42100.00	39600.00	37900.00	35900.00	34500.00	34400.00

Table 4.10 (con't) - Performance data on 5 ton split heatpump systems

```
*******************
** 5 Ton Systems **
**  Split Units  **
*******************
```

	60H	60I	60J	60K	60L 2 Speed Compressor Hi Spd	60L 2 Speed Compressor Lo Spd
SYSTEM RATINGS						
CD Cooling	0.15	0.15	0.15	0.15	0.15	
CD Heating	0.20	0.20	0.20	0.20	0.20	
SEER	10.06	10.36	10.38	11.78	13.41	
HSPF	7.45	7.71	8.06	8.93	8.60	
SHF 95 deg	0.68	0.68	0.69	0.69	0.68	0.83
SHF 82 deg	0.67	0.67	0.67	0.67	0.67	0.79
95 deg F COP	2.80	2.87	2.86	3.25	3.16	3.50
CAPACITY	59400.00	59200.00	58500.00	58500.00	59300.00	36900.00
EER	9.55	9.81	9.77	11.09	10.78	11.94
82 deg F COP	3.19	3.28	3.29	3.73	3.58	4.20
CAPACITY	63200.00	63000.00	62500.00	62500.00	63300.00	40000.00
EER	10.87	11.20	11.22	12.73	12.23	14.32
47 deg F COP	2.90	2.98	3.16	3.52	3.24	4.46
CAPACITY	55800.00	55410.00	58000.00	58000.00	58100.00	45200.00
35 deg F COP	2.68	2.76	2.93	3.26	2.95	3.13
CAPACITY	46100.00	456700.00	47900.00	47900.00	47600.00	28000.00
17 deg F COP	2.32	2.38	2.52	2.79	2.50	2.26
CAPACITY	33700.00	33300.00	34800.00	34800.00	34400.00	18300.00

Table 4.11 - Hardware data on 5 ton package heatpump systems

```
*******************
** 5 Ton Systems **
** Packaged Units **
*******************
```

MODEL	60PA	60PB	60PC	60PD	60PE	60PF	60PG
DESIGN OPTIONS	1A,1B,2		1A,1C,2,3	1A,1C,2,3	1A,1C,2,3	1A,1C,2,3	1A,1C,1D,2
			4	4,5	4,5	4,5	3,4,5
SUPERHEAT	25 CL/5 HT	25 CL/5 HT	15 CL/5 HT	15 CL/5 HT	15 CL/5 HT	15 CL/5 HT	10 CL/5 HT
SUBCOOL	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT
COMPRESSOR	BG 9.213	BG 9.637	BG 9.637	BJ 9.087	BJ 8.375	BJ 8.375	BJ 8.001
EER	9.21	9.21	9.21	9.51	9.51	9.51	9.51
OUTDOOR COIL							
Face Area (ft^2)	14.0000	14.0000	17.0000	17.0000	20.0000	20.0000	25.0000
# of Rows	5.0000	3.0000	2.0000	2.0000	2.0000	2.0000	2.0000
# of Parallel Ckts	4.0000	4.0000	4.0000	4.0000	4.0000	4.0000	4.0000
Fins/Inch	15.0000	15.0000	17.0000	17.0000	19.0000	19.0000	19.0000
Fin Thickness	0.0052	0.0052	0.0045	0.0045	0.0045	0.0045	0.0045
O.D. of Tubes	0.3880	0.3880	0.3880	0.3880	0.3880	0.3880	0.3880
I.D. of Tubes	0.3620	0.3620	0.3620	0.3620	0.3620	0.3620	0.3620
Vert Space (in)	1.2500	1.2500	1.2500	1.2500	1.2500	1.2500	1.2500
Hor Space (in)	1.0830	1.0830	1.0830	1.0830	1.0830	1.0830	1.0830
# of Return Bends	130.0000	78.0000	52.0000	52.0000	52.0000	52.0000	52.0000
Refrig. Control	TXV	TXV	TXV	TXV	TXV	TXV	TXV
Fin Design	WAVY	WAVY	WAVY	WAVY	WAVY	WAVY	LOUVERED
INDOOR COIL							
Face Area (ft^2)	5.0000	5.0000	6.0000	6.0000	6.0000	7.0000	7.0000
# of Rows	4.0000	4.0000	4.0000	4.0000	4.0000	4.0000	4.0000
# of Parallel Ckts	6.0000	6.0000	6.0000	6.0000	6.0000	6.0000	6.0000
Fins/Inch	13.0000	13.0000	13.0000	13.0000	13.0000	13.0000	13.0000
Fin Thickness	0.0052	0.0052	0.0052	0.0052	0.0052	0.0052	0.0052
O.D. of Tubes	0.3250	0.3250	0.3250	0.3250	0.3250	0.3250	0.3250
I.D. of Tubes	0.3030	0.3030	0.3030	0.3030	0.3030	0.3030	0.3030
Vert Space (in)	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Hor Space (in)	0.6250	0.6250	0.6250	0.6250	0.6250	0.6250	0.6250
# of Return Bends	72.0000	72.0000	72.0000	72.0000	72.0000	72.0000	72.0000
Refrig. Control	TXV	TXV	TXV	TXV	TXV	TXV	TXV
Fin Design	WAVY	WAVY	WAVY	WAVY	WAVY	WAVY	WAVY
OUTDOOR FAN							
CFM	3500.00	3500.00	3500.00	3500.00	4000.00	4000.00	4000.00
Fan & Motor eff.	0.09	0.09	0.14	0.14	0.18	0.18	0.23
INDOOR FAN							
CFM	1200.00	1200.00	1200.00	1200.00	1200.00	1200.00	1200.00
Fan & Motor eff.	0.17	0.17	0.24	0.24	0.27	0.27	0.31
Ref. Lines (6 ft)							
Liquid Line O.D.	3/8	3/8	3/8	3/8	3/8	3/8	3/8
Suction Line O.D.	1 1/8	1 1/8	1 1/8	1 1/8	1 1/8	1 1/8	1 1/8

Table 4.11 (con't) - Hardware data on 5 ton package heatpump systems

** 5 Ton Systems ** ** Packaged Units **					
MODEL	60PH	60PI	60PJ	60PK	60PL
DESIGN OPTIONS	1A,1C,1D,2 3,4,5	1A,1C,1D,2 3,4,5	1A,1C,1D,2 3,4,5	1A,1C,1D,2 3,4,5	1A,1C,1D,2 3,4,6
SUPERHEAT	10 CL/5 HT	10 CL/5 HT	10 CL/5 HT	10 CL/5 HT	10 CL/5 HT
SUBCOOL	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT
COMPRESSOR	BJ 7.233	BJ 7.200	BJ 7.001	BI	CF 6.746
EER	9.51	9.51	9.51	10.00	9.80
OUTDOOR COIL					
Face Area (ft^2)	25.0000	25.0000	30.0000	30.0000	30.0000
# of Rows	2.0000	2.0000	2.0000	2.0000	2.0000
# of Parallel Ckts	4 CL/6 HT	4 CL/6 HT	4 CL/6 HT	4 CL/6 HT	4 CL/6 HT
Fins/Inch	19.0000	19.0000	19.0000	19.0000	19.0000
Fin Thickness	0.0045	0.0045	0.0045	0.0045	0.0045
O.D. of Tubes	0.3880	0.3880	0.3880	0.3880	0.3880
I.D. of Tubes	0.3620	0.3620	0.3620	0.3620	0.3620
Vert Space (in)	1.2500	1.2500	1.2500	1.2500	1.2500
Hor Space (in)	1.0830	1.0830	1.0830	1.0830	1.0830
# of Return Bends	52.0000	52.0000	52.0000	52.0000	52.0000
Refrig. Control	TXV	TXV	TXV	TXV	TXV
Fin Design	LOUVERED	LOUVERED	LOUVERED	LOUVERED	LOUVERED
INDOOR COIL					
Face Area (ft^2)	7.0000	8.0000	8.0000	8.0000	8.0000
# of Rows	4.0000	4.0000	4.0000	4.0000	4.0000
# of Parallel Ckts	8 CL/4 HT	8 CL/4 HT	8 CL/4 HT	8 CL/4 HT	8 CL/4 HT
Fins/Inch	13.0000	13.0000	13.0000	13.0000	13.0000
Fin Thickness	0.0052	0.0052	0.0052	0.0052	0.0052
O.D. of Tubes	0.3250	0.3250	0.3250	0.3250	0.3250
I.D. of Tubes	0.3030	0.3030	0.3030	0.3030	0.3030
Vert Space (in)	1.0000	1.0000	1.0000	1.0000	1.0000
Hor Space (in)	0.6250	0.6250	0.6250	0.6250	0.6250
# of Return Bends	72.0000	72.0000	72.0000	72.0000	72.0000
Refrig. Control	TXV	TXV	TXV	TXV	TXV
Fin Design	WAVY	WAVY	WAVY	WAVY	WAVY
OUTDOOR FAN					
CFM	4000.00	4000.00	4500.00	4500.00	5000.00
Fan & Motor eff.	0.23	0.23	0.23	0.23	0.23
INDOOR FAN					
CFM	1200.00	1200.00	1200.00	1200.00	1200.00
Fan & Motor eff.	0.31	0.31	0.31	0.31	0.31
Ref. Lines (6 ft)					
Liquid Line O.D.	3/8	3/8	3/8	3/8	3/8
Suction Line O.D.	1 1/8	1 1/8	1 1/8	1 1/8	1 1/8

Table 4.12 - Performance data on 5 ton package heatpump systems

```
*******************
** 5 Ton Systems **
** Package Units **
*******************
```

** 5 Ton Systems ** ** Package Units **	60PA	60PB	60PC	60PD	60PE	60PF	60PG
SYSTEM RATINGS							
CD Cooling	0.25	0.25	0.25	0.25	0.20	0.20	0.15
CD Heating	0.25	0.25	0.25	0.25	0.20	0.20	0.20
SEER	6.63	6.70	6.87	7.27	8.06	8.76	9.04
HSPF	5.80	5.83	6.70	6.94	7.31	7.39	7.53
SHF 95 deg	0.65	0.65	0.65	0.65	0.65	0.65	0.65
SHF 82 deg	0.64	0.64	0.64	0.64	0.64	0.64	0.64
95 deg F COP	1.98	2.01	2.06	2.17	2.32	2.51	2.52
CAPACITY	59800.00	60000.00	59700.00	59400.00	59800.00	59300.00	59700.00
EER	6.76	6.84	7.01	7.39	7.92	8.56	8.61
82 deg F COP	2.22	2.24	2.30	2.44	2.62	2.85	2.86
CAPACITY	63700.00	63600.00	63400.00	63000.00	63700.00	63200.00	63500.00
EER	7.58	7.66	7.85	8.31	8.95	9.74	9.77
47 deg F COP	2.26	2.16	2.14	2.47	2.58	2.69	2.72
CAPACITY	60300.00	60100.00	58500.00	61900.00	60700.00	58900.00	59400.00
35 deg F COP	2.23	2.14	2.13	2.40	2.51	2.58	2.62
CAPACITY	54500.00	51700.00	49500.00	51600.00	50500.00	49200.00	49600.00
17 deg F COP	2.04	1.94	1.93	2.18	2.28	2.34	2.37
CAPACITY	42400.00	39900.00	38400.00	39900.00	38500.00	37000.00	37300.00

Table 4.12 (con't) - Performance data on 5 ton package heatpump systems

******************* ** 5 Ton Systems ** ** Package Units ** *******************	60PH	60PI	60PJ	60PK	2 Speed Compressor 60PL High Spd	60PL Low Spd
SYSTEM RATINGS						
CD Cooling	0.15	0.15	0.15	0.15	0.15	
CD Heating	0.20	0.20	0.20	0.20	0.20	
SEER	9.54	10.12	10.22	10.57	13.70	
HSPF	8.04	8.11	8.16	8.51	9.11	
SHF 95 deg	0.65	0.65	0.65	0.65	0.65	0.76
SHF 82 deg	0.64	0.64	0.64	0.64	0.64	0.74
95 deg F COP	2.67	2.82	2.84	2.93	3.06	3.59
CAPACITY	59500.00	59400.00	59700.00	59700.00	59800.00	387006.00
EER	9.10	9.63	9.70	10.01	10.45	12.27
82 deg F COP	3.02	3.21	3.24	3.35	3.47	4.32
CAPACITY	63200.00	63100.00	63500.00	63400.00	63600.00	41800.00
EER	10.31	10.94	11.05	11.42	11.84	14.73
47 deg F COP	2.82	3.01	3.05	3.09	3.12	3.81
CAPACITY	57300.00	60100.00	60300.00	59900.00	59800.00	37700.00
35 deg F COP	2.69	2.88	2.91	2.93	2.93	3.29
CAPACITY	48100.00	49900.00	50000.00	49900.00	49600.00	30400.00
17 deg F COP	2.42	2.58	2.61	2.62	2.59	2.51
CAPACITY	36000.00	36900.00	37000.00	36800.00	36600.00	20600.00

Central Air Conditioners

The final central air conditioner designs are the same as those for the heat pump with two exceptions. First, the cooling degradation factors, Cd, were lowered by 0.05 compared to those for heat pumps. Data from several sources[5,6,7] tend to support the smaller Cd for air conditioners. For instance, data from reference 4 indicated that central air conditioners in 1979 had average Cds of 0.15. The best Cd used in this study for heat pumps in the cooling mode was 0.15. Thus, the best Cd for central air conditioners was 0.10. This value is comparable to the 0.12 used in the previous efficiency standards analysis for air conditioners[6]. Data from the California Energy Commission indicate that some central air conditioners have Cds as low as 0.04[7].

Another difference between the air conditioner designs and those for heat pumps concerns the indoor fans for split systems. Many air conditioning system are matched to either gas or oil furnaces. Thus, the air conditioner uses the blower unit that comes with the furnace rather than being matched to a manufactures indoor blower coil. Thus, for some of their split system air conditioners, a manufacturer may sell only the condenser unit (condenser, compressor, and expansion device) plus indoor coil. The DOE test procedure allows for a particular indoor coil to not be matched to a specific blower. Rather than measuring the indoor fan power during a test, the fan power is specified as 365 watts per 1000 cfm of indoor airflow. This fan power is the same whether the air conditioner is a high or low efficiency unit.
For those units with a matched indoor fan coil unit, the fan power is measured and used in the calculation of the SEER the same as with heat pumps. While the 365 watts per 1000 cfm is a reasonable estimate for fan power for the lower efficiency units, it overestimates what the indoor fan power for higher efficiency units that might have higher efficiency fans and motors. This overestimate of fan power decreases the calculated SEER for split system air conditioners when compared an equivalent heat pump system.

In this analysis, all the split system air conditioners with the exception of the two speed and variable speed units, were assumed to use the assigned indoor fan power of 365 watts per 1000 cfm. This assumption is consistent with the previous analysis of split system central air conditioners[6]. The lowered degradation coefficients tended to offset the reduction in SEER caused by the assignment of indoor fan power. The reduction of SEER for the split system air conditioners was typically only a few tenths of a SEER compared to heat pumps.

Because the hardware descriptions for the central air conditioner models were the same as for the heat pumps, these descriptions are not repeated in this section. Only for the performance results at 95 F, 82 F, are the degradation coefficients and sensible heating factors are provided.

3 Ton Split Systems

As with the 3 ton split system heat pumps, there are twelve units in this class of central air conditioners. Their letter designations are the same as the heat pumps, running from 36A through 36L. The SEERs run from 7.00 for 36A and increase sequentially up to 14.07 for 36L for conventionally designed units (Table 4.13). In 1986, 3 ton split systems were available with SEERs from a low of 6.4 to a high of 15.0[3].

3 Ton Package Systems

The three ton package central air conditioners designation runs from 36PA to 36PL for units using conventional design options (Table 4.14). Unit efficiencies are slightly higher than for the 3 ton split systems, running from a low SEER of 7.07 to a high of 14.69. The split systems have a lower efficiency because package systems get to use actual fan power rather than the 365 watts per 1000 cfm used by the split systems. The available SEERs in 1986 ranged from 6.35 to 9.60 for 3 ton package systems[3].

5 Ton Split Systems

Tables 4.15 lists the units in the 5 ton split system line that use conventional design options. Unit 60A is the baseline unit and 60L is the best unit. The best performance for the 5 ton split systems using conventional technology is a SEER of 13.26. The best 5 ton split system listed in the ARI directory had a SEER of 13.0[3].

5 Ton Package Systems

Tables 4.16 list the units in the 5 ton package line. The designations are the same as the 5 ton split systems, except they contain a "P" to identify them as package units. The best performance for the 5 ton package system is a SEER of 13.26. The best unit in the ARI directory had a SEER of 9.5[3].

Table 4.13 - Performance data on 3 ton split A.C. systems

```
*******************
** 3 Ton A.C. **
** Split Units **
*******************
```

	36A	36B	36C	36D	36E	36F	36G
SYSTEM RATINGS							
CD	0.20	0.20	0.15	0.15	0.15	0.15	0.10
SEER	7.00	7.46	9.12	9.91	10.20	11.90	12.13
SHF 95 deg	0.74	0.74	0.75	0.75	0.75	0.75	0.75
SHF 82 deg	0.72	0.72	0.73	0.73	0.73	0.73	0.73
95 deg F COP	2.00	2.40	2.53	2.76	2.82	3.21	3.18
CAPACITY	35500.00	35400.00	35600.00	35400.00	35700.00	35700.00	35600.00
EER	6.83	8.19	8.64	9.42	9.63	10.96	10.85
82 deg F COP	2.28	2.43	2.89	3.14	3.23	3.77	3.74
CAPACITY	38000.00	35300.00	38000.00	37900.00	38000.00	38300.00	38200.00
EER	7.78	8.29	9.86	10.72	11.02	12.87	12.77

Table 4.13 (con't) - Performance data on 3 ton split A.C. systems

3 Ton A.C. Split Units	36H	36I	36J	36K 2 Speed Compressor High Spd	36K 2 Speed Compressor Low Spd	36L
SYSTEM RATINGS						
CD	0.10	0.10	0.10	0.10		0.10
SEER	12.42	13.00	13.42	13.74		14.07
SHF 95 deg	0.75	0.76	0.76	0.76	0.97	0.76
SHF 82 deg	0.73	0.73	0.73	0.73	0.93	0.73
95 deg F COP	3.28	3.37	3.48	3.45	3.48	3.66
CAPACITY	35700.00	35600.00	35600.00	35600.00	20800.00	36000.00
EER	11.20	11.50	11.88	11.78	11.88	12.49
82 deg F COP	3.83	4.01	4.14	3.88	4.17	4.34
CAPACITY	38200.00	38200.00	38100.00	38200.00	22600.00	38500.00
EER	13.07	13.69	14.13	13.24	14.23	14.81

Table 4.14 - Performance data on 3 ton package A.C. systems

****
** 3 Ton A.C. **
** Package Units **
****

	36PA	36PB	36PC	36PD	36PE	36PF	36PG
SYSTEM RATINGS							
CD	0.20	0.20	0.20	0.20	0.15	0.15	0.10
SEER	7.07	7.86	8.08	8.43	9.96	10.18	10.77
SHF 95 deg	0.73	0.73	0.74	0.74	0.75	0.75	0.75
SHF 82 deg	0.71	0.71	0.72	0.72	0.73	0.73	0.73
95 deg F COP	2.05	2.27	2.32	2.42	2.76	2.83	2.88
CAPACITY	35600.00	35600.00	35600.00	35600.00	35700.00	35700.00	35700.00
EER	7.01	7.75	7.92	8.26	9.41	9.65	9.84
82 deg F COP	2.30	2.56	2.63	2.74	3.16	3.22	3.32
CAPACITY	37900.00	37900.00	38000.00	38000.00	38000.00	38000.00	38200.00
EER	7.86	8.74	8.98	9.37	10.77	11.00	11.34

Table 4.14 (con't) - Performance data on 3 ton package A.C. systems

** 3 Ton A.C. ** ** Package Units **	36PH	36PI	36PJ	36PK	2 Speed Compressor High Spd 36PL	Low Spd 36PL
SYSTEM RATINGS						
CD	0.10	0.10	0.10	0.10	0.10	
SEER	12.27	12.80	13.76	14.09	14.69	
SHF 95 deg	0.75	0.76	0.75	0.76	0.75	0.97
SHF 82 deg	0.73	0.73	0.73	0.73	0.73	0.94
95 deg F COP	3.20	3.32	3.55	3.63	3.53	3.73
CAPACITY	35700.00	35700.00	35700.00	35600.00	35600.00	20700.00
EER	10.91	11.35	12.11	12.38	12.03	12.74
82 deg F COP	3.78	3.95	4.25	4.35	4.06	4.48
CAPACITY	38300.00	38500.00	38300.00	38200.00	38200.00	22400.00
EER	12.91	13.48	14.49	14.83	13.85	15.27

Table 4.15 - Performance data on 5 ton split A.C. systems

** 5 Ton A.C. ** ** Split Units **	60A	60B	60C	60D	60E	60F	60G
SYSTEM RATINGS							
CD	0.20	0.20	0.20	0.15	0.15	0.15	0.15
SEER	6.85	6.85	7.56	8.27	9.09	9.69	9.82
SHF 95 deg	0.67	0.67	0.68	0.68	0.68	0.68	0.68
SHF 82 deg	0.66	0.67	0.67	0.67	0.67	0.67	0.67
95 deg F COP	1.99	1.99	2.19	2.33	2.54	2.71	2.73
CAPACITY	59300.00	59500.00	59200.00	59800.00	59500.00	59200.00	59400.00
EER	6.79	6.79	7.47	7.95	8.67	9.25	9.32
82 deg F COP	2.23	2.23	2.46	2.62	2.88	3.07	3.11
CAPACITY	63000.00	62900.00	62600.00	63300.00	63500.00	63100.00	63100.00
EER	7.61	7.61	8.40	8.94	9.83	10.48	10.62

Table 4.15 (con't) - Performance data on 5 ton split A.C. systems

```
*******************
** 5 Ton A.C.  **
**  Split Units  **
*******************
```

5 Ton A.C. Split Units	60H	60I	60J	60K	60L 2 Speed Compressor Hi Spd	60L 2 Speed Compressor Lo Spd
SYSTEM RATINGS						
CD	0.10	0.10	0.10	0.10	0.10	
SEER	10.31	10.47	10.51	11.90	13.26	
SHF 95 deg	0.68	0.68	0.69	0.69	0.68	0.83
SHF 82 deg	0.67	0.67	0.67	0.67	0.67	0.79
95 deg F COP	2.79	2.84	2.82	3.20	3.11	3.42
CAPACITY	59400.00	59200.00	58500.00	58500.00	59300.00	36900.00
EER	9.52	9.69	9.63	10.92	10.62	11.67
82 deg F COP	3.18	3.23	3.24	3.67	3.53	4.08
CAPACITY	63200.00	63000.00	62500.00	62500.00	63300.00	40000.00
EER	10.85	11.02	11.06	12.53	12.05	13.93

Table 4.16 - Performance data on 5 ton package A.C. systems

****
** 5 Ton A.C. **
** Package Units **
****

					2 Speed Compressor High Spd	2 Speed Compressor Low Spd
	60PH	60PI	60PJ	60PK	60PL	
SYSTEM RATINGS						
CD	0.10	0.10	0.10	0.10	0.15	
SEER	9.80	10.40	10.50	10.85	13.26	
SHF 95 deg	0.65	0.65	0.65	0.65	0.65	0.76
SHF 82 deg	0.64	0.64	0.64	0.64	0.64	0.74
95 deg F COP	2.67	2.82	2.84	2.93	3.06	3.59
CAPACITY	59500.00	59400.00	59700.00	59700.00	59800.00	38700.00
EER	9.10	9.63	9.70	10.01	10.45	12.27
82 deg F COP	3.02	3.21	3.24	3.35	3.47	4.32
CAPACITY	63200.00	63100.00	63500.00	63400.00	63600.00	41800.00
EER	10.31	10.94	11.05	11.42	11.84	14.73

Table 4.16 (con't) - Performance data on 5 ton package A.C. systems

```
###################
## 5 Ton A.C. ##
## Package Units ##
###################
```

5 Ton A.C. Package Units	60PA	60PB	60PC	60PD	60PE	60PF	60PG
SYSTEM RATINGS							
CD	0.20	0.20	0.20	0.20	0.15	0.15	0.10
SEER	6.82	6.89	7.07	7.48	8.28	9.01	9.28
SHF 95 deg	0.65	0.65	0.65	0.65	0.65	0.65	0.65
SHF 82 deg	0.64	0.64	0.64	0.64	0.64	0.64	0.64
95 deg F COP	1.98	2.01	2.06	2.17	2.32	2.51	2.52
CAPACITY	60000.00	59800.00	59700.00	59400.00	59800.00	59300.00	59700.00
EER	6.76	6.84	7.01	7.39	7.92	8.56	8.61
82 deg F COP	2.22	2.24	2.30	2.44	2.62	2.85	2.86
CAPACITY	63600.00	63700.00	63400.00	63000.00	63700.00	63200.00	63500.00
EER	7.58	7.66	7.85	8.31	8.95	9.74	9.77

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CHAPTER 5

VARIABLE SPEED COMPRESSORS AND OTHER ADVANCED DESIGN OPTIONS

Six conventional design options for improving heat pump and air conditioner performance were discussed in Chapter 3. These options have already been implemented in some of the units currently on the market. In this chapter, options that are considered "advanced" technology for residential applications are discussed: variable speed compressors, scroll compresssors, two speed and variable speed fan motors, and electronic expansion valves.

These options are not widely used on U.S. manufactured residential sized heat pumps. The most important of the options listed above is the variable speed compressor. The scroll compressor should be a technology ideal for application of variable speed electric motors. Likewise, application of variable speed fan motors will probably be most widespread on variable speed compressor systems. Electronic expansion valves should offer the precise refrigerant control that is desirable for variable speed systems.

The Department of Energy must make an estimate of the "maximum technologically feasible" efficiencies for all appliances that they regulate[1]. To arrive at what might be the "maximum technologically feasible" air conditioner or heat pump that can be constructed in the next few years will require the application of these design options.

To remain consistent with our previous report[2] and the numbering of design options in Chapter 3, the four options considered in this chapter are labelled options 7 through 10.

Variable Speed Compressors (Option 7)

Variable speed compressors are essentially compressors driven by a variable speed electric motor. An electronic inverter varies the compressor motor power supply frequency which in turn varies the motor rotational speed. The primary advantage of the variable speed heat pump or air conditioner is that they can vary their capacity over a wide range to closely match the building load. Because the heat pump just matchs the building load, it operates almost continuously. Thus, the unit cycles less frequently, and the losses due to cycling are reduced. Proponents claim an efficiency improvement from 10% to 40% over a single-speed compressor system[3,4,5,6,7].

Other claimed advantages of variable speed units over single speed units include[3,7]: (1) improved compressor reliability due to the reduction of frequent on/off operation; (2) improved comfort due to the reduction in width of fluctuation in the space temperature as a result of on/off operation; (3) reduction in cycling losses due to the reduction of on/off operation; (4) improved heating capacity at low outdoor temperature which reduces the need for resistance heating; and (5) reduced time for bringing the building temperature to the set temperature by switching to the high speed mode.

At the heart of a variable speed heat pump or air conditioner is a variable speed compressor/motor. The speed of the motor is varied with the use of an electronic inverter. The inverter converts a standard 60 Hz power source to one typically ranging in frequency from 30 to as high as 110 Hz. Since compressor motor speed is dependent on the power source frequency, adjusting frequency directly affects the motor speed. There is a penalty in the overall efficiency of the motor with the losses in the electronic inverter. Table 5.1 illustrates the effect on compressor performance of varying the speed of the compressor. These data were obtained from a U.S. compressor manufacturer that

Table 5.1 - Performance data for a variable speed compressor.

Frequency (hz)	Capacity (Btu/hr)	Power (watts)	Mass Flow (lb/hr)	EER (Btu/w-hr)
30	8350	1060	123	7.91
45	13400	1500	197	8.94
60	18200	2020	266	9.00
75	22900	2560	336	8.95
90	25300	3040	373	8.33

is currently marketing variable speed compressors to heat pump and central air conditioner manufacturers. The data above are at the rating conditions shown earlier (Table 4.4) for single speed compressors. The frequency, which is proportional to the rotational speed, varies by a factor of three for this unit. Capacity varies by approximately the same proportion. The efficiency of the compressor peaks near it's standard operating frequency (60 hz) and drops off with either reduced or increased speed. Poor performance at the lower speeds is principally due to losses in the inverter. At higher speeds, the drop in performance is probably due to higher losses in valving. Note that the rated EER of this unit is far below that of its single speed counterpart. The best single speed compressors available today have EERs between 10.5 and 11.0. The variable speed unit's efficiency is 15 to 20% below that. It should be emphasized that the unit shown in Table 5.1 is a "first generation" variable speed compressor for U.S. manufacturers. As improvements are made in the inverters, and manufacturers improve their compressor designs with better valving or higher efficiency compressors (scrolls or rotaries), the efficiency of the variable speed units should improve.

Variable speed compressors have already been widely applied in the Japanese residential heat pump market. Currently, 20% of all residential heat pumps sold in Japan employ variable speed compressors. While other forms of capacity modulation are possible (variable stroke length or cylinder unloading), variable speed motors should be the most cost-effective and easiest to implement in residential systems.

Figures 5.1 and 5.2 demonstrate the effect on a heat pump's cooling and heating capacity and COP of varying the compressor motor speed from 1580 to 4250 revolutions per minute for a Japanese manufactured variable speed compressor[3]. The compressor speed is dependent on the building load. At low building load conditions, the compressor is run at a lower speed with a resulting lower capacity. When this is done, the need for the unit to cycle on and off is reduced and an increase in efficiency is realized. At higher building loads the compressor runs at higher speeds to meet the load.

Another consideration relating to the variable speed performance is the latent capacity of the unit at lower speeds. If the heat exchangers are designed for high speed operation, they will be considerably oversized for lower speeds. This usually implies a smaller latent capacity. Thus, it may be necessary to redesign the evaporator (or condenser) so that only a portion of it is used during the lower speeds. A variable (or two) speed fan could also be used to better control both the latent capacity and energy use.

Scroll Compressor (Option 8)

The concept of the scroll compressor has a long history. It first appeared in a U.S. patent in the early 1900's. The main elements of the scroll compressor are two identical involute spiral scrolls[3]. One of the scrolls is fixed and the other orbits around the center of the fixed scroll. A hermetic package of the scroll compressor would probably be used for residential applications. Expected efficiency improvements of the scroll compressor over the best conventional reciprocating compressor should be about 10%.

The scroll compressor is still primarily in the development stages. The Japanese have built and used scroll compressors in heat pumps[3]. Preliminary information from one U.S. compressor manufacturer indicates that the scroll compressor should be available to U.S. OEMs in 1987. It could appear in heat pump lines by 1988 or 1989. The developers of this compressor claim that it has several advantages over a conventional compressor[3]: (1) lower leakage during the compression process resulting in high efficiency; (2) higher reliability because this compressor uses no suction or discharge valves; (3) a smaller torque change compared to a conventional compressor resulting in low noise and low vibrations.

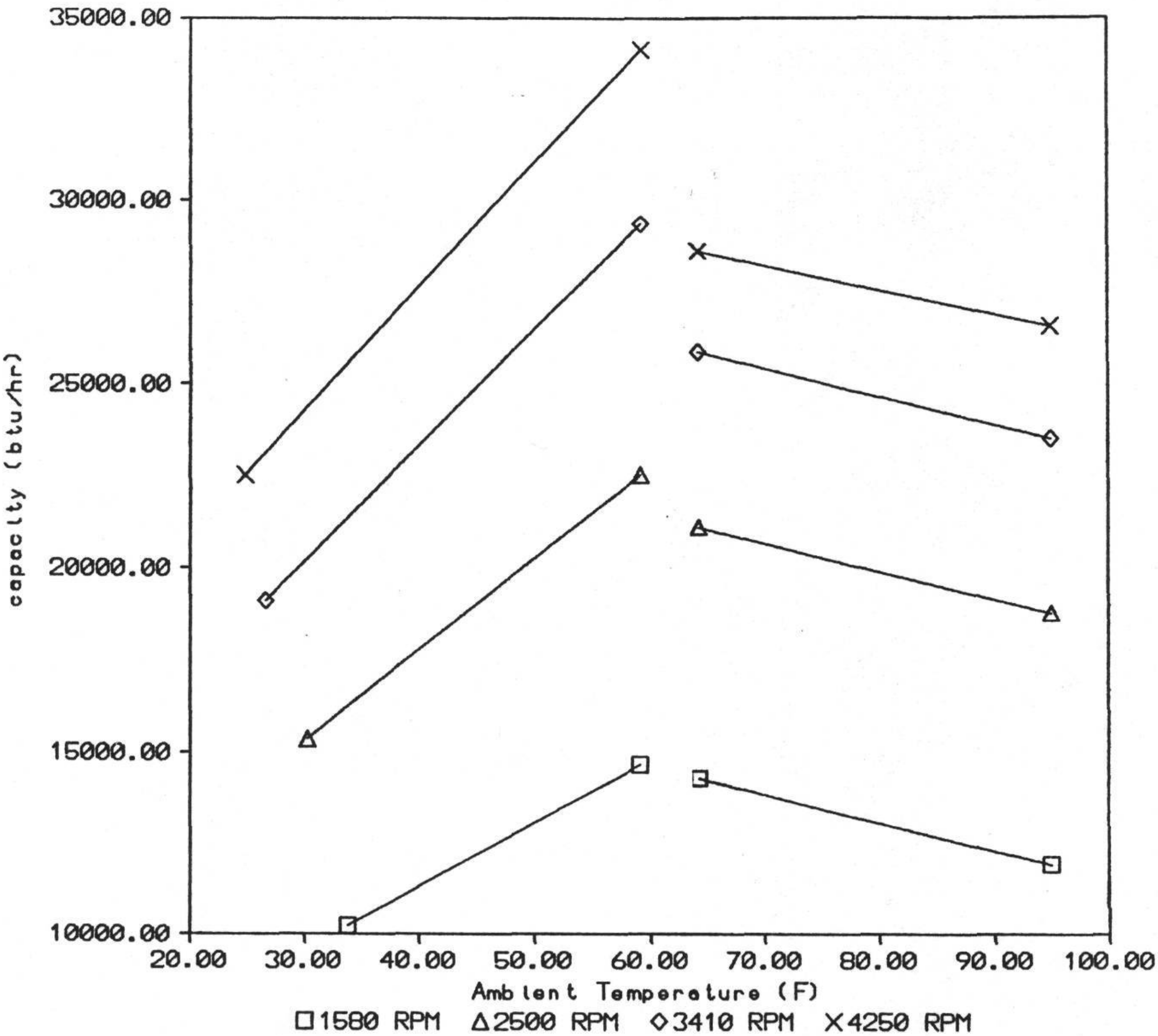

Figure 5.1 - Capacity versus outdoor temperature for a heat pump with a variable speed motor (Source: Ref. 13)

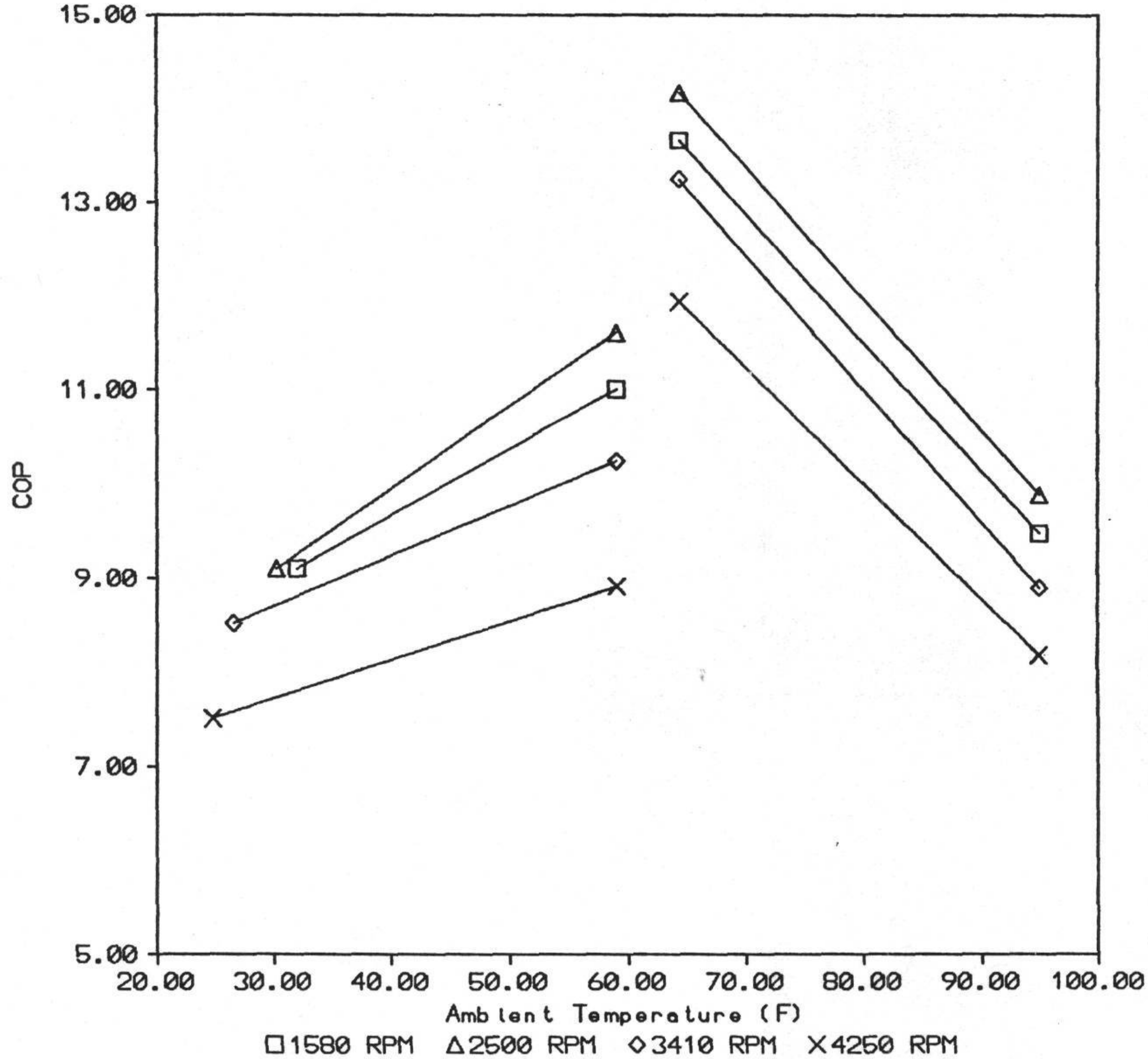

Figure 5.2 - COP versus outdoor temperature for a heat pump with a variable speed motor (Source: Ref. 13)

Two-speed and variable speed fan motors (Option 9)

With the introduction of variable speed compressor motors in heat pumps, the next logical step for improved capacity control would be the use of multi-speed or variable speed fan motors. The two-speed fan motors would be similiar to the two-speed motors used in compressors, having two sets of poles(one for high speed and the other for low speed). The variable speed fan motors would utilize inverter technology similar to variable speed motors for compressors.

Two speed fan motors are already in use on larger commercial air cooled chillers and heat pumps. In these units, the savings in fan energy costs are able to quickly offset the added costs of the two speed motors. Two speed fans have also been used in residential sized air conditioners to vary the outdoor airflow. These fans were thermostatically controlled to increase speed at a fixed outdoor temperature. Two speed or variable speed motors make the most sense when the compressor is capacity modulated. Variable speed motors could be used for the indoor coil to better control latent capacity and reduce fan energy in a unit with a variable speed compressor. Variable speed fans are only considered an option when used in conjunction with option #7, variable speed compressors. The expected savings due to either two speed or variable speed fans should not exceed five percent.

Electronic Expansion Valves (Option 10)

The electronic expansion valve should make it possible to obtain better control of flow conditions (degree of superheat at the outlet of the evaporator, subcooling at the outlet of the condenser, etc.) than that which can be obtained with either a thermostatic expansion valve or capillary tubes[8,9]. Some electronic valves have an electric motor whose rotational motion is converted into vertical movement within the valve via gears[9]. Another design uses a solenoid to drive a plunger which controls the flow opening[8]. Either design would employ an electronic microprocessor that would send a signal to the valve to either open or close more, depending on conditions being sensed.

This technology is currently employed on room air conditioners and heat pumps in Japan[8,9]. Claims of efficiency improvements from 5 to 10% in single speed systems have been made for both heating and cooling. If manufacturers are already optimizing their systems for 82 F, the electronic valve may not provide any improvement in cooling SEER. Another benefit of this valve is it that should provide for a shorter defrost time. Because the defrost time is not measured in the test procedure, the savings of the valve would not be counted in the HSPF. The valve could provide better control of flow conditions at the more extreme temperatures(17 F in heating and 95 F cooling). The wide range of control offered by these valves may make them good fits for control in variable speed systems. The valves should also improve reliability over conventional expansion devices because it responds faster and can maintain superheat into the compressor over a wider range than conventional expansion devices. For this analysis, an electronic expansion valve was assumed to have no effect on SEER and a 5% improvement in HSPF.

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Chapter 6

SEASONAL PERFORMANCE MODEL FOR VARIABLE SPEED HEAT PUMPS AND AIR CONDITIONERS

To estimate the seasonal performance of variable speed heat pumps and air conditioners, a seasonal performance model(SPM) was developed that is based on the proposed DOE test procedure[1]. This procedure is a modification of the earlier DOE test procedure for single and two speed heat pumps and air conditioners[2], and relies heavily on a test procedure developed by the Air Conditioning and Refrigeration Institute[3]. The output from the SPM is an estimate of the heating seasonal performance factor (HSPF) for variable speed heat pumps and the seasonal energy efficiency ratio (SEER) for variable speed air source heat pumps and air conditioners. The SPM for single and two speed heat pumps was discussed in an earlier report[4].

The model is divided into two separate calculation procedures. One calculates SEER and the other HSPF. Each calculation procedure is discussed below.

SEER Calculation

The input required for the SEER calculations are shown in Table 6.1. The test conditions and methodology for the SEER calculations are diagrammed in Figure 6.1. Capacity (in Btu/hr) and power consumption (in watts) data are required for four outdoor temperatures: 95 F, 87 F, 82 F, and 67 F; and three speeds: maximum, intermediate, and minimum speed. In addition, a degradation coefficient must be specified for the unit. The capacity and power data are estimated by the ORNL heat pump model[5] for the variable speed unit at each temperature.

Table 6.1 - Input required for the variable speed SEER calculation.

Input	Variable
Maximum Speed Capacity at 95 F	Q2ss95
Maximum Speed Capacity at 82 F	Q2ss82
Minimum Speed Capacity at 82 F	Q1ss82
Minimum Speed Capacity at 67 F	Q1ss67
Intermediate Speed Capacity at 87 F	Qvss87
Maximum Speed Power at 95 F	E2ss95
Maximum Speed Power at 82 F	E2ss82
Minimum Speed Power at 82 F	E1ss95
Minimum Speed Power at 67 F	E1ss67
Intermediate Speed Power at 87 F	EVss87
Cooling Degradation Cd	Cdc

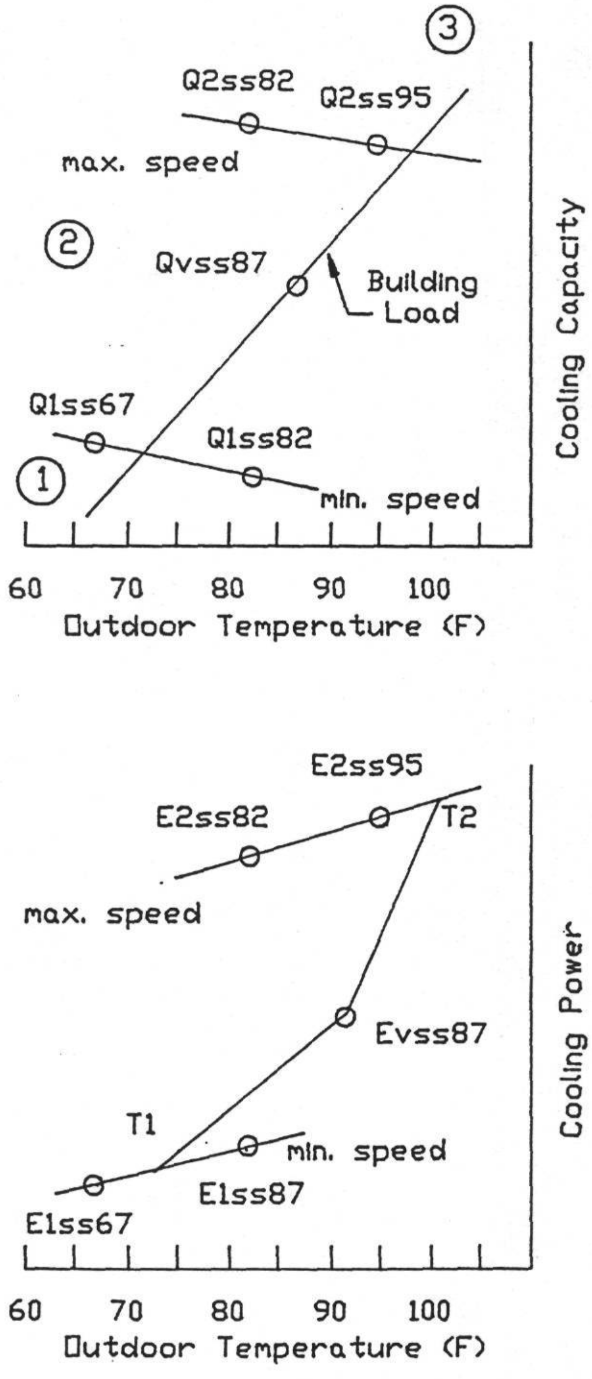

Figure 6.1 Diagram of points used in SEER calculation procedure

For a single speed heat pump, a degradation factor and one run of the ORNL heat pump model at 82 F are required to obtain the SEER for an air conditioner or heat pump[4]. With variable speed heat pumps, five runs must be made at three compressor speeds and four outdoor temperatures in addition to an estimate of the degradation coefficient to obtain the SEER. Figure 6.1 also shows the estimated building load, which is estimated from the cooling capacity data[1,3,6].

The test conditions for which data are required in the SEER calculation are shown in Table 6.2.

Table 6.2 - Required tests for the variable speed SEER calculation.

TEST	INDOOR COIL Air Entering DB	INDOOR COIL Air Entering WB	OUTDOOR COIL Air Entering DB	OUTDOOR COIL Air Entering WB
Q2ss95,E2ss95	80	67	95	75
Q2ss82,E2ss82	80	67	82	65
Q1ss82,E1ss82	80	67	82	65
Q2ss67,E1ss67	80	67	67	53.5
Qvss87,Evss87	80	67	87	69

For variable speed compressor units, the seasonal energy efficiency ratio is determined by a bin method. The cooling season is divided into 5 F temperature bins. The number of cooling hours for each temperature bin are listed in Table 6.3. The

Table 6.3 - Distribution of cooling hours for SEER Calculation.

Bin Number j	Bin Temperature Tj(F)	Bin Hours nj
1	67	214
2	72	231
3	77	216
4	82	161
5	87	104
6	92	52
7	97	18
8	102	4

cooling energy produced by the unit, Q(TJ), is estimated for each bin, and then summed over the entire cooling season. A similar calculation is done for the energy input, E(Tj), into the unit. The cooling produced by the unit summed over the cooling season divded by the energy input over the cooling season is the SEER. In equation form, it is given as:

$$SEER = \frac{\Sigma Q(Tj)}{\Sigma E(Tj)} \qquad (6.1)$$

Q(Tj) and E(Tj) are evaluated at each temperature bin according to three possible cases (discussed below).

To estimate the SEER for variable speed heat pumps and air conditiners, the test procedure requires that a building load be specified. The test procedure assumes that the building cooling load, BL, varies linearly with the difference between the outdoor and indoor temperatures (Equation 6.2). The building is assumed to need cooling down to an outdoor temperature of 65 F.

$$BL(Tj) = \frac{(Tj - 65) * [Q2ss95]}{(95 - 65) * \text{Size Factor}} \qquad (6.2)$$

where,

Size Factor = 1.1 for 10% oversizing

With variable speed heat pumps and air conditioners , the calculation of SEER proceeds according to one of three cases at a particular temperature bin. These cases include: Case I, where the unit operates at minimum compressor speed and has more capacity than the building load; Case II, where cooling capacity just matches the building demand; and Case III, where the unit operates continuously at maximum speed to meet the building load. Case 1 typically occurs at relatively cool temperatures, where the loads on the building are not very high. Case II typically occurs during periods of warm weather where the unit can vary its speed to match the load. Case III occurs during the hottest part of the day, where the unit must run continously at high speed to maintain comfort conditions in the residence. The calculation procedure for each case is described below.

CASE I

For units operating at minimum compressor speed for which the steady state cooling capacity [Q1ssTj] is greater than or equal to the building cooling load BL(Tj) (The area circled 1 in Figure 6.1) , the unit's capacity is estimated:

$$QlssTj = Qlss67 + \left(\frac{(Qlss82 - Qlss67)}{(82 - 67)}\right) * (Tj - 67) \quad (6.3)$$

QlssTj is the steady state capacity at the minimum compressor speed intended for normal operation in the cooling mode at temperature Tj. Likewise, the unit's power consumption is also estimated:

$$ElssTj = Elss67 + \left(\frac{(Elss82 - Elss67)}{(82 - 67)}\right) * (Tj - 67) \quad (6.4)$$

ElssTj is the electrical power input at the minimum compressor speed in the cooling mode at temperature Tj. The fraction of time, Xl, the compressor is on is estimated by:

$$Xl = \frac{BL(Tj)}{QlssTj} \quad (6.5)$$

The part load factor, PLF, at a particular temperature is given by:

$$PLF = 1 - Cdc*(1 - Xl) \quad (6.6)$$

Cdc is the cooling degradation coefficient. The PLF is a measure of the losses of the air conditioner or heat pump due to cycling. The total cooling (in Btus), Q(Tj), produced by the unit at a temperature, Tj, is estimated by multiplying the steady state cooling capacity, QlssTj, by the number of hours in a given bin and by the fraction "on-time" for the compressor:

$$Q(Tj) = Xl * QlssTj * nj \quad (6.7)$$

A similar expression for the energy input, E(Tj), to the compressor is developed which also includes losses associated with the compressor cycling on and off:

$$E(Tj) = \frac{Xl * ElssTj * nj}{PLFl} \quad (6.8)$$

Q(Tj) and E(Tj) are then used in Equation (6.1) along with similar expressions for Case II and Case III to obtain the SEER.

CASE II

This case is used when the heat pump varies its speed to match the building load (The area circled 2 in Figure 6.1). This occurs between the minimum and maximum speeds of the compressor. Because the unit's capacity, QvssTj, just matches the building load, it is given by the expression:

$$QvssTj = BL(Tj) \quad (6.9)$$

QvssTj is the steady state capacity delivered by the unit at any speed between the minimum and maximum compressor speeds at temperature, Tj.

The ARI test procedure specifies varying the compressor speed until the heat pump capacity matches the building load at 87 F. An alternative procedure described in reference 6 is used in this report. The performance at the intermediate speed for 87 F outdoors is specified and an interpolation procedure determines the temperature where the heat pump capacity matches the building load. This temperature is labeled N87. The following calculations are then made.

when $Tj \geq N87$ then,

$$EvssTj = EvssN87 + \left(\frac{E2ssT2 - EvssN87}{T2 - N87}\right) * (Tj - N87) \quad (6.10)$$

where,

T2 = temperature Tj at which Q2ssTj = BL(Tj)
EvssT2 = the electrical power input at maximum compressor speed at temperature T2

EvssTj is the electrical power input required by the unit at temperature Tj and some variable compressor speed between the minimum and maximum compressor speeds.

when $Tj < N87$ then,

$$EvssTj = EvssN87 + \left(\frac{E1ssT1 - EvssN87}{T1 - N87}\right) * (T1 - Tj) \quad (6.11)$$

where,

T1 = temperature Tj at which Q1ssTj = BL(Tj)

E1ssTj is the electrical power input at minimum compressor speed at temperature T1. Finally, expression for total load and energy use for each bin are estimated for use in Equation (6.1):

$$Q(Tj) = QvssTj * nj \quad (6.12)$$

$$E(Tj) = EvssTj * nj \quad (6.13)$$

CASE III

Case III corresponds to the circled area 3 on Figure 6.1. The unit operates continuously at maximum compressor speed. The capacity, Q2ssTj, for a specified outdoor temperature, Tj, is given by:

given by:

$$Q2ssTj = Q2ss82 + \left(\frac{Q2ss95 - Q2ss82}{95 - 82}\right) * (Tj - 82) \qquad (6.14)$$

A similar expression for the power, E2ssTj, for a particular temperature is also developed:

$$E2ssTj = E2ss82 + \left(\frac{E2ss95 - E2ss82}{95 - 82}\right) * (Tj - 82) \qquad (6.15)$$

The following expressions for Q(Tj) and E(Tj) are then used in Equation (6.1):

$$Q(Tj) = Q2ssTj * nj \qquad (6.16)$$

$$E(Tj) = E2ssTj * nj \qquad (6.17)$$

HSPF Calculation Procedure (Heat Pumps Only)

The input required for the HSPF calculations are shown in Table 6.4. The test conditions and methodology for the HSPF calculations are diagrammed in Figures 6.2. Capacity (in Btu/hr) and power consumption (in watts) data are required from four outdoor temperatures: 62F, 47F, 35F, and 17F; and three speeds: maximum, intermediate, and minimum speed. In addition, a degradation coefficient, compressor cut on temperature, and compressor cutoff temperature, must be specified for the unit. The capacity and power are estimated by the ORNL heat pump model[5] for the variable speed unit at each temperature. For a single speed heat pump, a degradation factor, three runs of the ORNL heat pump model at 17 F, 35 F, and 47 F, and compressor cutoff and cuton temperatures are required to obtain the HSPF for a heat pump[4]. With variable speed heat pumps, five runs must be made at three compressor speeds and four outdoor temperatures in addition to an estimate of the degradation coefficient and compressor cutoff and cut on temperatures. Figure 6.2 also shows the building load, which is estimated from the high speed heat pump capacity[1,3,6].

Table 6.4 - Input required for the variable speed HSPF calculation.

Input	Variable
Maximum Speed Capacity at 47 F	Q2ss47
Maximum Speed Capacity at 35 F	Q2ss35
Maximum Speed Capacity at 17 F	Q2ss17
Minimum Speed Capacity at 62 F	Q1ss62
Minimum Speed Capacity at 47 F	Q1ss47
Maximum Speed Power at 47 F	E2ss47
Maximum Speed Power at 35 F	E2ss35
Maximum Speed Power at 17 F	E2ss17
Minimum Speed Power at 62 F	E1ss62
Minimum Speed Power at 47 F	E1ss47
Compressor Cut Off Temperature	Toff
Compressor Turn On Temperature	Ton
Heating Degradation Cd	Cdh

The experimental test conditions for which data are required in the HSPF calculation are shown in Table 6.5.

Table 6.5 - Test Conditions used in HSPF Calculations

	Indoor Coil Air Entering		Outdoor Coil Air Entering	
Test	DB	WB	DB	WB
Q2ss47,COP2ss47	70	60	47	43
Q2ss35,COP2ss35	70	60	35	33
Q2ss17,COP2ss17	70	60	17	15
Q1ss62,COP1ss62	70	60	62	56.5
Qvss47,COP1ss47	70	60	47	43

The heating seasonal performance factor (HSPF) is found from the following equation:

$$\text{HSPF} = \frac{\Sigma\, nj * BL(Tj)}{3.413 * \left(\dfrac{\Sigma\, nj * X(Tj) * d(Tj) * E(Tj)}{PLF(X)}\right) + RH(Tj)} \qquad (6.18)$$

where,

RH(Tj) = supplementary resistance heat term at temperature Tj required in those cases where the heat pump automatically turns off (Tj<Ton) or when it is needed to meet the balance of the building heating requirements,

nj = number of heating hours in the jth temperature bin given in Table 6.6,

BL(Tj) = building load at temperature Tj,

d(Tj) = heat pump low temperature cut-out factor,

X(Tj) = heat pump heating load factor, and

PLF(X) = heat pump part load factor.

Table 6.6 - Distribution of heating hours in temperature bins for use in HSPF Calculation (Region IV).

Bin Number j	Bin Temperature Tj(F)	Bin Hours nj
1	62	297
2	57	250
3	52	232
4	47	209
5	42	225
6	37	245
7	32	283
8	27	196
9	22	124
10	17	81
11	12	58
12	7	29
13	2	13
14	-3	4
15	-8	2

The quantities BL(Tj), d(Tj), X(Tj), PLF(X) and RH(Tj) are defined by the following equations:

$$BL(Tj) = \frac{(65 - Tj)}{(65 - 5)} * 0.77 * DHR \qquad (6.19)$$

$$d(Tj) = 0; \quad Tj \leq Toff \quad \text{or} \quad \frac{Q(Tj)}{3.413 * E(Tj)} \geq 1 \tag{6.20}$$

$$d(Tj) = 0.5; \quad Toff < Tj < Ton \quad \text{and} \quad \frac{Q(Tj)}{3.413 * E(Tj)} \geq 1 \tag{6.21}$$

$$d(Tj) = 1.0; \quad Tj > Ton \quad \text{and} \quad \frac{Q(Tj)}{3.413 * E(Tj)} \geq 1 \tag{6.22}$$

$$X(Tj) = \begin{cases} \frac{BL(Tj)}{Q(Tj)}; & Q(Tj) > BL(Tj) \\ 1; & Q(Tj) \leq BL(Tj) \end{cases} \tag{6.23}$$

$$PLF(X) = 1 - Cdh * (1 - X(Tj)) \tag{6.24}$$

$$RH(Tj) = \frac{[BL(Tj) - Q(Tj)] * X(Tj) * d(Tj) * nj}{3.413} \tag{6.25}$$

where,

DHR = Standard Design Heating Requirement
Cdh = heating degradation coefficient

As with the single speed test procedure, the standard design heating requirement is determined from the steady state capacity of the heat pump at 47 F rounded off to the nearest value shown in Table 6.6.

Table 6.6 Standard Design Heating Requirements (Btu/hr)

5,000	25,000	50,000	90,000
10,000	30,000	60,000	100,000
15,000	35,000	70,000	110,000
20,000	40,000	80,000	130,000

In using the above equations to calculate HSPF, the heat pump capacity Q(Tj), and the power E(Tj) are determined using one of three cases, similar to the calculatin for cooling SEER. The particular case depends on both the speed of the heat pump and the building load.

CASE 1

Units operating at minimum compressor speed for which the building heating load, BL(Tj),is less than or equal to the heating capacity, Q(Tj), use the following expressions:

$$E(Tj) = \frac{E1ssTj * X1(Tj) * d(Tj) * nj}{PLF} \quad (6.26)$$

$$RH(Tj) = \frac{BL(Tj) * [1 - d(Tj)] * nj}{3.413} \quad (6.27)$$

$$X1(Tj) = \frac{BL(Tj)}{Q1ssTj} \quad (6.28)$$

$$PLF = 1 - Cdh\ (1 - X1(Tj)) \quad (6.29)$$

$$d(Tj) = \begin{cases} 0; & Tj \leq Toff \\ 0.5; & Toff < Tj \leq Ton \\ 1; & Tj > Ton \end{cases} \quad (6.30)$$

CASE 2

This case is used when the heat pump varies its speed to match the building load.

$$QvssTj = BL(Tj) \quad (6.31)$$

$$E(Tj) = EvssTj * nj \quad (6.32)$$

$$Q(Tj) = QvssTj * nj \quad (6.33)$$

$$EvssTj = E2ssT4 - \left(\frac{E2ssT4 - E1ssT3}{T4 - T3}\right) * (T4 - Tj) \quad (6.34)$$

where,

T3 = temperature at which Q1ssTj = BL(Tj) as shown in Figure 6.2.

T4 = temperature at which Q2ssTj = BL(Tj)

E1ssT3 = electrical power input at temperature T3 (low speed)

E2ssT4 = electrical power input at temp T4 (high speed)

CASE 3

When a unit operates continuously at maximum compressor speed at an outdoor temperature, Tj, the following expressions must be evaluated:

$$E(Tj) = E2ssTj * X2(Tj) * d(Tj) * nj \qquad (6.35)$$

$$RH(Tj) = \frac{[BL(Tj) - Q2ssTj * X2(Tj) * d(Tj)] * nj}{3.413} \qquad (6.36)$$

$$X2(Tj) = 1.0 \qquad (6.37)$$

$$d(Tj) \begin{cases} 0.0; & Tj \le Toff \text{ or } \dfrac{Q2ssTj}{3.413 * E2ssTj} \le 1 \\ 0.5; & Toff < Tj \le Ton \text{ and } \dfrac{Q2ssTj}{3.413 * E2ssTj} \le 1 \\ 1.0; & Tj \ge Ton \text{ and } \dfrac{Q2ssTj}{3.413 * E2ssTj} \ge 1 \end{cases} \qquad (6.38)$$

In each of the above cases, the heating capacity and power input are calculated by the following equations:

$$Q1ssTj = Q1ss47 + \frac{Q1ss62 - Q1ss47}{62 - 47} * (Tj - 47) \qquad (6.39)$$

$$E1ssTj = E1ss47 + \frac{E1ss62 - E1ss47}{62 - 47} * (Tj - 47) \qquad (6.40)$$

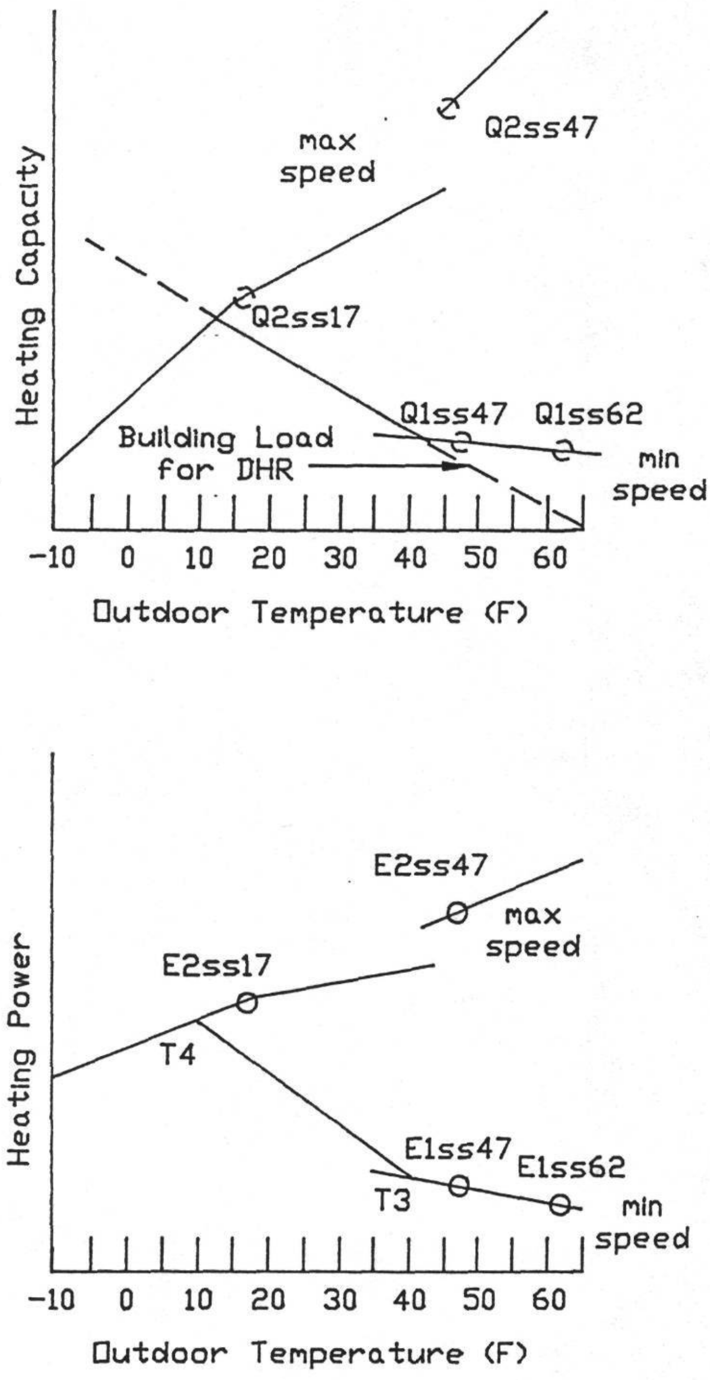

Figure 6.2 Diagram of points used in the HSPF calculation procedure

When Tj >= 45 or Tj <= 17 then:

$$Q2ssTj = Q2ss17 + \frac{Q2ss47 - Q2ss17}{47 - 17} * (Tj - 17) \quad (6.41)$$

$$E2ssTj = E2ss17 + \frac{E2ss47 - E2ss17}{47 - 17} * (Tj - 17) \quad (6.42)$$

When 17 < Tj < 45 then:

$$Q2ssTj = Q2ss17 + \frac{Q2def35 - Q2ss17}{35 - 17} * (Tj - 17) \quad (6.43)$$

$$E2ssTj = E2ss17 + \frac{E2def35 - E2ss17}{35 - 17} * (Tj - 17) \quad (6.44)$$

To account for frosting/defrosting effects on the heat pump at the 35 F test condition and for installation of a demand defrost system, two corrections are made to the steady state 35 F capacity values calculated by the ORNL model. The correction for frosting/defrosting results in a 10% reduction in capacity (a 0.9 correction factor). This correction was developed from several runs of the Science Applications Incoporated's (SAI) seasonal performance model of heat pumps[7]. The 0.9 correction is the same as was used for single speed heat pumps[5]. The correction factor for demand defrost increases the capacity by 7%. This is the value specified in the DOE test procedure[2]. Thus, the corrected capacity at 35 F, Q2def35, is given as:

$$Q2def35 = Q2ss35 * 1.07 * 0.9 \quad (6.45)$$

Power consumption, E2def35, at 35 F is also adjusted down by 1% for frosting/defrosting effects. This procedure is the same that was used for single-speed heat pumps[5]:

$$E2def35 = E2ss35 * 0.99 \quad (6.46)$$

References

1. "Energy Conservation Program for Consumer Products: Proposed Rulemaking and Public Hearing Regarding Test Procedures for Central Air Conditioners, Including Heat Pumps", Docket. No. CAS-RM-79-102, Department of Energy, May 1986.

2. "Test Procedure for Central Air Conditioners, Including Heat Pumps", Federal Register, Dec. 27, 1979, pp. 76700-76723.

3. "Standard for Unitary Air-Conditioning and Air-Source Heat Pump Equipment", ARI Standard 210/240-84, Air Conditioning and Refrigeration Institute, Arlington, VA, 1984.

4. S.K. Fischer and C.K. Rice, "A Steady-State Computer Design Model for Air-to-Air Heat Pumps", ORNL/CON-80, Oak Ridge National Laboratory, Dec. 1981.

5. D. L. O'Neal, et al, "An Analysis of Efficiency Improvements in Residential Sized Heat Pumps", ESL/85-24, Energy Systems Laboratory, Texas A & M University, May 1986.

6. D.G. Erbs, C.E. Bullock, R.J. Voorhis, "New Testing and Rating Procedures for Seasonal Performance of Heat Pumps with Variable Speed Compressors", ASHRAE Transactions, v. 92, pt. 2.

7. "User's Manual for Heat Pump Seasonal Performance Model (SPM) With Selected Parametric Examples", Science Applications, Inc., June 1982.

CHAPTER 7

VARIABLE SPEED HEAT PUMPS AND CENTRAL AIR CONDITIONER DESIGNS

The final designs and efficiency estimates for heat pumps and central air conditioners utilizing variable speed and other advanced technology options are presented below. The general design guidelines are first discussed. The final designs are presented for heat pumps then central air conditioners.

Design Guidelines

Five U.S.(Copeland and Tecumseh) and Japanese (Hitachi, Mitsubishi, and Sanyo) compressor manufacturers were contacted and asked to provide us with detailed performance data on the variable speed compressors that they are currently manufacturing or are planning to manufacture soon. Of the five manufacturers, only one was willing to provide us with variable speed performance data. We received a set of compressor maps for one compressor at five speeds (30, 45, 60, 75, and 90 hz). The nominal performance of this compressor at the standard rating conditions was shown in Table 5.1. The compressor data was the same review data the compressor manufacturer was sending to heat pump and air conditioner manufacturers.

Because we only received one set of compressor data from one manufacturer, we chose to design all the variable speed heat pumps and central air conditioners around this one compressor. The larger heat pumps and air conditioners would use the same performance maps, except with a larger compressor displacement.

The overall design philosophy to designing the variable speed heat pumps and air conditioners was similar to the single speed and two speed units. A base system was designed. For the variable speed units, the base system already had larger heat exchangers, higher fin densities, better circuiting, demand defrost control systems (in heat pumps), and higher fan/motor efficiencies (Table 7.1 and 7.2). Because variable speed compressors are probably going to be used by manufacturers to push the efficiency of air conditioners and heat pumps, it was felt the base unit for variable speeds should already have some of the better design features incorporated into it. Air flow on both the indoor and outdoor coils was fixed to produce optimum SEER in the units.

The indoor coil on split systems was assumed to be a part of a fan coil unit for both the central air conditioners and heat pumps. This assumption differs from the single speed air conditioners analyses where 365 watts/1000 cfm was used for the indoor fan power calculation as specified in the test procedure[1]. If variable speed units are going to be used to evaluate the maximum efficiency achievable, then they should have matched indoor fan coil units with high efficiency

Table 7.1 - Hardware data on baseline variable speed heatpump systems

****
** Baseline ***
** Variable Speed ***
Heat Pump Systems
****

MODEL	3 Ton Units Split	3 Ton Units Package	5 Ton Units Split	5 Ton Units Package
DESIGN OPTIONS	1A,1C,1D,3 4,7	1A,1C,1D,3 4,7	1A,1C,1D,3 4,7	1A,1C,1D,3 4,7
SUPERHEAT	10 CL/ 5 HT	10 CL/ 5 HT	10 CL/ 5 HT	10 CL/ 5 HT
SUBCOOL	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT
COMPRESSOR	AS	AS	AS	AS
EER @ 60 hz	9.00	9.00	9.00	9.00
OUTDOOR COIL				
Frontal Area (sf)	20.0	20.0	25.0	25.0
# of Rows	2	2	2	2
# of Parallel Ckts	4	4	4	4
Fins/Inch	17	17	17	17
Fin Thickness (in)	0.0052	0.0052	0.0052	0.0052
O.D. of Tubes	0.3880	0.3880	0.3880	0.3880
I.D. of Tubes	0.3620	0.3620	0.3620	0.3620
Vert Space (in)	1.2500	1.2500	1.2500	1.2500
Hor Space (in)	1.0830	1.0830	1.0830	1.0830
# of Return Bends	52	52	52	52
Refrig. Control	TXV	TXV	TXV	TXV
Fin Design	LOUVERED	LOUVERED	LOUVERED	LOUVERED
INDOOR COIL				
Frontal Area (sf)	4.5	4.5	6.0	6.0
# of Rows	4	4	4	4
# of Parallel Ckts	6	6	6	6
Fins/Inch	13	13	13	13
Fin Thickness (in)	0.0052	0.0052	0.0052	0.0052
O.D. of Tubes	0.3250	0.3250	0.3250	0.3250
I.D. of Tubes	0.3030	0.3030	0.3030	0.3030
Vert Space (in)	1.0000	1.0000	1.0000	1.0000
Hor Space (in)	0.6250	0.6250	0.6250	0.6250
# of Return Bends	72	72	72	72
Refrig. Control	TXV	TXV	TXV	TXV
Fin Design	WAVY	WAVY	WAVY	WAVY
OUTDOOR FAN				
CFM	2600	2600	4200	4200
Fan & Motor eff.	0.25	0.23	0.25	0.23
INDOOR FAN				
CFM	800	800	1350	1350
Fan & Motor eff.	0.35	0.31	0.35	0.31
REF. LINES (6 ft)				
Liquid Line O.D.	3/8	3/8	3/8	3/8
Suction Line O.D.	7/8	7/8	1 1/8	1 1/8

Table 7.2 - Hardware data on baseline variable speed A.C. systems

```
********************
**   Baseline    ***
** Variable Speed ***
**  A.C.  Systems  **
********************
```

MODEL	3 Ton Units Split	3 Ton Units Package	5 Ton Units Split	5 Ton Units Package
DESIGN OPTIONS	1A,1C,1D,3 7	1A,1C,1D,3 7	1A,1C,1D,3 7	1A,1C,1D,3 7
SUPERHEAT	10	10	10	10
SUBCOOL	15	15	15	15
COMPRESSOR	AS	AS	AS	AS
EER @ 60 hz	9.00	9.00	9.00	9.00
OUTDOOR COIL				
Frontal Area (sf)	20.0	20.0	25.0	25.0
# of Rows	2	2	2	2
# of Parallel Ckts	4	4	4	4
Fins/Inch	17	17	17	17
Fin Thickness (in)	0.0052	0.0052	0.0052	0.0052
O.D. of Tubes	0.3880	0.3880	0.3880	0.3880
I.D. of Tubes	0.3620	0.3620	0.3620	0.3620
Vert Space (in)	1.2500	1.2500	1.2500	1.2500
Hor Space (in)	1.0830	1.0830	1.0830	1.0830
# of Return Bends	52	52	52	52
Refrig. Control	TXV	TXV	TXV	TXV
Fin Design	LOUVERED	LOUVERED	LOUVERED	LOUVERED
INDOOR COIL				
Frontal Area (sf)	4.5	4.5	6.0	6.0
# of Rows	4	4	4	4
# of Parallel Ckts	6	6	6	6
Fins/Inch	13	13	13	13
Fin Thickness (in)	0.0052	0.0052	0.0052	0.0052
O.D. of Tubes	0.3250	0.3250	0.3250	0.3250
I.D. of Tubes	0.3030	0.3030	0.3030	0.3030
Vert Space (in)	1.0000	1.0000	1.0000	1.0000
Hor Space (in)	0.6250	0.6250	0.6250	0.6250
# of Return Bends	72	72	72	72
Refrig. Control	TXV	TXV	TXV	TXV
Fin Design	WAVY	WAVY	WAVY	WAVY
OUTDOOR FAN				
CFM	2600	2600	4200	4200
Fan & Motor eff.	0.25	0.23	0.25	0.23
INDOOR FAN				
CFM	800	800	1350	1350
Fan & Motor eff.	0.35	0.31	0.35	0.31
REF. LINES (6 ft)				
Liquid Line O.D.	3/8	3/8	3/8	3/8
Suction Line O.D.	7/8	7/8	1 1/8	1 1/8

fan/motor combinations. A review of the ARI directory indicates that the highest efficiency units (typically two speed) have matched fan coils[2].

Other guidelines (See Table 4.1) used in the conventional designs were also used in designing the variable speed units. For instance, all the variable speed heat pumps and air conditioners had degradation coefficients of 0.15 and 0.10, respectively. The variable speed test procedure outlined in Chapter 6 was used to estimate the performance of all units.

The performance of the base variable speed heat pumps and air conditioners is shown in Table 7.3 and 7.4, respectively. Even with the relatively low compressor efficiencies of the compressor we used, the calculated SEERs and HSPFs are quite impressive. The base three ton variable speed split system heat pump has an estimated SEER of 13.67, which is 9% higher than the efficiency of the best 3 ton heat pump on the market in 1986[2]. The base three ton variable speed central air conditioner has a SEER of 13.80, which is about 8% lower than the efficiency of the best 3 ton air conditioner on the market in 1986[2].

Heat Pumps

Five variable speed designs were developed for each class of heat pumps. The classes are discussed in the same order as the conventionally designed units: 3 ton split, 3 ton package, 5 ton split, and 5 ton package systems.

<u>3 Ton Split Systems</u>

Tables 7.5 and 7.6 provide the detailed hardware and performance data, respectively, for the 3 ton split system heat pumps. Each unit has an alpha-numeric designation. The first two numbers specify the capacity, the first letter indicates it's a variable speed units, and the last letter indicates the model within the variable speed line. Model 36VA is the base unit. The models are arranged in increasing SEER from left to right in the tables. The hardware descriptions (Table 7.5) are in the same format as the conventional designs in Chapter 4.

The first improved design (36VB) has larger heat exchangers in both the evaporator and condenser. Unit 36VC has a compressor/motor efficiency that is 10% better than the one used in the base unit. As mentioned in Chapter 5, the variable speed compressor's steady state EERs are about 15 to 20% below comparable single-speed compressors. Our contacts with the manufacturer that provided the data indicated that they expected some improvements in performance as they refined the technology. Unit 36VD has a 15% better compressor than used in the base plus an electronic expansion valve. Finally, unit 36VE uses a scroll compressor whose efficiency is assumed to be 20% better than the compressor in 36VA. This unit provides a SEER of 17.08 and HSPF of 9.49.

Table 7.3 - Performance data on baseline variable speed heatpump systems

```
********************
**    Baseline    **
** Variable Speed **
**   Heat Pump    **
********************
```

COOLING MODE		3 Ton Units Split	3 Ton Units Package	5 Ton Units Split	5 Ton Units Package
Max Speed 95F					
	EER	8.88	8.90	8.14	8.12
	CAPACITY	36050.00	36030.00	60090.00	60090.00
Max Speed 82F					
	EER	10.20	10.23	9.27	9.25
	CAPACITY	38540.00	38530.00	64400.00	64420.00
Min Speed 82F					
	EER	13.80	13.88	12.46	12.23
	CAPACITY	18680.00	18670.00	32260.00	32020.00
Min Speed 67F					
	EER	17.74	17.85	15.74	15.42
	CAPACITY	20440.00	20440.00	35290.00	35050.00
Int Speed 87F					
	EER	11.82	11.86	10.71	10.64
	CAPACITY	30800.00	30790.00	52120.00	51990.00
	SEER	13.67	13.74	12.10	11.96

HEATING MODE		3 Ton Units Split	3 Ton Units Package	5 Ton Units Split	5 Ton Units Package
Max Speed 47F					
	COP	2.69	2.70	2.50	2.49
	CAPACITY	35500.00	35220.00	56980.00	56820.00
Max Speed 35F					
	COP	2.49	2.50	2.34	2.33
	CAPACITY	29280.00	29040.00	47360.00	47350.00
Max Speed 17F					
	COP	2.14	2.15	2.06	2.05
	CAPACITY	20910.00	20770.00	34850.00	34860.00
Min Speed 62F					
	COP	4.17	4.22	3.89	3.87
	CAPACITY	20120.00	19990.00	36010.00	35990.00
Min Speed 47F					
	COP	3.41	3.44	3.25	3.22
	CAPACITY	15620.00	15530.00	28530.00	28540.00
	HSPF	8.24	8.28	7.95	7.90

Table 7.4 - Performance data on baseline variable speed A.C. systems

```
********************
**    Baseline    **
** Variable Speed **
** Air Conditioner**
********************
```

COOLING MODE		3 Ton Units Split	3 Ton Units Package	5 Ton Units Split	5 Ton Units Package
Max Speed 95F					
	EER	8.88	8.90	8.14	8.12
	CAPACITY	36050.00	36030.00	60090.00	60090.00
Max Speed 82F					
	EER	10.20	10.23	9.27	9.25
	CAPACITY	38540.00	38530.00	64400.00	64420.00
Min Speed 82F					
	EER	13.80	13.88	12.46	12.23
	CAPACITY	18680.00	18670.00	32260.00	32020.00
Min Speed 67F					
	EER	17.74	17.85	15.74	15.42
	CAPACITY	20440.00	20440.00	35290.00	35050.00
Int Speed 87F					
	EER	11.82	11.86	10.71	10.64
	CAPACITY	30800.00	30790.00	52120.00	51990.00
	SEER	13.80	13.87	12.22	12.08

Table 7.5 - Hardware data on 3 ton split variable speed heat pumps

3 Ton Split Variable Speed Systems

MODEL	36VA	36VB	36VC	36VD	36VE
DESIGN OPTIONS	1A,1C,1D,3 4,7	1A,1C,1D,3 4,7	1A,1C,1D,3 4,5,7	1A,1C,1D,3 4,5,7,10	1A,1C,1D,3 4,5,7,8,10
SUPERHEAT	10 CL/ 5 HT	10 CL/ 5 HT	10 CL/ 5 HT	10 CL/ 5 HT	10 CL/ 5 HT
SUBCOOL	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT
COMPRESSOR	AS	AS	AS	AS	AS
EER @ 60 hz	9.00	9.00	9.90	10.35	10.80
OUTDOOR COIL					
Frontal Area (sf)	20.0	25.0	25.0	25.0	25.0
# of Rows	2	2	2	2	2
# of Parallel Ckts	4	4	4	4	4
Fins/Inch	17	17	17	17	17
Fin Thickness (in)	0.0052	0.0052	0.0052	0.0052	0.0052
O.D. of Tubes	0.3880	0.3880	0.3880	0.3880	0.3880
I.D. of Tubes	0.3620	0.3620	0.3620	0.3620	0.3620
Vert Space (in)	1.2500	1.2500	1.2500	1.2500	1.2500
Hor Space (in)	1.0830	1.0830	1.0830	1.0830	1.0830
# of Return Bends	52	52	52	52	52
Refrig. Control	TXV	TXV	EXV	EXV	EXV
Fin Design	LOUVERED	LOUVERED	LOUVERED	LOUVERED	LOUVERED
INDOOR COIL					
Frontal Area (sf)	4.5	5.5	5.5	5.5	5.5
# of Rows	4	4	4	4	4
# of Parallel Ckts	6	6	6	6	6
Fins/Inch	13	13	13	13	13
Fin Thickness (in)	0.0052	0.0052	0.0052	0.0052	0.0052
O.D. of Tubes	0.3250	0.3250	0.3250	0.3250	0.3250
I.D. of Tubes	0.3030	0.3030	0.3030	0.3030	0.3030
Vert Space (in)	1.0000	1.0000	1.0000	1.0000	1.0000
Hor Space (in)	0.6250	0.6250	0.6250	0.6250	0.6250
# of Return Bends	72	72	72	72	72
Refrig. Control	TXV	TXV	EXV	EXV	EXV
Fin Design	WAVY	WAVY	WAVY	WAVY	WAVY
OUTDOOR FAN					
CFM	2600	2800	2800	2600	2600
Fan & Motor eff.	0.25	0.25	0.25	0.25	0.25
INDOOR FAN					
CFM	800	700	700	700	700
Fan & Motor eff.	0.35	0.35	0.35	0.35	0.35
REF. LINES (6 ft)					
Liquid Line O.D.	3/8	3/8	3/8	3/8	3/8
Suction Line O.D.	7/8	7/8	7/8	7/8	7/8

Table 7.6 - Performance data on 3 ton split variable speed heat pumps

3 TON SPLIT VARIABLE SPEED HEAT PUMPS

COOLING MODE		36VA	36VB	36VC	36VD	36VE
Max Speed 95F						
	EER	8.88	9.06	10.05	10.57	11.19
	CAPACITY	36050.00	36030.00	36040.00	35050.00	36050.00
Max Speed 82F						
	EER	10.20	10.42	11.55	12.14	12.88
	CAPACITY	38540.00	38620.00	38630.00	38620.00	38620.00
Min Speed 82F						
	EER	13.80	14.35	15.75	16.56	17.41
	CAPACITY	18680.00	19020.00	18980.00	19050.00	19020.00
Min Speed 67F						
	EER	17.74	18.53	20.19	21.31	22.36
	CAPACITY	20440.00	20760.00	20720.00	20800.00	20760.00
Int Speed 87F						
	EER	11.82	12.17	13.40	14.10	14.96
	CAPACITY	30800.00	31080.00	31050.00	31100.00	31050.00
	SEER	13.67	14.02	15.42	16.20	17.08

HEATING MODE		36VA	36VB	36VC	36VD	36VE
Max Speed 47F						
	COP	2.69	2.65	2.88	3.01	3.16
	CAPACITY	35500.00	35480.00	34620.00	33940.00	33570.00
Max Speed 35F						
	COP	2.49	2.47	2.68	2.79	2.92
	CAPACITY	29280.00	29320.00	28530.00	28060.00	27630.00
Max Speed 17F						
	COP	2.14	2.16	2.31	2.41	2.51
	CAPACITY	20910.00	20980.00	20330.00	19980.00	19630.00
Min Speed 62F						
	COP	4.17	4.27	4.63	4.85	5.08
	CAPACITY	20120.00	20400.00	20070.00	19910.00	19700.00
Min Speed 47F						
	COP	3.41	3.52	3.79	3.98	4.14
	CAPACITY	15620.00	15870.00	15560.00	15410.00	15220.00
	HSPF	8.24	8.42	8.89	9.22	9.49

3 Ton Package Systems

Tables 7.7 and 7.8 list the hardware and performance data for the 3 ton variable speed package systems. Unit 36VPA is the baseline unit, while unit 36VPE is the best advanced technology unit. The design options are similar to those used for the 3 ton split systems. The best unit had an SEER of 16.96 and a HSPF of 9.47. The SEER value is a 66% improvement in efficiency over the best available 3 ton package unit on the market in 1986[2].

5 Ton Split Systems

Tables 7.9 and 7.10 list the 5 ton variable speed split system units. The best performing unit has a SEER of 15.25. This is about 22% above the best unit on the market in 1986[3]. As with the conventionally designed unit, the maximum SEER for 5 ton systems is less than 3 ton systems because of the restrictions on heat exchanger sizes.

5 Ton Package Systems

Tables 7.11 and 7.12 list the units in the 5 ton package line. Unit 60VPA is the baseline system and 60VPE is the best unit.

Table 7.7 - Hardware data on 3 ton package variable speed heat pumps

** 3 Ton Package ** ** Variable Speed ** ** Systems **					
MODEL	36VPA	36VPB	36VPC	36VPD	36VPE
DESIGN OPTIONS	1A,1C,1D,3 4,7	1A,1C,1D,3 4,7	1A,1C,1D,3 4,5,7	1A,1C,1D,3 4,5,7,10	1A,1C,1D,3 4,5,7,8,10
SUPERHEAT	10 CL/ 5 HT	10 CL/ 5 HT	10 CL/ 5 HT	10 CL/ 5 HT	10 CL/ 5 HT
SUBCOOL	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT
COMPRESSOR	AS	AS	AS	AS	AS
EER @ 60 hz	9.00	9.00	9.90	10.35	10.80
OUTDOOR COIL					
Frontal Area (sf)	20.0	25.0	25.0	25.0	25.0
# of Rows	2	2	2	2	2
# of Parallel Ckts	4	4	4	4	4
Fins/Inch	17	17	17	17	17
Fin Thickness (in)	0.0052	0.0052	0.0052	0.0052	0.0052
O.D. of Tubes	0.3880	0.3880	0.3880	0.3880	0.3880
I.D. of Tubes	0.3620	0.3620	0.3620	0.3620	0.3620
Vert Space (in)	1.2500	1.2500	1.2500	1.2500	1.2500
Hor Space (in)	1.0830	1.0830	1.0830	1.0830	1.0830
# of Return Bends	52	52	52	52	52
Refrig. Control	TXV	TXV	EXV	EXV	EXV
Fin Design	LOUVERED	LOUVERED	LOUVERED	LOUVERED	LOUVERED
INDOOR COIL					
Frontal Area (sf)	4.5	5.5	5.5	5.5	5.5
# of Rows	4	4	4	4	4
# of Parallel Ckts	6	6	6	6	6
Fins/Inch	13	13	13	13	13
Fin Thickness (in)	0.0052	0.0052	0.0052	0.0052	0.0052
O.D. of Tubes	0.3250	0.3250	0.3250	0.3250	0.3250
I.D. of Tubes	0.3030	0.3030	0.3030	0.3030	0.3030
Vert Space (in)	1.0000	1.0000	1.0000	1.0000	1.0000
Hor Space (in)	0.6250	0.6250	0.6250	0.6250	0.6250
# of Return Bends	72	72	72	72	72
Refrig. Control	TXV	TXV	EXV	EXV	EXV
Fin Design	WAVY	WAVY	WAVY	WAVY	WAVY
OUTDOOR FAN					
CFM	2600	2600	2600	2600	2600
Fan & Motor eff.	0.23	0.23	0.23	0.23	0.23
INDOOR FAN					
CFM	800	700	700	700	700
Fan & Motor eff.	0.31	0.31	0.31	0.31	0.31
REF. LINES (6 ft)					
Liquid Line O.D.	3/8	3/8	3/8	3/8	3/8
Suction Line O.D.	7/8	7/8	7/8	7/8	7/8

Table 7.8 - Performance data on 3 ton package variable speed heat pumps

3 TON PACKAGE VARIABLE SPEED HEAT PUMPS

COOLING MODE		36VPA	36VPB	36VPC	36VPD	36VPE
Max Speed 95F						
	EER	8.90	8.95	9.94	10.55	11.16
	CAPACITY	36030.00	36040.00	36040.00	35960.00	36040.00
Max Speed 82F						
	EER	10.23	10.33	11.44	12.11	12.84
	CAPACITY	38530.00	38630.00	38620.00	38570.00	38620.00
Min Speed 82F						
	EER	13.88	14.35	15.68	16.44	17.28
	CAPACITY	18670.00	19130.00	19070.00	19000.00	19020.00
Min Speed 67F						
	EER	17.85	18.53	20.18	21.13	22.16
	CAPACITY	20440.00	20880.00	20820.00	20750.00	20760.00
Int Speed 87F						
	EER	11.86	12.09	13.31	14.06	14.90
	CAPACITY	30790.00	31170.00	31120.00	31050.00	31070.00
	SEER	13.74	13.94	15.30	16.09	16.96

HEATING MODE		36VPA	36VPB	36VPC	36VPD	36VPE
Max Speed 47F						
	COP	2.70	2.64	2.87	3.00	3.14
	CAPACITY	35220.00	35430.00	34520.00	34060.00	33560.00
Max Speed 35F						
	COP	2.50	2.47	2.67	2.80	2.93
	CAPACITY	29040.00	29310.00	28490.00	28040.00	27690.00
Max Speed 17F						
	COP	2.15	2.16	2.31	2.40	2.50
	CAPACITY	20770.00	21020.00	20350.00	19970.00	19680.00
Min Speed 62F						
	COP	4.22	4.26	4.62	4.83	5.05
	CAPACITY	19990.00	20460.00	20110.00	19910.00	19780.00
Min Speed 47F						
	COP	3.44	3.52	3.79	3.95	4.12
	CAPACITY	15530.00	15930.00	15610.00	15420.00	15286.00
	HSPF	8.28	8.43	8.90	9.13	9.47

Table 7.9 - Hardware data on 5 ton split variable speed heat pumps

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********************
** 5 Ton Split **
** Variable Speed **
** Systems **
********************
```

MODEL	60VA	60VB	60VC	60VD	60VE
DESIGN OPTIONS	1A,1C,1D,3 4,7	1A,1C,1D,3 4,7	1A,1C,1D,3 4,5,7	1A,1C,1D,3 4,5,7,10	1A,1C,1D,3 4,5,7,8,10
SUPERHEAT	10 CL/ 5 HT	10 CL/ 5 HT	10 CL/ 5 HT	10 CL/ 5 HT	10 CL/ 5 HT
SUBCOOL	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT
COMPRESSOR	AS	AS	AS	AS	AS
EER @ 60 hz	9.00	9.00	9.90	10.35	10.80
OUTDOOR COIL					
Frontal Area (sf)	25.0	30.0	30.0	30.0	30.0
# of Rows	2	2	2	2	2
# of Parallel Ckts	4	4	4	4	4
Fins/Inch	17	17	17	17	17
Fin Thickness (in)	0.0052	0.0052	0.0052	0.0052	0.0052
O.D. of Tubes	0.3880	0.3880	0.3880	0.3880	0.3880
I.D. of Tubes	0.3620	0.3620	0.3620	0.3620	0.3620
Vert Space (in)	1.2500	1.2500	1.2500	1.2500	1.2500
Hor Space (in)	1.0830	1.0830	1.0830	1.0830	1.0830
# of Return Bends	52	52	52	52	52
Refrig. Control	TXV	TXV	EXV	EXV	EXV
Fin Design	LOUVERED	LOUVERED	LOUVERED	LOUVERED	LOUVERED
INDOOR COIL					
Frontal Area (sf)	6.0	8.0	8.0	8.0	8.0
# of Rows	4	4	4	4	4
# of Parallel Ckts	6	6	6	6	6
Fins/Inch	13	13	13	13	13
Fin Thickness (in)	0.0052	0.0052	0.0052	0.0052	0.0052
O.D. of Tubes	0.3250	0.3250	0.3250	0.3250	0.3250
I.D. of Tubes	0.3030	0.3030	0.3030	0.3030	0.3030
Vert Space (in)	1.0000	1.0000	1.0000	1.0000	1.0000
Hor Space (in)	0.6250	0.6250	0.6250	0.6250	0.6250
# of Return Bends	72	72	72	72	72
Refrig. Control	TXV	TXV	EXV	EXV	EXV
Fin Design	WAVY	WAVY	WAVY	WAVY	WAVY
OUTDOOR FAN					
CFM	4200	3900	4200	3600	3600
Fan & Motor eff.	0.25	0.25	0.25	0.25	0.25
INDOOR FAN					
CFM	1350	1350	1350	1350	1200
Fan & Motor eff.	0.35	0.35	0.35	0.35	0.35
REF. LINES (6 ft)					
Liquid Line O.D.	3/8	3/8	3/8	3/8	3/8
Suction Line O.D.	1 1/8	1 1/8	1 1/8	1 1/8	1 1/8

Table 7.10 - Performance data on 5 ton split variable speed heat pumps

5 TON SPLIT VARIABLE SPEED HEAT PUMPS

COOLING MODE		60VA	60VB	60VC	60VD	60VE
Max Speed 95F						
	EER	8.14	8.50	9.47	9.81	10.20
	CAPACITY	60090.00	60060.00	60050.00	59920.00	60000.00
Max Speed 82F						
	EER	9.27	9.72	10.87	11.20	11.57
	CAPACITY	64400.00	64460.00	64530.00	64170.00	64010.00
Min Speed 82F						
	EER	12.46	13.11	14.17	14.95	16.11
	CAPACITY	32260.00	31720.00	31490.00	31750.00	32900.00
Min Speed 67F						
	EER	15.74	16.66	17.87	18.89	20.45
	CAPACITY	35290.00	34690.00	34460.00	34710.00	36000.00
Int Speed 87F						
	EER	10.71	11.29	12.43	12.94	13.52
	CAPACITY	52120.00	51870.00	51770.00	51750.00	52290.00
	SEER	12.10	12.84	13.98	14.64	15.38

HEATING MODE		60VA	60VB	60VC	60VD	60VE
Max Speed 47F						
	COP	2.50	2.62	2.84	2.93	2.95
	CAPACITY	56980.00	55280.00	53870.00	52910.00	52640.00
Max Speed 35F						
	COP	2.34	2.44	2.62	2.71	2.75
	CAPACITY	47360.00	45870.00	44700.00	43650.00	43520.00
Max Speed 17F						
	COP	2.06	2.12	2.26	2.34	2.40
	CAPACITY	34850.00	33640.00	32570.00	31840.00	31770.00
Min Speed 62F						
	COP	3.89	4.16	4.45	4.65	4.77
	CAPACITY	36010.00	34890.00	34430.00	34050.00	34600.00
Min Speed 47F						
	COP	3.25	3.43	3.67	3.83	3.99
	CAPACITY	28530.00	27560.00	27050.00	26770.00	27210.00
	HSPF	7.95	8.18	8.87	9.17	9.52

Table 7.11 - Hardware data on 5 ton package variable speed heat pumps

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*******************
** 5 Ton Package **
** Variable Speed **
**    Systems    **
*******************
```

MODEL	60VPA	60VPB	60VPC	60VPD	60VPE
DESIGN OPTIONS	1A,1C,1D,3 4,7	1A,1C,1D,3 4,7	1A,1C,1D,3 4,5,7	1A,1C,1D,3 4,5,7,10	1A,1C,1D,3 4,5,7,8,10
SUPERHEAT	10 CL/ 5 HT	10 CL/ 5 HT	10 CL/ 5 HT	10 CL/ 5 HT	10 CL/ 5 HT
SUBCOOL	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT	15 CL/10 HT
COMPRESSOR	AS	AS	AS	AS	AS
EER @ 60 hz	9.00	9.00	9.90	10.35	10.80
OUTDOOR COIL					
Frontal Area (sf)	25.0	30.0	30.0	30.0	30.0
# of Rows	2	2	2	2	2
# of Parallel Ckts	4	4	4	4	4
Fins/Inch	17	17	17	17	17
Fin Thickness (in)	0.0052	0.0052	0.0052	0.0052	0.0052
O.D. of Tubes	0.3880	0.3880	0.3880	0.3880	0.3880
I.D. of Tubes	0.3620	0.3620	0.3620	0.3620	0.3620
Vert Space (in)	1.2500	1.2500	1.2500	1.2500	1.2500
Hor Space (in)	1.0830	1.0830	1.0830	1.0830	1.0830
# of Return Bends	52	52	52	52	52
Refrig. Control	TXV	TXV	EXV	EXV	EXV
Fin Design	LOUVERED	LOUVERED	LOUVERED	LOUVERED	LOUVERED
INDOOR COIL					
Frontal Area (sf)	6.0	8.0	8.0	8.0	8.0
# of Rows	4	4	4	4	4
# of Parallel Ckts	6	6	6	6	6
Fins/Inch	13	13	13	13	13
Fin Thickness (in)	0.0052	0.0052	0.0052	0.0052	0.0052
O.D. of Tubes	0.3250	0.3250	0.3250	0.3250	0.3250
I.D. of Tubes	0.3030	0.3030	0.3030	0.3030	0.3030
Vert Space (in)	1.0000	1.0000	1.0000	1.0000	1.0000
Hor Space (in)	0.6250	0.6250	0.6250	0.6250	0.6250
# of Return Bends	72	72	72	72	72
Refrig. Control	TXV	TXV	EXV	EXV	EXV
Fin Design	WAVY	WAVY	WAVY	WAVY	WAVY
OUTDOOR FAN					
CFM	4200	4200	3900	3600	3600
Fan & Motor eff.	0.23	0.23	0.23	0.23	0.23
INDOOR FAN					
CFM	1350	1350	1200	1200	1200
Fan & Motor eff.	0.31	0.31	0.31	0.31	0.31
REF. LINES (6 ft)					
Liquid Line O.D.	3/8	3/8	3/8	3/8	3/8
Suction Line O.D.	1 1/8	1 1/8	1 1/8	1 1/8	1 1/8

Table 7.12 - Performance data on 5 ton package variable speed heat pumps

5 TON PACKAGE VARIABLE SPEED HEAT PUMPS

COOLING MODE		60VPA	60VPB	60VPC	60VPD	60VPE
Max Speed 95F						
	EER	8.12	8.55	9.22	9.61	10.29
	CAPACITY	60090.00	60060.00	60070.00	59960.00	60070.00
Max Speed 82F						
	EER	9.25	9.83	10.51	11.00	11.73
	CAPACITY	64420.00	64590.00	64220.00	63970.00	64260.00
Min Speed 82F						
	EER	12.23	12.79	14.39	15.21	15.79
	CAPACITY	32020.00	31330.00	32550.00	32660.00	32550.00
Min Speed 67F						
	EER	15.42	16.22	18.30	19.18	19.99
	CAPACITY	35050.00	34290.00	35650.00	35630.00	35640.00
Int Speed 87F						
	EER	10.64	11.25	12.19	12.72	13.51
	CAPACITY	51990.00	51700.00	52170.00	52090.00	52200.00
	SEER	11.96	12.68	13.87	14.55	15.25

HEATING MODE		60VPA	60VPB	60VPC	60VPD	60VPE
Max Speed 47F						
	COP	2.49	2.63	2.72	2.82	2.96
	CAPACITY	56820.00	55270.00	54060.00	53160.00	52690.00
Max Speed 35F						
	COP	2.33	2.44	2.53	2.63	2.75
	CAPACITY	47350.00	45980.00	44990.00	44060.00	43660.00
Max Speed 17F						
	COP	2.05	2.12	2.23	2.30	2.39
	CAPACITY	34860.00	33680.00	32940.00	32270.00	31830.00
Min Speed 62F						
	COP	3.87	4.11	4.35	4.55	4.73
	CAPACITY	35990.00	34900.00	35100.00	34690.00	34580.00
Min Speed 47F						
	COP	3.22	3.39	3.63	3.79	3.94
	CAPACITY	28540.00	27550.00	27690.00	27360.00	27200.00
	HSPF	7.90	8.14	8.84	9.13	9.42

Central Air Conditioners

The final variable speed central air conditioner designs are the same as the variable speed heat pump designs except for the degradation coefficient. The same procedure for calculating the SEER for variable speed heat pumps is used for the air conditioners. Because the hardware descriptions are the same (with the exception of demand defrost control which is applicable to only heat pumps) for the central air conditioners and heat pumps, no descriptions are provided in this section for the air conditioners. The labeling of each model is in the same format as the heat pumps.

3 Ton Split Systems

As with the variable speed heat pumps, there are five units in this class of central air conditioners (Table 7.13). Their letter designations are the same as the heat pumps, running from 36VA through 36VE. The SEERs run from a low of 13.80 to a high of 17.24. The highest value is 15% higher than the best unit on the market in 1986[3].

3 Ton Package Systems

Model designations run from 36PVA through 36PVE for the three ton package systems (Table 7.14). Unit efficiencies for the package systems are very close to those of the split systems.

5 Ton Split Systems

Table 7.15 lists the performance data of the 5 ton variable speed central air conditioners. Unit 60VA is the baseline unit and 60VE is the best unit. The highest SEER was a 15.54. The best 5 ton unit in the ARI directory in 1986 had an SEER of 13.0.

5 Ton Package Systems

Table 7.16 lists the units in the 5 ton variable speed package line. The best performancer for these systems had a SEER of 15.41, which is just slightly below the best for the 5 ton split systems.

Table 7.13 - Performance data on 3 ton split variable speed A.C. systems

3 TON SPLIT VARIABLE SPEED AIR CONDITIONERS

COOLING MODE		36VA	36VB	36VC	36VD	36VE
Max Speed 95F						
	EER	8.88	9.06	10.05	10.57	11.19
	CAPACITY	36050.00	36030.00	36040.00	35050.00	36050.00
Max Speed 82F						
	EER	10.20	10.42	11.55	12.14	12.88
	CAPACITY	38540.00	38620.00	38630.00	38620.00	38620.00
Min Speed 82F						
	EER	13.80	14.35	15.75	16.56	17.41
	CAPACITY	18680.00	19020.00	18980.00	19050.00	19020.00
Min Speed 67F						
	EER	17.74	18.53	20.19	21.31	22.36
	CAPACITY	20440.00	20760.00	20720.00	20800.00	20760.00
Int Speed 87F						
	EER	11.82	12.17	13.40	14.10	14.96
	CAPACITY	30800.00	31080.00	31050.00	31100.00	31050.00
	SEER	13.80	14.15	15.56	16.03	17.24

Table 7.14 - Performance data on 3 ton package variable speed A.C. systems

3 TON PACKAGE VARIABLE SPEED AIR CONDITIONERS

COOLING MODE		36VPA	36VPB	36VPC	36VPD	36VPE
Max Speed 95F						
	EER	8.90	8.95	9.94	10.55	11.16
	CAPACITY	36030.00	36040.00	36040.00	35960.00	36040.00
Max Speed 82F						
	EER	10.23	10.33	11.44	12.11	12.84
	CAPACITY	38530.00	38630.00	38620.00	38570.00	38620.00
Min Speed 82F						
	EER	13.88	14.35	15.68	16.44	17.28
	CAPACITY	18670.00	19130.00	19070.00	19000.00	19020.00
Min Speed 67F						
	EER	17.85	18.53	20.18	21.13	22.16
	CAPACITY	20440.00	20880.00	20820.00	20750.00	20760.00
Int Speed 87F						
	EER	11.86	12.09	13.31	14.06	14.90
	CAPACITY	30790.00	31170.00	31120.00	31050.00	31070.00
	SEER	13.87	14.07	15.44	16.24	17.11

Table 7.15 - Performance data on 5 ton split variable speed A.C. systems

5 TON SPLIT VARIABLE SPEED AIR CONDITIONERS

COOLING MODE		60VA	60VB	60VC	60VD	60VE
Max Speed 95F						
	EER	8.14	8.50	9.47	9.81	10.20
	CAPACITY	60090.00	60060.00	60050.00	59920.00	60000.00
Max Speed 82F						
	EER	9.27	9.72	10.87	11.20	11.57
	CAPACITY	64400.00	64460.00	64530.00	64170.00	64010.00
Min Speed 82F						
	EER	12.46	13.11	14.17	14.95	16.11
	CAPACITY	32260.00	31720.00	31490.00	31750.00	32900.00
Min Speed 67F						
	EER	15.74	16.66	17.87	18.89	20.45
	CAPACITY	35290.00	34690.00	34460.00	34710.00	36000.00
Int Speed 87F						
	EER	10.71	11.29	12.43	12.94	13.52
	CAPACITY	52120.00	51870.00	51770.00	51750.00	52290.00
	SEER	12.22	12.96	14.12	14.78	15.54

Table 7.16 - Performance data on 5 ton package variable speed A.C. systems

5 TON PACKAGE VARIABLE SPEED AIR CONDITIONERS

COOLING MODE		60VPA	60VPB	60VPC	60VPD	60VPE
Max Speed 95F						
	EER	8.12	8.55	9.22	9.61	10.29
	CAPACITY	60090.00	60060.00	60070.00	59960.00	60070.00
Max Speed 82F						
	EER	9.25	9.83	10.51	11.00	11.73
	CAPACITY	64420.00	64590.00	64220.00	63970.00	64260.00
Min Speed 82F						
	EER	12.23	12.79	14.39	15.21	15.79
	CAPACITY	32020.00	31330.00	32550.00	32660.00	32550.00
Min Speed 67F						
	EER	15.42	16.22	18.30	19.18	19.99
	CAPACITY	35050.00	34290.00	35650.00	35630.00	35640.00
Int Speed 87F						
	EER	10.64	11.25	12.19	12.72	13.51
	CAPACITY	51990.00	51700.00	52170.00	52090.00	52200.00
	SEER	12.08	12.68	14.01	14.69	15.41

References

1. "Test Procedure for Central Air Conditioners, Including Heat Pumps", Federal Register, Dec. 27, 1979, pp. 76700-76723.

2. "Energy Conservation Program for Consumer Products: Proposed Rulemaking and Public Hearing regarding Test Procedures for Central Air Conditioners, including Heat Pumps", Docket. No. CAS-RM-79-102, Department of Energy, May 1986.

3. "Directory of Certified Unitary Air Conditioner, Air Source Heat Pumps, and Sound-Rated Outdoor Unitary Equipment", Air Conditioning and Refrigeration Institute, Jan. 1 - June 30, 1986, Arlington, VA.

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

This study has considered the efficiency improvements that are possible in residential sized heat pumps and central air conditioners. The major conclusions and recommendations are discussed below.

Conclusions

A major conclusion that should be drawn from this analysis is that the efficiency improvements on the cooling side of heat pumps are comparable to those of central air conditioners. For regulatory purposes, this could allow both heat pumps and central air conditioners to come under the same minimum efficiency standard on the cooling side.

While major improvements in the efficiency of heat pumps and central air conditioners have occured over the past ten years, this study has demonstrated that large efficiency improvements are possible by optimizing performance with conventional design options and application of variable speed compressor technology. The biggest improvements appear possible in single package units where the highest efficiencies on the market in 1986 are still below the maximum efficiencies evaluated by A.D. Little, Inc. in the June 1980 engineering analysis for the Appliance Efficiency Standards. With the application of variable speed compressors, manufacturers should be able to design both split and package units that have SEERs ranging from 12 to 17 for 3 ton systems. The application of this technology promises to push the efficiency of systems far beyond anything possible with the best single or two-speed compressors.

Recommendations

First, the ORNL heat pump model should be modified to handle water source heat pumps. Two of the classes mentioned in Chapter Two are water source heat pumps. With modifications to the outdoor heat exchanger model, the ORNL heat pump model could be used to evaluate the effect of design changes on water source heat pumps. The primary modification would be the addition of several subroutines that could simulate the performance of water-to-refrigerant heat exchangers. This work should be started immediately to allow enough time for the development of the necessary data, implementation of the subroutines, and validation of the modified ORNL model.

Second, as performance data for new variable speed and scroll compressors are made available by compressor manufacturers, the analysis performed in Chapter 7 should be updated. This action will ensure that the efficiency numbers used in any regulatory analysis are current.