ENERGY CONSERVATION

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Summary and Evaluation of Field Performance Data on Unitary Heat Pumps

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Report Prepared by

ARTHUR D. LITTLE, INC.
Cambridge, Massachusetts 02140-2390

under
Subcontract 86X-00219

for

OAK RIDGE NATIONAL LABORATORY

operated by

MARTIN MARIETTA ENERGY SYSTEMS, INC.

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April 1986

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ABSTRACT

Over 100 individuals in 90 organizations (utilities, manufacturers, government agencies, universities, installers, associations, contractors and others) were contacted to establish the status of field (thermal) performance data on unitary heat pumps. This topical report presents a summary and evaluation of existing data in light of user needs. A subsequent task will focus on the need for additional testing and/or analysis.

The key reasons cited for needing heat pump field test data were load management, consumer information, product design and model validation. The major types of thermal performance data needs reported included energy consumption and savings (HSPF and SEER), load profiles, and information on advanced designs. Reliability and maintenance were also of great interest in addition to thermal performance.

Thirty-eight programs involving over 700 heat pump units were identified and categorized in three levels based on the parameters measured. Level I programs (nearly 600 units) measured energy input normally using utility load research methods, to obtain semi-quantitative performance information and "hands on" operating experience. In Level II programs (almost 150 units) both energy input and output were obtained allowing estimation of HSPF. However the output determination methods (usually flip-flop or estimation of building load) involved 10 to 20% uncertainty in the heating mode and were not normally suitable for cooling. Level III programs (less than 60 units) involved measurement of input, output and at least some isolation of dynamic losses due to part load cycling and frost/defrost. Generally these programs involved more careful control and measurement of climatic, installation, and operational test conditions than the prior levels and the method of output measurement (normally duct enthalpy) were more accurate than for Level II although determination of cooling load continued to be a problem.

Overall, the data base on heat pump field performance is large but uneven in terms of completeness and quality. Energy input data is abundant and frequently reliable but the results are seldom either statically valid or easily generalized. A considerable amount of HSPF (and much less SEER) data is also available. Certain comparisons of these experimental performance factors with ARI 240-81 predictions have indicated good apparent agreement (within $\pm$ 10%). However, questions remain both as to the general applicability of ARI 240-81, and to the specific methods used in normalizing the test data. Relatively little detailed data on dynamic losses is available and even less comparison with analysis. However, results to date do indicate that these losses can degrade seasonal performance by over 20% in some instances - and be much less important in other circumstances. Unresolved experimental problems include optimization of flip-flop techniques, practical field measurement of cooling load and means of detecting performance degradation. Also very few programs presented error analyses.

1.0 SUMMARY

1.1 Background

Accurate knowledge of heat pump installed performance is essential for energy planning and equipment development. It is of particular interest in more northerly areas where the economic advantage of the electric heat pump over other heating options may not be clear cut. Unfortunately, heat pump installed performance will vary greatly depending on climatic conditions, occupancy patterns, and installation procedures. (Heat pump heating seasonal performance factor is much more sensitive to these variable than is the seasonal efficiency of fossil furnaces). Certain analytical models and rating methods are available for estimating heat pump performance and installed performance has been measured in a number of field test programs. However it is not clear that the analytical methods and field test data currently available are sufficient to satisfy user needs.

The objectives of this assessment of field performance data on Unitary Heat Pumps are to establish the status of existing data on heat pump field performance, to compare it with user data needs, and to determine what type of additional work is warranted. This topical report deals primarily with evaluation of the existing field test data. A subsequent task will focus on the need for additional testing and for analysis.

1.2 Results

1. Over 100 individuals in 90 organizations were contacted relative to field programs and data needs either for detailed interviews or for questions on specific points. The number of organizations contacted, by sector, was as follows:

o	manufacturers -	7
o	utilities -	42
o	government agencies -	12
o	universities	8
o	installers -	3
o	associations -	9
o	contractors/others -	9
		90

2. 38 programs involving over 700 heat pumps were identified. Approximately 90% of the heat pumps were residential air to air units. Almost all the programs involved heating; about 20% had some cooling data.

3. The key reasons cited for needing field test data were:

   - Load management
   - Consumer information
   - Product design
   - Model validation.

4. The major types of data needs reported were:

   - Energy consumption and savings (HSPF and SEER to a lesser extent)
   - Reliability/Maintenance
   - Advanced design evaluation (water source, ground coupled, dual fuel, etc.)
   - Load Profiles.

5. The programs could be categorized in three levels, based on the type of measurements obtained.

   - Level I - energy input only
   - Level II - input and output
   - Level III - input, output, and dynamic losses.

6. Fifteen Level I programs, involving almost 600 heat pump units, were identified. These programs were primarily conducted by utilities and probably many additional programs are in utility files. The Level I programs were characterized by simple "load research" instrumentation - typically wattmeters and WR4C recorders. The potential accuracy of this method is good (error typically 1% or less) and the frequency of readings (typically 15 minutes) adequate. Except for start-up problems data reliability was normally good. However, these programs were generally conducted by utilities to obtain "hands on" qualitative information. In most instances, the numbers of units tested were insufficient to obtain statistically valid data and even when relatively large numbers were tested statistical analysis was not generally employed.

7. Twelve level II programs involving over 100 heat pumps were identified - primarily early EPRI programs and utility programs. In these programs output was typically obtained either by the "flip-flop" method (estimated error 10 - 15%) or from calculation of building load (error likely to be in excess of 20%). The results were typically used to obtain approximate values of HSPF. Comparison with analyses were very limited. Some results were compared directly with manufacturers "ideal" (steady state) performance (neglecting dynamic losses due to part load cycling and frost/defrost); very few comparisons were made with analyses which included dynamic losses.

8. Twelve Level III programs* involving 57 heat pumps were identified. These programs, the most comprehensive in terms of instrumentation and analysis, are typically the more recent ones

---

* The sum of programs identified in Levels I, II & III (39) exceeds the total number of programs identified (38) since one program (RP432) had both Level I and Level II elements.

under EPRI and Government sponsorship. Heat pump output is normally measured by the duct enthalpy method for heating (and sensible cooling). The method is reported to have an error of 5 to 10%. For estimating total cooling output including latent contribution three techniques have been employed and/or considered.

- Assumed total/sensible ratio (simple - but with significant error - probably about 15%).

- Measured condensate used successfully, with nominal error (reported as about 5% of latent contribution) in closely monitored tests but considered by some to be too cumbersome for unattended field measurements.

- Measured relative humidity (not used successfully to date).

All of the Level III programs present HSPF - frequently with comparison to predictions based on the ARI 240-81 rating method. The emphasis (and accuracy) has normally been less for cooling.

9. Experimental values of HSPF range from 4.1 to 8.1 BTU/Watt-hr for a sample of 78 residential air to air heat pumps from eight Level II and Level III programs. The methods of correlation and/or comparison with analysis differ greatly from program to program, however some general trends were:

   - HSPF was generally higher in warmer climates, although factors other than climate, such as sizing, were also important.

   - When compared to "ideal" HSPF's, based on manufacturer's steady state data and neglecting dynamic losses due to part load cycling and frost/defrost, the "shortfall" was sometimes substantial. Results from

early ORNL and NBS programs indicated a "shortfall" of about 20%. In an early EPRI program (RP-432-1), while experimental scatter tended to obscure the results, the "shortfall" appeared to range from 0 to 30%. It should be emphasized that this "shortfall" is indicative of an inadequacy of the "predictive" method rather than a failure of heat pumps to live up to expectation. A major value of this early data was to give a preliminary indication of the magnitude of dynamic losses.

- Limited test data has indicated good apparent agreement with ARI 240-81. Test results presented for 11 units from 3 programs generally fell within 10% of the calculated values based on the ARI method. However, the techniques for applying the ARI method were not uniform and some may have circumvented some of the error which would normally be encountered in applying ARI 240-81.

10. Observed field performance of heat pump/air conditioning systems can depart significantly from ideal steady state performance, because of non-steady state operation due to part load cycling and frost/defrost. Total loss due to such effects ranges from negligible to sometimes greater than 20%. However, to date there has been relatively little isolation of the individual loss components and even less correlation with test conditions and/or analyses. Some tentative observations based on the limited data available are:

    - Losses due to frosting and defrosting can be small or large dependent on type of defrost control, system design, and climatic conditions. Defrost losses of over 14% were reported in regions of moderate to high humidity, while test results from regions of low humidity, such as Albuquerque indicate much reduced - or even negligible frost/defrost losses.

- Part load cycling loss has been observed to be dependent upon thermostat cycling rate and ratio of capacity to load, among other things. Some simplified analyses, such as the ARI 240-81 calculational procedure, assume an arbitrarily fixed cycling rate.

11. Application of ARI 240-81 to predict installed HSPF tends to be imprecise due to a number of errors, some specific to ARI 240-81 - others generic to any analysis, such as

    - The actual manufacturer steady state COP for a given heat pump may differ by $\pm$ 5% from the nominal ARI value.

    - The ARI defrost loss is based on a single test point of 35°F DB/30°F DP. It would be expected, and at least some experimental evidence suggests, that defrost loss would depend on outside humidity and temperature

    - Cycling loss is based on a thermostat model predicting a peak cycling rate at 3 cph. Field tests indicated cycling loss was dependent on cycling rate and that actual cycling rates could vary substantially.

    - Calculation of HSPF requires knowledge of building load which can only be estimated roughly. An error in balance point of 5°F can produce an error of up to 10% in HSPF. Also a 1°F change in internal temperature is roughly equivalent to a 1% change in COP.

12. Although ARI 240-81 is a comparative, rather than predictive, method and deals empirically with dynamic losses it is in fact the source of most "predicted" values used for comparison with test results. While the limited results to date frequently agree within + 10% it is not clear that the ARI method could be expected to consistently predict HSPF with this accuracy since:

- The comparison with test results have frequently involved some experimental feed back such as measured steady state performance and load.

- In at least one program, the ARI method, while achieving good overall agreement with experimental HSPF, tended to overestimate cycling loss and underestimate frost/defrost loss.

13. Very few of the experimental programs have presented error analyses.

1.3 Conclusions

1. The data base on heat pump energy input (both consumption and demand profiles) is large (nearly 600 units field tested in the Level I programs identified) and generally reliable. However this data is of limited general usefulness since it was normally obtained for qualitative "hands on" experience and in only a few cases were the systems selection and subsequent analysis sufficient for statistically valid results. This data is not suitable for determining individual system performance factors (since output was not measured) or for verifying physically based models. However it is possible that some portions of this data might have further value in conjunction with statistically based models to determine average performance - or performance variation - for individual systems.

2. A considerable, although lesser, quantity of data (over 100 units in Level II programs) is available on HSPF. However experimental uncertainties in measurement of output and definition of test conditions make for uneven quality. To date comparison with analysis has been limited and frequently somewhat inconclusive.

3. Very little information has been obtained on heat pump cooling SEER - primarily because of difficulty in measuring cooling output.

4. Relatively little detailed field data is available on dynamic losses due to part load cycling and frost/defrost. Initial comparisons with analysis (ARI 240-81) have indicated significant errors associated with the assumptions of fixed values of thermostat cycling rate and outside humidity.

5. Although heat pump installation and occupancy patterns are believed to be critical to as installed performance very little field data is available to define these impacts.

6. Key unresolved experimental problems include:

   - optimization of flip-flop time periods
   - practical field measurement of cooling output
   - monitoring of system to detect performance degradation (i.e. due to refrigerant leakage, heat exchanger blockage, or dirty air filters).

7. No general analytical method including detail treatment of dynamic losses has been available for use in evaluation of experimental results.

8. The current rating method (ARI 240-81), in spite of its apparently good agreement with test results, has a number of demonstrated and potential limitations which could give incorrect signals for equipment design such as:

   o The C_D default value of .25 which doesn't adequately reflect true cycling losses. A manufacturer is permitted to use C_D = .25 in calculating HSPF (and SEER) even when the actual C_D is higher (say C_D = .35)

- thereby overestimating seasonal performance. Alternately a manufacturer may elect to use C_D = .25 even his unit may have less cycling loss (i.e., C_D = .15) in order to avoid testing expense - in this case seasonal performance will be underestimated.

- The fixed defrost temperature - humidity test condition which may not penalize different size outdoor heat exchangers equally.

- The lack of specification of SHR (or latent cooling) which ignores the tendency for large indoor coils to provide less than optimum dehumidification in humid regions under some conditions.

- The lack of specification on heat exchanger deterioration which ignores possible long term blockage in very tightly finned coil designs.

9. Both physically based and statistical models have advantages for the analysis and extension of field test data. Statistical models may be most appropriate for utility load planning, whereas physically based models are best suited to equipment design. Both may have value for defining the probable range of individual consumer savings.

2.0 INTRODUCTION

Heat pump installed performance depends on a number of climatic, occupancy and installation variables as well as the design features of the heat pump itself. For instance heating seasonal performance factor depends on the steady state performance of the heat pump, the losses due to part load cycling and frost/defrost, and the supplementary energy requirements. Each of these factors can be quite installation specific. Steady state COP will vary with both indoor and outdoor temperature. Cycling losses and supplementary energy requirements are strongly affected by both control strategies and the sizing of the heat pump relative to the load - the load, in turn, being dependent on climate, building characteristics and occupancy patterns. Testing and rating procedures currently in use do include consideration of the loss factors mentioned above but is not generally known whether the values that result from the procedures give a representative indication of the actual installed performance that the unit will deliver.

In the last several years a number of heat pump field test programs have been conducted and much valuable information has been obtained. However many of these programs are lacking in terms of either completeness and accuracy of the primary test information obtained, the control and/or monitoring of the test conditions, and the analysis and normalization of the information obtained. In particular very little test information giving complete dynamic performance, including the magnitude of individual losses such as cycling and frost/defrost, is available which could be used as the basis for model development. Therefore, a need existed to assess the status of existing field performance data on unitary heat pumps and, by comparison with user needs, to determine what additional field test data or analysis might be merited.

This present study includes both residential and light commercial heat pumps. This topical report deals with evaluation of field performance data and includes, in the section immediately following, a summary of

the data needs identified. The data collection survey work included telephone interviews ranging from indepth discussions to inquiries on specific topics with over 100 individuals in 90 organizations, and review and analysis of reports and other information obtained from the above interviews - supplemented by follow up conversations, and by a few selected site visits.

3.0 SUMMARY OF USER NEEDS IDENTIFIED

3.1 Expressed Needs of User Sectors

Manufacturers, utility companies, government organizations, university researchers, heat pump installers, and heat pump associations were contacted to identify user needs for field performance data on unitary heat pumps. The most common objectives for needing heat pump field data and the type of field data perceived as being most needed to fulfill these objectives are listed in Table 1 and discussed below.

1. Manufacturers

Most heat pump manufacturers contacted expressed the need for more heat pump field data*. Over half stated the need for more data to improve product design, validate models, and facilitate load management; about one-third mentioned promotional purposes.

Because of the proprietary nature of much of the manufacturers field and lab results, there tended to be different data interest for each manufacturer in meeting these objectives. However almost one half did emphasize the need for more defrost/cycling and reliability field data. Other data needs included: night-time setback, water-source systems, single vs. dual speed compressors, utility load profiles, and zoning.

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* In this, and in other sectors, a large percentage (typically 80 - 90%) of the organizations contacted (and listed in Appendix A) were interviewed in depth relative to user needs. The remaining contacts were asked more limited questions relative to needs and/or field testing.

TABLE 1
SUMMARY OF USER NEEDS BY SECTOR
(In Order of Importance)

Sector	Why Field Data is Needed	Type of Data Needed
Manufacturers	o product design o validate models o load management o consumer information	o defrost o cycling o reliability o water source systems o load profiles o night-time set back o single vs. dual compressors o zoning
Utilities	o load management o consumer information o cost-effectiveness o verify ARI and manufacturer claims o validate models o load growth o rate making	o HSPF for service area o water source, ground-coupled and dual fuel system o load profiles o reliability o installation o defrost/cycling
Government	o validate models o product design o verify ARI and manufacturer claims o cost-effectiveness o military specifications o consumer information	o reliability o HSPF vs. climate o efficiency testing
Universities	o product design o consumer information o sizing o prediction methods o validation of test procedures	o HSPF o maintenance/reliability o cycling/defrost o water source, ground-coupled systems o proper charge o climatic effects
Installers/Others	o contractor education o comparative HP analysis o validate models	o SPF o new equipment o as installed performance

2. Utilities

Forty-two utility companies were contacted throughout the United States (see Figure 1). Sixty percent of the utilities stated that field data was mostly needed for load management. Almost fifty percent stated that more data was needed in order to help provide information on heat pumps to the customers. Other primary motives for conducting more field tests were to verify the Air Conditioning and Refrigeration Institute (ARI) and manufacturer's claims; to determine the cost-effectiveness associated with heat pump interconnection to the local utility grid; to use in planning load growth; and to validate performance models.

To meet the above objectives, approximately 60 percent of those utilities contacted expressed the need to obtain data related to the heating seasonal performance factor (HSPF) for their service area. There was also strong interest in demand profiles. In general cooling was of less interest than heating, at least partly because the competition with alternative equipment was normally not a major issue (i.e. not comparable to the heating mode competition with fossil furnaces). Over 20 percent mentioned that reliability, and field performance data for water-source, ground-coupled and dual fuel heat pump systems data are not adequately available. Of lesser concern, but still of interest, were field data on defrosting, cycling and installation. Utilities in the Southwest, while expressing the same general range of interest, had a much less intense interest in heat pumps because of the perceived strong competitive position of gas-fired heating. In some areas it was also felt that, for residential use, evaporative cooling tended to preempt compression cooling.

3. Government

Twelve government organizations involved with heat pump activities were contacted. Data needs expressed included more

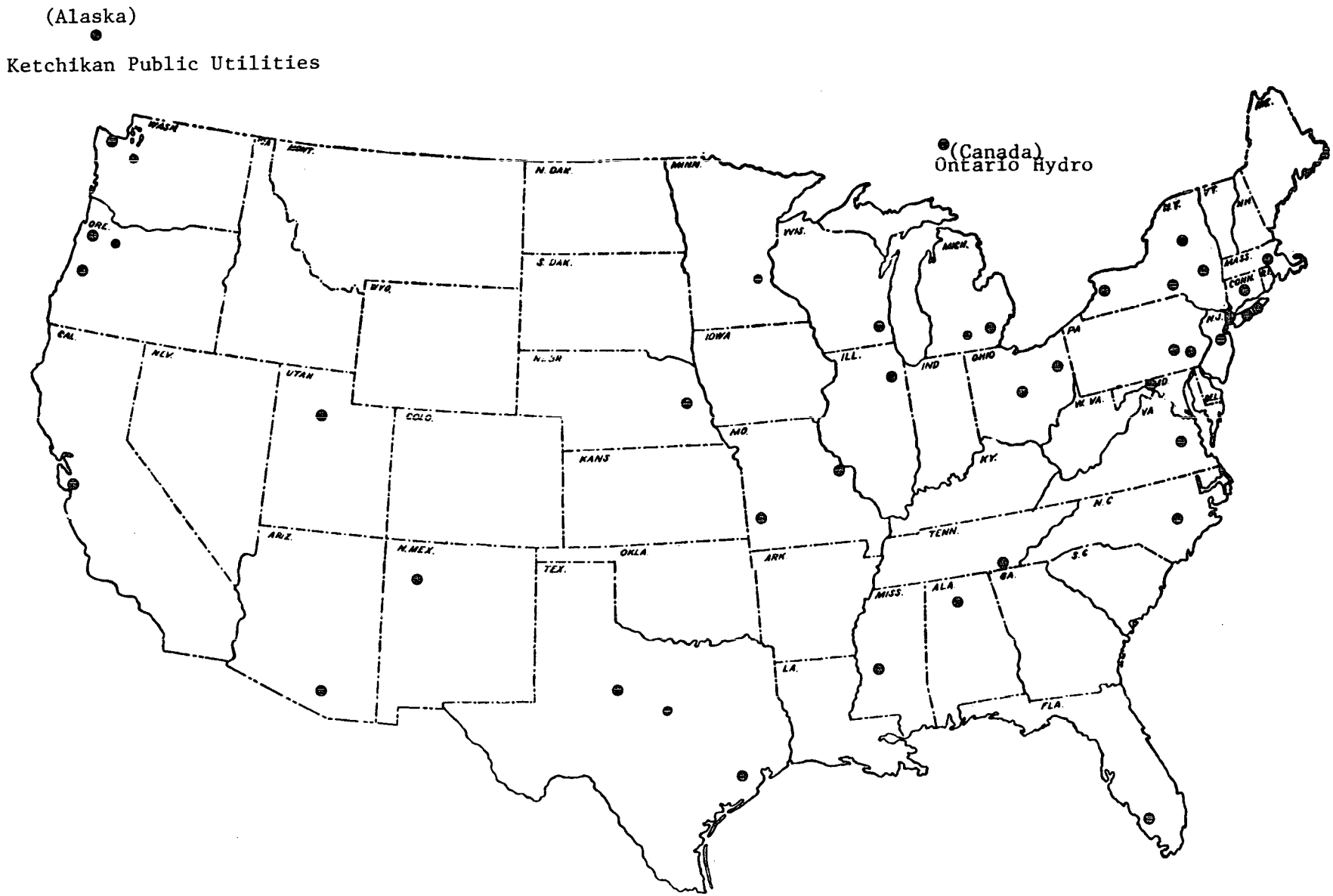


FIGURE 1. Location of Utility Contacts

field data to help validate existing heat pump models, to improve product design to establish cost-effectiveness of heat pumps, and to facilitate determining new military specifications and promoting heat pumps to consumers.

Many of the government organizations stated that reliability data would benefit the above objectives. Others also wanted more statistically valid data related to the performance and efficiency of heat pumps in various geographic regions throughout the United States.

4. Universities

Seven universities, actively involved in heat pump research, were contacted throughout the U.S. All of those expressing a need for more field data stated that it is needed to improve heat pump technology. Almost seventy percent mentioned a lack of appropriate data for consumer selection of heating system and for system sizing by installers and contractors.

The type of data needed for the above were quite varied among the University groups. All, however, did express the need for better data of HSPF. Almost seventy percent also wanted cycling/defrost and reliability/maintenance field data. Emphasis was also stated for the need to analyze and obtain more and better field data related to the proper charge of all systems and the climatic effects on the overall operation of the heat pump.

5. Installers

Four installers were contacted. There was general consensus that the current available data on heat pump systems was adequate for installer needs. They did, however, stress the importance of needing to have more contractor/installer education for proper installation of systems with particular emphasis on sizing of heat pumps and ducts.

6. Associations and Contractors

Nine professional and industry associations and nine Government and Industry Contractors that are involved with heat pump activities were contacted. The type of data that would be useful to these organizations varies considerably. Among the data needs identified were: performance factors for heating (and cooling), load profiles, cycling/defrost, efficiency standards, ground-water heat pumps, reliability and control strategies.

3.2 Aggregate Of User Data Needs

The key reasons cited for needing field data were:

- Load Management

  Utilities in particular were concerned with the impact of heat pumps on utility systems with respect to load growth and capacity requirements.

- Consumer Information

  Data on consumer energy (and dollar) savings both on an average and on an individual basis was frequently mentioned both as input to market penetration studies and to provide consumers with rational expectations as to the economics of heat pumps in their area.

- Product Design

  Manufacturers and university groups tended to express similar concerns in needing more detailed data for the performance optimization of system components including field studies on the impact of factors such as: cycling, defrost, thermostat set-back, zoning, proper charge, and climatic/temperature variability. Interest was also expressed in the field

performance of advanced design options such as dual speed compressors and add-on systems with oil or gas back-up. (It was also stated by some that the the level of detail implied by field studies probably has most application to future activities since most current design work is based on component steady state performance.) Product design is also clearly influenced by equipment rating methods - as well as actual performance.

- Model Validation

  Several sectors mentioned the need for field data for the validation and/or development of analytical models and/or rating procedures. In many cases these models may be as, or more, effective than the actual field data for the purposes of load management, consumer information, and product design as discussed above.

The major types of data needs reported were:

- Energy Consumption and Savings - Seasonal Performance Factors

  Utility companies, universities, government organizations and some associations and contractors were concerned about the need to conduct more field studies related to the heating seasonal performance factor (HSPF) throughout climatically and geographically diversified areas. About half of the contacts made to these sectors stated the need for more HSPF data. Utilities, in particular, expressed the need to obtain HSPF data for their service areas. To a lesser extent there was interest in cooling SEER, although a few organizations considered SEER to be of equal importance with HSPF.

- Reliability/Maintenance

  Reliability and maintenance information is needed throughout all the sectors contacted. Almost one third of the total contacts

made emphasized the need for this type of data. Utilities need more reliability/maintenance data to facilitate load management. This type of data would also help utility groups, government agencies, manufacturers and universities compare heat pump systems overall performance to other heating systems. In turn, reliability/maintenance data is needed by almost all sectors to promote the use of these systems. (This study was not concerned with heat pump reliability and maintenance except for those instances (i.e. equipment degradation) where thermal performance was effected.)

- Advanced Designs Including Water-Source, Ground-Coupled Heat Pumps

  Approximately one quarter of all those contacted, expressed the need for more water-source, ground-coupled heat pumps and dual-fuel heat pump data. Many respondents were satisfied with the data on air-to-air systems, but felt the same quantity and quality of data was not available for other types of heat pumps.

- Load Profiles

  The utility perspective is somewhat different than other sectors because of their major need and interest in obtaining field data on demand profiles to guide load management. About 20 percent of the utilities contacted expressed the need for more demand profile data.

4.0 PROGRAMS REVIEWED

4.1 Data Collection

Thirty-eight heat pump field test programs were identified which had either been completed, or in progress, or in a few instances were just getting under way as of the time of this report. As illustrated in Table 2 these programs involved a total of 788 heat pumps of which 721 were residential air-to-air; 37 commercial; and 30 water-air and others (ground coupled and solar assisted). Of the 38 programs 14 dealt with heating only - the remaining 24 involved both heating and cooling although in several cases the emphasis was on heating. The greater interest in heating appears related to the uncertainty about the performance of heat pumps in the heating mode and in particular the competitive position relative to other options such as gas furnaces - especially in more northerly climates. Locations of the field test programs are shown in Figure 2.

4.2 Program Levels

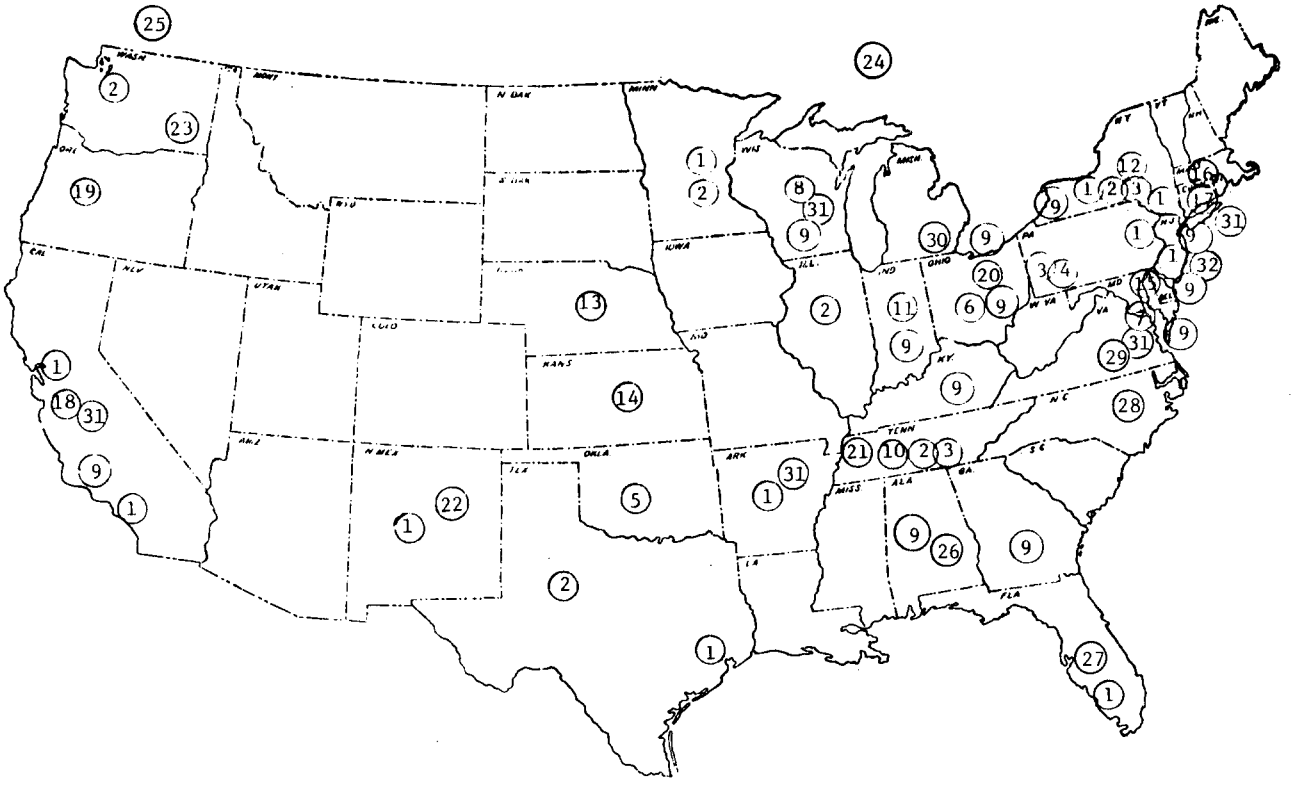
The field test programs identified in Task 1 were grouped in three levels differing in terms of complexity and objectives:

Level I - electric energy consumption and demand profiles
(Level I programs were primarily utility load research programs in which electric energy input to the heat pump was the primary experimental measurement.)

Level II - performance factors
(In these programs heat pump output as well as input were measured.)

Level III - detailed dynamic performance
(The programs include measurement of losses due to frost/defrost and part load operation, as well as Level II data.)

Table 3 summarizes the objectives and features of these program levels.



KEY FOR FIELD TEST PROGRAMS

1. EPRI RP 432-1
2. EPRI RP 789-1, 789-3, 2033-9
3. EPRI RP 1495-1
4. EPRI RP 1201-14
5. EPRI RP 1196-6
6. Ohio State
7. NBS-I,II
8. Wisconsin
9. AGA
10. ORNL-I,II
11. Purdue
12. ESEERCO-I & II
13. Lincoln Electric Service
14. Kansas City Power & Light
15. Baltimore Gas & Electric
16. New England Power
17. Northeast Utilities
18. Palo Alto
19. Eugene
20. Ohio Edison
21. TVA
22. UNM
23. BPA
24. Ontario Hydro
25. Alaska Power Administration (I & II)
26. Alabama
27. Florida Power
28. Carolina Power
29. Virginia Electric
30. Detroit Edison
31. ORNL Energy Storage
32. Princeton

Notes:

(1) For clarity only one site per program shown within each state.

(2) BPA sites not completely defined as of April 1985.

(3) AGA sites represent initial locations as of May 1985.

FIGURE 2

LOCATION OF FIELD TEST PROGRAMS

TABLE 2 FIELD TEST PROGRAM SUMMARY

PROGRAM	LOCATION	TYPE: Commercial	TYPE: Residential: Air-Air	TYPE: Residential: Water-Air	TYPE: Residential: Other	TEST PERIOD	LEVEL	HEATING (H) or COOLING (C)
EPRI RP 432-1 (Westinghouse)[2]	U.S.		77 (E) 43 (E)			1975-1977	I II	H&C
EPRI RP 789-1 (Carrier)	MA, NY, MN, WA.	1 (E)	4 (E)		1 (O)	1975-1980	III	H&C
EPRI RP789-3 (Carrier)[2]	TX, NY(3), TN, MN, IL		6 (E,G)			1979-1983	III	H&C
EPRI RP 2033-9	TX, AL, NY, TN, MN, IL, MD, GA.	2	10 (E,G,O)		1	1982-1983	III	H&C
EPRI RP 1495-1 (GE)	NY, TN, PA,		7 (E)			1981-1982	III	H
EPRI/ORNL RP 1201-14 (8)	PA.			2(E)		1981-1983	III	H&C
EPRI RP 1191-6 (Okla. State)	OK.		1 (E)		2 (E)	1981-1983	II	H&C
EPRI RP 137-1 (Ohio State)	OH.		2 (E)			4/74-11/75	III	H&C
NBS I	DC.		1 (E)			1974	III	H
NBS II	DC.		3 (E)			1980	III	H&C
American Gas Association[7]	U.S.		25 (E)			1984	II	HC
University of New Mexico	NM.		4 (E)			1975-1978	III	H
ORNL-I	TN.		2 (E)			1977-1980	II	H&C
ORNL-II	TN.		1 (E)			1981-1983	III	H&C
Purdue University	IN.		1 (N)			1978-1979	III	H

TABLE 2 FIELD TEST PROGRAM SUMMARY (Continued)

PROGRAM	LOCATION	TYPE: Commercial	TYPE: Residential: Air-Air	TYPE: Residential: Water-Air	TYPE: Residential: Other	TEST PERIOD	LEVEL	HEATING (H) or COOLING (C)
ESEERCO (I)	NY.		11 (E)			1976-1979	II	H
ESEERCO (II)	NY.			14 (E)	1 (E)	1983-1984	II	H&C
Lincoln Electric Service	NB.		3 (E,G)			1974-	II	H
TVA	TN.		18 (E)			1982-1983	I	H
Kansas City Power & Light	KN.		12 (G,E)			1981-1984	I	H
Wisconsin Electric	WI.		7 (G)			1979-1981	I	H
Baltimore Gas & Electric(3)	MD.		25 (E)(4)			1976-1977	I	H&C
New England Power Service	New England		10 (O,G,E)	2 (E)	3 (E)	1982-1984	I	H&C
City of Palo Alto	CA.		2 (E)			1980-1981	II	H
Alaska Power Admin - I	AK.			1 (E)		1982-	II	H
Alaska Power Admin - II	AK.	3	8 (E)			1981-1984	II	H
Eugene Water & Electric	OR.		5 (E)		1	1978-1974	I	H&C
Ohio Edison	OH.		18 (E)			1972-1974	II	H&C
Florida Power Corporation	FL.		2 (E)			1978-1979	I	H
			1 (E)			1981	I	H

TABLE 2 FIELD TEST PROGRAM SUMMARY (Continued)

PROGRAM	LOCATION	TYPE: Commercial	TYPE: Residential: Air-Air	TYPE: Residential: Water-Air	TYPE: Residential: Other	TEST PERIOD	LEVEL	HEATING (H) OR COOLING (C)
Alabama Power Company	AL		15 (E)			1974-1975	I	H&C
			4 (E)			1976-1978	I	H&C
			30 (E)			(NA)	I	H&C
Northeast Utilities	New England		4 (O,S)			1979-1981	I	H&C
			19 (E)			1984-1985	I	H&C
		1(5)				1984-1985	I	H&C
Ontario Hydro	Toronto, Canada		2 (O,G)			1978-1982	II	H
Carolina Power & Light(6)	NC		60 (E)			1981-1982	I	H&C
Virginia Electric & Power(6)	VA		40 (E)			1982-1984	I	H&C
			20 (O)			1983-1984	I	H&C
			20 (G)			1979-1981	I	H&C
Detroit Edison(6)	MI		12 (E)			1979-1981	I	H&C
BPA(7)	Pacific Northwest	30	25			1985-	I	H&C
ORNL Energy Storage								
Long Island Lighting	NY		35(E)			1979-1980	I	C
Pacific Gas & Electric	CA		30(E)			1980-1981	I	C
Wisconsin Electric	WI		25(E)			1980-1981	I	C
Arkansas Power & Light	AR		31(E)			1980-1981	I	C
Virginia	VA		31(E)			1980-1981	I	H&C
Princeton	NJ		10(E)			1975-1976	III	H&C
TOTALS		37	721	20	10			

Notes:

(1) "Other" includes ground coupled, and air to water systems. Letters in parenthesis indicate back-up (E-electricity, G-natural gas or propane, O-oil, S-storage and/or solar, N-none).
(2) Performance study of advanced HP designs and add-on (residual fuel) systems.
(3) Not for public use.
(4) Represents advanced HP designs.
(5) Includes 48 2-ton water-air HP units.
(6) Not summarized in detail; report/information not available at time of report preparation.
(7) Number of HP sites to be monitored still uncertain (sites still being selected).
(8) Experimental program conducted by Allegheny Electric Cooperative under contract to EPRI; analysis and modeling by University of Pittsburgh under contract to ORNL.

TABLE 3

THREE LEVELS OF FIELD TEST PROGRAM

	LEVEL I	LEVEL II	LEVEL III
Primary Measurements	Energy Input	o Energy Input o Energy Delivered	o Energy Input o Energy Delivered o Frost/Defrost Loss o Part Load Loss
Experimental Results	Energy Consumption & Demand Profiles	Performance Factors	Detail Dynamic Performance
Objective	Utility Load Research	o Generalized Data o Check Against ARI 240-81	o R&D o Model Development
Typical Examples	Most Utility Programs o RP432-1	o Some Utilities o RP432-1 o ORNL-I	o Recent EPRI Programs o ORNL-II o NBS-I & II
Number* of Programs Identified	15	12	12
Number of Heat Pumps	595	136	57

* The sum of programs identified in Levels I, II & III (39) exceeds the total number of programs identified (38) since one program (RP432) had both Level I and Level II elements.

5.0 LEVEL I PROGRAMS

5.1 Objectives and Characteristics of Level I Programs

The Level I Programs were primarily conducted by utilities. Fifteen Level I programs involving almost 600 heat pumps were identified in this study. In general, the data acquisition system was simple, typically consisting of wattmeters recorded on one or more tape recorders such as is normally used for load research work. Since heat pump output was not measured in Level I programs, quantitative information on performance would require a statistically valid sample - probably 10 or more carefully selected representative sites. Therefore, while the total cost per site is quite modest, the cost of a statistically valid Level I program could be significant. In recognition of these cost trade-offs, Level I programs normally were designed to obtain either:

- Qualitative energy consumption and demand profiles, which also provided some "hands on" experience, and reliability and maintenance information with heat pumps in a utility service area. This objective could be accomplished with a small number of Level I sites.

- Statistically relevant information on energy consumption, demand profiles, etc. which could be compared with a statistically relevant database on other equipment. Most utilities did not stress this approach in the reports and information we have in hand although some had a reasonably large number of systems (over 20) which might provide a sufficient data base for statistical analysis. TVA was the major exception in that its program involved a large number (18) of similar systems and an intensive statistical analysis.

5.2 Level I Critical Issues

As shown in Table 4, the critical issues for Level I programs are relatively few and simple.

Table 4

LEVEL I CRITICAL ISSUES

PRIMARY MEASUREMENTS	o Energy Input o Accuracy/reliability - Meter and data acquisition System potential accuracy - Operating experience (i.e., data loss) - Provisions for redundant back-up o Frequency of readings o Partitioning of Energy Input
TEST CONDITIONS	o Site Selection - heat pump equipment - building/occupancy - statistical number of sites o Weather Data - Parameters (temperature, humidity) - Location (on site or airport)
NORMALIZATION	o Data Averaging o Correction for Weather o Statistical Analysis

The primary measurement is energy input. Normally, watt-hour meters and tape recorders used for these purposes are capable of sufficient accuracy (normally less than one percent error) and can provide sufficiently frequent readings, i.e., every 15 minutes. However, reliability, or data loss, can be a problem if the equipment is not properly serviced - particularly if the tapes are not synchronized and replaced on a timely basis.

In Level I programs, the two major areas of concern relative to control and monitoring of test conditions are site selection and weather data. In order that the data obtained be most useful, it is important that the sites be selected so as to be representative of the equipment, building design, and occupancy patterns existing in the utility service area. Also, the type and number of sites should be selected for statistical relevance, if this is an objective of the testing.

Weather data, especially temperature and, to a lesser extent, humidity is necessary for relating the information obtained to average conditions. On site data is most desirable (and necessary for the Levels II and III programs). However, particularly for the qualitative type Level I programs, airport data may suffice.

For the Level I, non-statistical, programs, there is little opportunity for normalization other than numerical averaging of some of the results and/or correcting for weather (i.e., degree days). In statistical programs, there are clear opportunities for using statistical modeling techniques both to normalize the data and to identify the important independent variables and their effects.

5.3 Review and Evaluation of Level I Programs

Level I programs are briefly described in Table 5. Summary descriptions of these programs are given in Appendix B. Three of the fifteen Level I programs Carolina Power & Light Company, Virginia Electric & Power company and Detroit Edison do not appear in Table 5 and are not summarized in Appendix B due to lack

Table 5

LEVEL I PROGRAMS: ELECTRIC ENERGY CONSUMPTION AND DEMAND PROFILES

Program	Heat Pump Type[1]	Data Acquisition System	Weather Data	Energy Input Quantities Measured	Presentation of Results
New England Power Service Company	6A-A (O, G) 2W-A (O, G) 4 A-A (E) 3 other	Watt-hour meters, 3 channel mag tape recorders	Temperature sensor at half of sites	Total heat pump system and supplementary energy kWh oil and gas consumption	Electrical energy consumption and demand data
Baltimore Gas and Electric[2]	25 A-A	Watt-hour meters, WR-4C Mag tape re-, corders	Ambient temperature local airport	Compressor, combined supplementary heat, fan, compressor, and total house kWh	Hourly and monthly average electricity consumption and demand data
Kansas City Power & Light	1 A-A (G) 1 A-A (E)	Watt-hour meters, MAG tape recorders, and gas meters	Ambient temperature	Heat pump system, supplemental heat, and total house kWh	Energy dollar savings (heat pump vs. fossil furnace)
Wisconsin Electric	7 A-A (G)	Watt-hour and gas flow meters, manual monthly reading	Ambient temperature local airport	Gas flow and kWh consumption - compressor, fan, total HP system	Electric energy consumption and conservation data
Eugene Water & Electric Board	5 A-A 1 other	Watt-hour meters, demand meters, manual monthly readings	Ambient temperature Eugene Airport	Monthly space heating, water heating, and total house kWh	Electric energy consumption and demand data
TVA	18 A-A (E)	Watt-hour meters, WR4C-4 mag tape recorders	Ambient temperature Nashville weather station	Compressor, supplemental heat and total house kWh	Electrical energy consumption and savings (heat pump vs. electric furnace) detailed statistical analysis
Florida Power Corporation	3 A-A (E)	Watt-hour meters, recording temp. monitors	Degree days	Total house kWh, total HP system, hot water	Electrical energy consumption and demand data

Table 5

LEVEL I PROGRAMS: ELECTRIC ENERGY CONSUMPTION AND DEMAND PROFILES

(Continued)

Program	Heat Pump Type	Data Acquisition System	Weather Data	Energy Input Quantities Measured	Presentation of Results
Northeast Utilities	1 A-A (O) 3 A-A (S)	Watt-hour meters, WR4C mag tape recorders	Degree days	Compressor, fan, strip heaters, oil burner, storage heaters	Electrical energy consumption
	19 A-A (E)	Watt-hour meters	-	Total HP system, kWh consumption, electrical baseboard H&C	Electrical energy consumption
	1 comm. (48 W-A)	Watt-hour and BTU meters, load recorder	-	Compressor, fan, total HP system	Electrical energy consumption and demand data
BPA(3)	25 res. 30 comm.	Watt-hour meters	Some on-site data	Total HP system, total house kWh	Electrical energy consumption and demand data
Alabama Power Company	15 A-A (E)	Watt-hour meters, Mag-Tape Recorder	1965 Birmingham Alabama data	Total house kWh, cooling heating, air-handling, defrost	Electrical energy consumption, COP and demand data
	4 A-A (E)	Watt-hour meters	1965 Birmingham Alabama data	Total house kWh, strip heat, dryer, water heater, cooling range, fan, return air temp, defrost.	Electrical energy consumption, defrost
	30 A-A (E)	Watt-hour meters	-	-	Electrical energy consumption
EPRI 432-1	77 A-A (E)	Watt-hour meters, WR4C Mag. Tape recorders	Outdoor dry bulb, humidity, wind solar from regional weather station	Compressor (heating and cooling), indoor fan, resistance supplement, total house	Electrical energy consumption and demand
ORNL Energy Storage(4)	152 A-A (E)	Primarily watt-hour meters	Some outdoor dry-bulb	Generally compressor packages and total house, sometimes indoor fans	Electrical energy consumption and demand

Notes

(1) A-A, air-to-air; W-A, water-to-air. Letters in parenthesis indicate back-up (E-Electricity; G-natural gas or propane; O-oil; S-storage or solar; N-none)
(2) Report not for public use.
(3) Sites and number of HP's to be monitored uncertain.
(4) Control houses for energy storage experiments at five utilities (see Table 2 and Appendix B).

of information at the time of report preparation. These programs are however included in the overall test summary of Table 2.

Most Level I programs have the advantage of modest objectives which could be satisfied with relatively simple equipment and analysis. The bulk of the programs appear to satisfy the requirements for qualitative, hands on information on heat pump performance which was the objective of most utilities. The energy input was normally measured with adequate accuracy and frequency of readings. Although there are often startup problems at the beginning of the tests, most utilities seem to feel that data loss due equipment reliability problems had not been a major concern. Likewise, weather data was usually available to permit normalization to average weather. Lastly, the choices of equipment, house style, occupancy patterns etc. seemed to be typical of the area.

In at least one program (TVA) Level I data in conjunction with statistical modeling to obtain estimates of average load profiles and energy savings. The results were judged to be at least marginally adequate for TVA planning. (The width of the error band for 95% confidence for the average demand was frequently only a few percent of peak load - however this few percent did represent significant generating capacities.) It is hoped that a larger test sample possibly with measurement of internal temperatures would yield substantially more accurate results.

The Level I testing constitutes a sizeable data base on energy consumption and demand profiles. We have identified 15 programs involving almost 600 heat pumps and there are undoubtedly more that did not come to our attention. Therefore this data might have broader use than the original utility objectives - more likely as a basis for statistical analyses. Since output was not measured it would be more difficult to use this data in conjunction with, or to verify, physically based analytical models.

Also it is possible that, with relatively little modification to the test equipment, future utility programs of this type might be upgraded to Level II, at least in the heating mode, by the use of the flip-flop method. (A description of the flip-flop method, including its shortcomings, is given on page 6-5.)

6.0 LEVEL II PROGRAMS

6.1 General Characteristics of Level II Programs

The Level II programs were generally designed to provide data which was both more detailed on a site specific basis and more capable of generalization than was the case for the Level I programs. Twelve programs involving over 100 heat pumps were identified. These programs all utilize some method of determining heat pump output (energy delivered) as well as input for each site so that seasonal performance factor could be obtained - at least for the heating mode. Very little cooling output data was obtained in the Level II programs identified.

The objectives of these programs frequently involved developing performance information for a range of climates (EPRI RP 432-1 and AGA) or getting reasonably definitive data for a particular region such as the Lincoln Electric Service studies.

6.2 Level II Critical Issues

Critical issues for Level II programs are listed in Table 6 and discussed below in the categories of primary test measurements, test conditions, and normalization.

6.2.1 Primary Measurements

The primary measurements for Level II programs are energy input and energy delivered.

- Energy input is, as was the case in Level I, easily measured by watt meters and either directly recorded on tape recorders such as the WR4C or with some type of intermediate micro processor

Table 6

LEVEL II CRITICAL ISSUES

PRIMARY MEASUREMENTS	o Energy Input (per Level I) o Energy Delivered - flip-flop * length, equality of periods * comparable inside temperatures * accuracy of outside temperatures - duct enthalpy flow * flow calibration/checks * differential temperature * water removal (cooling) - other methods * Calculated load * Load measured for similar house
TEST CONDITIONS	o Outdoor temperature (and humidity) o Intdoor temperature (and humidity) o Heat pump equipment - Size, type and model - ARI input (Steady State, C_D, etc) o Control strategy - Indoor thermostat cycling rate & set point - Compressor capacity variation - Supplement (outdoor thermostat, capacity variation) o Heat pump sizing and balance point o Duct design and supply/return temperatures o Deterioration due to: - Refrigerant leakage - Heat exchanger blockage
NORMALIZATION	o Correction to Average Weather o Comparison with "Expectations" * ARI method * Other methods

data acquisition system. This equipment is capable of sufficient accuracy (normally less than 1% error) and sufficiently frequent readings (normally every 15 minutes with the WR4C systems). However reliability or data loss can be a problem if the equipment is not properly serviced.

- Energy delivered is substantially more difficult to obtain. The three methods generally employed are:

  - The duct enthalpy method is the most direct method of measuring output. It has the potential of providing near continuous readings with good accuracy (i.e. within 5 to 10%) for sensible heating or sensible cooling. The measurement of latent cooling by either air stream humidity change or water removal from the coil is more difficult both in terms of response and accuracy. (The duct enthalpy method is mentioned for completeness and because it is a common technique for Level III. It has not however employed to date in any of the Level II programs identified - although it is included in AGA plans for cooling.)

  - The flip flop method, employed in about half the Level II programs, utilizes alternate heating of the building by resistance heat and the heat pump system being tested. Plotting this data as illustrated in Figure 3 defines both the energy input (heat pump data) and the energy output (resistance heat input = output since COP = 1.0) as functions of ambient temperature. These plots can be used in conjunction with the bin method of calculation to determine seasonal performance factor. The accuracy of this method is dependent on the experimental error associated with the input and output lines which in turn depends on the number, distribution, and scatter of the data points defining these lines. To date, no generally accepted procedures have been developed for flip-flop tests but experience has suggested

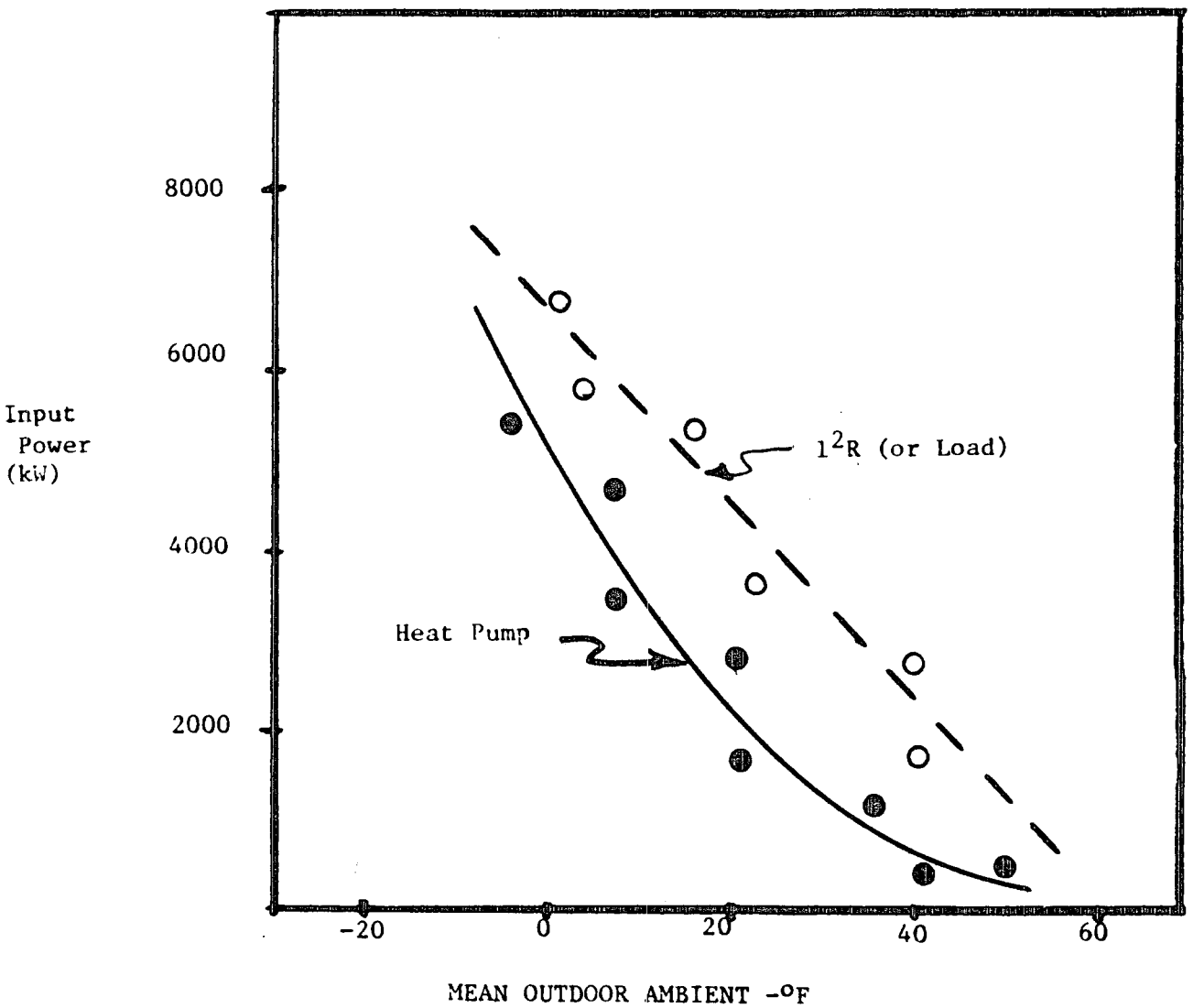


FIGURE 3

FLIP-FLOP METHOD OF DETERMINING LOAD AND HSPF

that a flip-flop schedule of equal periods of about one week each is near optimum and that accurate determination of on site temperature is critical. Accuracy is also dependent on the length of the heating season. A long season provides the opportunity for many flip-flop periods resulting in statistically well defined input and output lines. A short season will not provide enough data to define input and output accurately. Ideally the error could be as low as 7% in Northern locations but 10 - 15% is probably more realistic for the actual test results. While the flip-flop method requires less instrumentation than the duct enthalpy method, and in proper circumstances may yield acceptable accuracy, it also has many potential pitfalls. Some specific shortcomings of flip-flop tests extracted from a personal communication from Dr. Carl Hiller of EPRI are as follow:

1. Many flip-flop type tests end up using different thermostats, or different stages of the same thermostat having some offset in controlled temperature, for the heat pump vs. resistance heating modes. This results in the house being kept at a different temperature between the different flip-flop modes, and requires correction and normalization to identical operating conditions when analyzing the data. Such correction and normalization is frequently not done.

2. Flip-flop tests of house heating systems require an intelligent interval to be chosen for the flip-flop period, and in some climates no suitable interval may exist. This is because the thermal mass of the house can be such that it acts as an energy storage device, causing the energy input by one of the modes to be credited to the other mode. The thermal inertia of a house is frequently enough to cause such "carry over" of energy to last for 3 or 4 days, especially in mild weather. Unfortunately, especially in climates where heat pumps are predominantly found, mild weather conditions prevail, and furthermore, when severe weather conditions do occur, they tend to come and go over the same length of time as the flip-flop interval. This does <u>not</u> necessarily average out in the long run, because these warm or cold spells represent large fractions of the total seasonal energy consumption in milder climates. A fairly sophisticated correction and normalization procedure is necessary to correct for such inaccuracies, and is frequently not done.

3. Even if all other things are equal, or have been corrected to be equal, results of a specific test, under a specific year's weather are still not representative of how a particular system would behave "on the average." It is, therefore, necessary to normalize the observed performance to average weather conditions before meaningful conclusions can be drawn. Such normalization to average weather is frequently not done.

- Lastly, energy delivered can be estimated from calculated building load using a variety of calculation techniques. The accuracy of this method varies with the calculation technique but the error is likely to be in excess of 20%.

- A fourth method used in one program was the use of the load measured in a similar unoccupied building.

6.2.2 Test Conditions

Since seasonal performance factor is a function of many climatic, installation, and operating variables, control and/or monitoring of equipment installation and test conditions is important to assure that the equipment is properly installed and to provide a basis for normalization of the test results. Control of the installation involves proper duct sizing, proper heat pump sizing and proper mix of components. Proper monitoring includes both metered data such as weather, internal temperatures, supply and return temperatures and checks for degradation of steady state performance due to refrigerant leakage or heat exchanger blockage as well as non metered data such as the identification of the heat pump and the type of control strategy employed.

6.2.3 Normalization

Normalization of data for Level II programs generally involves correcting the measured performance factors to average weather conditions and comparison with predictions. The comparison most frequently

referenced is the ARI method (a comparative rather than predictive procedure) although other methods of analysis are also employed.

6.3 Review and Evaluation of Level II Programs

The salient features of the Level II programs are illustrated in Table 7. Brief program summaries are presented in Appendix B.

The twelve Level II programs involved almost 140 heat pumps of which about 115 were residential air-to-air units. All programs monitored energy input and output during heating and most monitored energy input during cooling. Very little of the data obtained to date in the Level II programs includes measurement of cooling load and cooling performance factor since the most common method of load measurement used (flip-flop) is not adaptable to cooling and an alternate approach (estimation of building load from degree days) is especially inaccurate for cooling. One exception is the ORNL-I program where the cooling load was assumed equal to that of an identical house where the load was measured. Some cooling COP data was also obtained in RP 1191-6. Measurement of cooling SEER is planned for the AGA programs.

The flip-flop method of output measurement was used in eight of the twelve programs (118 of 136 heat pumps). The length of the flip-flop periods varied from daily to weekly. (In one case an annual flip-flop was employed.) Although in an ideal case, it is estimated that the error could be kept to less than 10 percent, it is probable that actual errors were frequently closer to 10 to 15 percent - if not worse.

In three programs - (16 heat pumps) output was estimated from calculated values of building load. In two of these programs, building heat loss coefficients were estimated from the building characteristics and used in conjunction with average indoor and outdoor temperatures to estimate a (monthly) heating load. The heat pump output was taken to be the estimated building load corrected for internal heat generation due to non-HVAC electric usage and supplementary heat (stoves). In these cases the error

TABLE 7

LEVEL II PROGRAMS, PERFORMANCE FACTOR DETERMINATION

Program	Heat Pump Type[1]	Data Acquisition System	Weather Data	Energy Input Quantities Measured	Output or Load Determination	Presentation of Results
EPRI RP 432-1 (Westinghouse)	43 A-A (E)	Watt-hour meters, WR4C Mag. Tape Recorders	Outdoor dry bulb, humidity, wind solar from regional weather station	Compressor, (heating and cooling) indoor fan, resistance supplement-total house	Daily Flip-Flop[2]	SPF vs. Degree Day, vis a vis resistance, heat load profiles
EPRI RP 1191-6 (Okla State)	1A-A (E) 2 Others	Microprocessor Based System	Outdoor dry-bulb, humidity, insolation and wind	Compressor, resistance supplement blowers	Calculated from Oklahoma State Computer Program	Monthly Energy Consumption
LINCOLN ELECTRIC SERVICE	2 A-A (E) 1 A-A (G)	Mag. Tape Recorders	Local Weather Station	Heat pump and resistance supplement	Weekly, biweekly flip-flop	Seasonal perfor- determination via a bin method approach
ESEERCO I	11 A-A (E)	2 Mag. Tape Recorders	Collected directly at only 3 sites NOAA data	Compressor, resistance supplement, indoor fan (at two sites) and total house electric energy use	Daily or every other day flip-flop in some of the homes monitored	Average SPF for all tested and correlation of SPF to to best fit load line, manufacturer's data, and proprietary model
ESEERCO II	14 W-A (E) 1 other	Microprocessor Based DAS System	Temperature at site	Compressor, blowers, pump, resistance supplement and total house electrical use	Flip-flop technique every two days	Performance maps plotting SPF versus outdoor temperature and cycle number to outdoor temperature
OHIO EDISON	18 A-A (E)	Watt-hour Meter	Degree days	Compressor, fan, resistance supplement-total house	Annual flip-flop adjusted to equivalent degree days	Heating energy consumption and factors

TABLE 7

LEVEL II PROGRAMS, PERFORMANCE FACTOR DETERMINATION (Continued)

Program	Heat Pump Type	Data Acquisition System	Weather Data	Energy Quantities Measured	Load Determination	Presentation of Results
APA I	2 W-A (E)	Watt-hour Meter	Local monthly weather data	Heat pump system and total house	Used degree day approach to determine load	Average monthly COP, seasonal performance factors and energy savings
APA II	8 A-A (E) 3 comm.	Watt-hour Meter	Local weather station data	Similar to APA I	Similar to APA I	Similar to APA I
AGA	25 A-A (E)	Manual and IBM PC based DAS system capable of handling 11 sensors	Outdoor Dry Bulb temperature at each site; also humidity for cooling	Compressor, fans, total house, crankcase heater, resistance supplement	Flip-flop technique for heating, duct enthalpy for cooling	Primary goal of the program is SPF determination; other correlations, i.e., performance vs. HP type to be examined as funding permits.
ORNL-I	2 A-A (E)	Mag-Tape Recorder	Local Data	Outdoor unit (compessor/fan) and indoor unit (resistance supplement/fan)	Load assumed the same as an adjacent "identical home"	Monthly performance calculations compared to manufacturers steady-state COP
CITY OF PALO ALTO	1 A-A (E)	Watt-hour meters	Palo Alto Fire Station weather data	Total house, outdoor unit (compressor/fan) and indoor imot)resistance supplement/fan)	Daily flip-flop	Electrical energy consumption, energy savings, COP vs. temp
ONTARIO HYDRO	1 A-A (O) 1 A-A (G)	Temp sensors at inlet and outlet	-	Heat Pump unit (compressor controls, outdoor fan) and duct blower	Duct enthalpy	HP COP, electrical energy consumption.

NOTES

(1) A-A, air-to-air; W-A, water-to-air, Letters in parenthesis indicate back-up (E-electricity; G-natural gas or propane; O-oil; S-storage or solar; N-none)
(2) Flip-flop method implies the switching between alternative heating systems, usually heat pump and resistance heat, to define both input (heat pump operation) and output (resistance heat operation) as functions of ambient temperature.

was probably in the vicinity of 20% or more. In one instance a detailed computer load simulation was used and the error might have been somewhat less than 20%.

One program (2 heat pumps) used the load measured at a similar unoccupied house (error estimated at about 10%).

None of the Level II programs identified have used the duct enthalpy method to date. (AGA plans to use method for cooling.)

The degree of detail with which test conditions were monitored or controlled varied greatly among the individual programs. All had some measurement of outside temperature, although not necessarily at the specific test site - and in some programs outdoor humidity was measured as well. Indoor temperature was measured in about half the programs - and indoor humidity in one or two. Almost all programs had fairly good records on the heat pump equipment used, although ARI 240-81 input data may not be available for the older equipment. Many had descriptions of the control strategies employed - although control or monitoring of the actual indoor and outdoor thermostat settings was frequently lacking. In some programs measured or estimated balance points were recorded. However sizing of heat pumps and ducts was generally left to the installing contractor - and particularly in the case of ducts little information (such as supply/return temperatures) is available to judge their adequacy. There was virtually no information as to whether or not performance loss due to equipment deterioration may have occurred.

Presentation of test results and correlation with analysis has varied greatly in terms of the methods employed and agreement achieved.

- A correlation line was developed in RP432-1, comparing actual observed HSPF to theoretical steady state HSPF excluding dynamic losses. A wide scatter was noted, undoubtedly partly due to the flip-flop nature of the test. Actual observed performance ranged from 0 to 30% lower than the theoretical steady state HSPF.

- In ORNL-I actual test results showed HSPF values approximately 20% lower than the theoretical steady state HSPF.

- Two data points obtained by Lincoln Electric Service were compared with the ARI 240-81 values and found to agree within about 10 percent.

More discussion on field test results and correlation with analysis for Level II and III programs is given in Section 7.3.

The Level II information appears to be useful for locating specific performance factors particularly when data from several units is available and bracket the range of scatter attributable to experimental error and installation/occupancy factors. The value of most of presently available Level II data for model validation is very limited due to the aforementioned scatter.

The major uncertainties in Level II data arise from the measurement of load and the control and monitoring of test conditions. Load measurement can benefit from some rather specifically focused analysis such as the optimization of the length of flip-flop periods. Better control of test conditions is more subtle and involves a myriad of details of installation and monitoring involving sizing of heat pumps and ducts, control and recording of thermostat setup, and continuing checks of steady state performance to identify degradation due to refrigerant leaks. These concerns are recognized by most test managers and the relatively good correlation between analysis and test in some recent (and predominantly Level III) programs suggests that quality control is improving.

7.0 LEVEL III PROGRAMS

7.1 General Characteristics of Level III Programs

Level III programs seek to go further than Level II programs by establishing detailed dynamic performance particularly in terms of losses due to part load cycling and frosting/defrosting. These programs provide data useful for model development, as well as verification. Because of the need for more precise and essentially continuous measurement of energy output almost all of these programs use the duct enthalpy method of measuring energy output. Twelve Level III programs involving 57 heat pumps were identified.

7.2 Level III Critical Issues

The critical issues for Level III programs as listed in Table 8 and described below, include all those previously described for Level II with certain important additions.

7.2.1 Primary Measurements

Energy input and energy output are the same as described for Level II except that there is more emphasis on (and need for) accuracy and more nearly continuous measurements of energy output. As such most Level III programs use the duct enthalpy measurement of output.

Losses due to frosting/defrosting and part load cycling should be quantified and isolated. It is clearly important that any quantity identified as a loss be a true net loss rather than a particular category of energy consumption. For instance the energy input during the defrost process is not a net loss since some of that energy provides useful heating. In this case, the true net loss due to defrosting is the difference between the energy consumption during the defrost period and the "ideal energy" which would have been required to meet the building load during that period if no defrosting were necessary. The actual energy consumption can be measured directly.

Table 8

LEVEL III CRITICAL ISSUES

PRIMARY MEASUREMENTS	o Energy Input (per Levels I & II) o Energy Delivered (per Level II)(1) o Frost/Defrost - Cycles (number and length) vs. outdoor ambient - Losses due to frost formation and defrosting process - total and partitioned o Part Load Cycling(2) - Thermostat cycling rate - Cyclic response time - Losses due to start-up transients and off cycle parasitics - total and partitioned
TEST CONDITIONS	Level II plus special emphasis on: o Heating season outdoor humidity o Cooling season indoor and outdoor humidity o Indoor thermostat cycling rate setting o Type of defrost control
NORMALIZATION	o Level II plus isolation and analysis of losses due to frost/defrost and part load cycling.

Notes

(1) For Level III the duct enthalpy method which allows for continuous monitoring of instantaneous load is almost essential for measurement and understanding of frost/defrost and part load cycling losses.
(2) To date there is little commonality among the methods of measuring losses due to frost/defrosting and part load cycling.

The "ideal energy" can be obtained from the measured output (duct flow x temperature difference) divided by the steady-state COP corresponding to the measured indoor and outdoor temperatures.

For model development, understanding the physical mechanisms is essential. Therefore, in so far as is practical, there is value in partitioning these losses further into their major components. For instance the frosting/defrosting loss can be further subdivided into the components due to the loss in efficiency due to operation with frosted heat exchanger surfaces; the loss in capacity due to operation with frosted surfaces; and the energy lost during the defrosting process. Since the partitioning process may sometimes involve the small difference between two experimental quantities the results may carry a large percentage uncertainty and an error analysis is critical.

7.2.2 Test Conditions

Control and monitoring of test conditions is to a large extent similar to that required for Level II programs. However since these programs should provide input for model development there is additional emphasis on indoor humidity during the cooling season, outdoor humidity during the heating season, indoor thermostat cycling rate, and details of the defrost control.

7.2.3 Normalization

The Level III programs should at a minimum provide Level II type data which is normalized to average weather conditions and which can be readily used for model verification. Additionally it is important that the losses due to part load cycling and frosting/defrosting be defined in sufficient detail to:

- Verify independently the cycling and frosting/defrosting seasonal impacts predicted by bin type models such as ARI 240-81.

- Provide breakdowns of the losses into components and shorter time periods to provide for development and verification of dynamic simulation models.

7.3 Review and Evaluation of Level III Programs

The Level III programs are presented in Table 9. Summary descriptions are given in Appendix B.

These twelve programs involved 57 heat pumps, most of which were residential air-to-air heat pumps.

All as a minimum monitored energy input and output resulting in heating seasonal performance factor as did Level II programs. With one exception, all used the duct enthalpy method generally estimated to have an error of 5 - 10%. Most measured cooling energy input and a few (three programs, six heat pumps) had cooling output resulting in cooling seasonal performance factor.

In the Level III programs the data acquisition systems were generally more sophisticated and the control and monitoring of test conditions more precise than in the Level II programs. All had at least some type of measurement of dynamic losses and most provided some comparison between experimental results and analytical predictions.

Table 10 presents a sample of experimental values of HSPF obtained from eight programs (five Level II and three Level III) and an indication the type of comparison with analytical predictions which were employed. As shown, the earlier programs frequently presented no comparison with analysis - or used various types of comparisons with manufacturers' data which did not explicitly deal with dynamic losses. The more recent programs generally compared results with values obtained from ARI 240-81.

Table 11 presents a comparison of seasonal performance measured in Level III (and II) programs with predictions based on the ARI method. The results appear surprisingly good given the limitations of the ARI method and the number of potential error sources associated both with the primary

TABLE 9

LEVEL III PROGRAMS: DETAILED DYNAMIC PERFORMANCE EVALUATIONS

Program	Heat Pump Type[1]	Acquisition System	Weather Data	Energy Input	Output Determination	Dynamic Loss Measurements	Presentation of Results
EPRI RP 137-1 (Ohio State Univ.)	2 A-A (E)	IBM System 7 mini-computer in conjunction with an IBM 1130 CPU	Humidity, wind, solar, temp. and pressure measured	Continuous measurement of electrical energy input	Direct flow measurements within duct	Cyclic response	Ohio State model performance estimate vs. field test result (%)
EPRI RP 789-1 (Carrier Corp)	4 A-A (E) 1 Comm.	Multiplexing cassette recorder	Data collected at individual sites	Compressor, supplemental heating and total house (defrost energy segrated)	Direct measurement within ducts	Defrost energy and cycles, as well as number of heat pump cycles	HSPF and defrost energy as % of total heating kWh demand
EPRI RP 789-3 (Carrier Corp)	5 A-A (E) 1 A-A (G) 1 other	Like EPRI 789-1	Outdoor temperature	Like EPRI 789-1, along with all fan energies	Like EPRI 789-1	Like EPRI 789-1	Like 789-1 plus comparison of SPF with ARI 240-81 predictions
EPRI RP 2033-9 (Carrier Corp)	2 Comm. 10 A-A (E,G,O) 2 other	Similar to EPRI 789-1 and 789-3					
EPRI RP 1495-1 (General Electric)	7 A-A (E)	Mag. tapes	Data from nearby airport	Compressor, fan, resistance supplement - defrost energy use	Flip-flop method with resistance heat	Defrost energy, part load and defrost cycles, complementary defrost cycling laboratory tests	Comparison of HSPF results with ARI. Effect of cycling rate on losses.
EPRI RP 1201-14 (Univ. of Pittsburgh)	2 W-A (E)	Microprocessor based DAS	Data collected at site	House total, compressor, fan, water pump and resistance supplement	Sum of compressor kW and heat extracted from well water; checked against air duct measurements	Cycles recorded on counters. Cyclic response.	Energy and water use as a function of degree day. HSPF

TABLE 9

LEVEL III PROGRAMS: DETAILED DYNAMIC PERFORMANCE EVALUATIONS
(Continued)

Program	Heat Pump Type	Acquisition System	Weather Data	Energy Input	Load Determination	Dynamic Loss Measurements	Presentation of Results
NBS-I	1 A-A (E)	Chart recorders pulse counter/ printer	Temperature and humidity on site	Compressor, indoor fan, outdoor blower, (supplemental heat for defrost only)	Direct measurement within ducts	Correlation with respect to heating load factor	Many correlations (the first of their kind) and SPF measurement from data
NBS-II	3 A- A (E)	Microcomputer based DAS at each site	Dry bulb and dewpoint at sites	Compressor, fans resistance supplement	Direct measurement with ducts, including latent heat change	Cycling related by cyclic on time, thermostat and load factor	Comparison of field results to DOE test procedure, and results obtained from it
Univ. of New Mexico	4 (A-A) (E)	WR4C Mg. Tape recorders; A/D converters for continuous temperature signals	From a single recording station within Albuquerque	Major heat pump components, supplemental resistance heat, and the entire house	Flip-flop method with supplemental resistance heat and direct measurement(2)	Defrost energy measured and cyclic loss estimated	Load factor correlations and SPF estimates and comparisons
Purdue University	1 A-A (N)	Computer based DAS	Obtained on site	Heat Pump Compressor and blower	Duct measurement of thermal and mass flow at various points within system	Cycling correlations based on thermostat type and energy losses developed; fundamental frosting performance studied	Evaluation of steady state, transient and frosting performance
ORNL-II	1 A-A (E)	Microprocessor based DAS	On site weather station	Compressor, fans and resistance supplement	Duct enthalpy with condensate measurement	Detail measurement of cycling and defrost loss components	Comparison SPF with ARI. Partitioned dynamic losses. Heating and cooling C_D
Princeton University	10 A-A (E)	Magnetic tapes with computer data reduction	Dedicated local weather station	Compressor, auxiliary heat, defrost, total house	Direct measurement within ducts	Defrost energy	Compressor COP and seasonal performance factors

Note:

(1) A-A, air-to-air; W-A, water-to-air. Letters in parenthesis indicate back-up (E-electricity; G-natural gas or propane; O-oil; S-storage or solar; N-none).

(2) Two phases - 1970-1976 season, 4 units flip-flop; 1977-1978, 2 units direct measurement supplemented by laboratory test.

TABLE 10

FIELD MEASURED HSPF FOR RESIDENTIAL AIR-AIR HEAT PUMPS

PROGRAM	TEST PERIOD	LOCATION(S)	TYPE OF HEAT PUMP	NO. OF UNITS	RANGE OF HSPF(3)	COMPARISON WITH ANALYSIS
OHIO EDISON	1973-75	OH	NOT STATED	8	4.5 - 7.0	NOT STATED
RP 432-1	1975-77	FL,TX,CA,AR, NM,NY,MI,MN NJ,PA	VARYING 1 1/2 - 5 TON 1967-76	43	3.8 - 8.1	0 - 30% SHORTFALL RELATIVE TO "IDEAL"(1)
ESEERCO-I	1976-77	NY	VARYING 3 - 5 TON	11	4.8 - 6.6	WITHIN + 20-25% OF MANUFACTURER'S DATA USING ADJUSTED LOAD LINE(2)
RP 789-1	1976-77	MN,NY,MA,WA	CARRIER 38 BQ (MID 1960'S)	4	4.1 - 7.5	NOT STATED
RP 1495-1	1981-82	NY,PA,TN	IDENTICAL 2 1/2 TON SINGLE SPEED UNITS	7	4.6 - 6.0	2 - 12% SHORTFALL RELATIVE TO ARI (SEE TABLE 11)
ORNL-I	1977-80	TN	TYPICAL AND "HIGH EFFICIENCY"	2	5.4 & 6.8	20% SHORTFALL RELATIVE TO "IDEAL"(1)
ORNL-II	1982-83	TN	3 TON "STATE OF ART"	1	6.5 & 6.8	WITHIN 2% OF ARI (SEE TABLE 11)
LINCOLN ELECTRIC	1983-84	NB	YORK 2 TON RUUD 3 TON	2	6.6 & 7.3	WITHIN 10% OF ARI FOR REGION IV (SEE TABLE 11)

Notes:

(1) "Ideal" performance is based on manufacturer's steady state performance with no allowance for part load cycling and frost/defrost.
(2) Load line increased by two standard deviations.
(3) HSPF expressed in BTU/WATT-HR.

experimental measurements and the definition of the test conditions. Some factors associated with equipment, installation, and the ARI method which tend to introduce errors between measured and ARI values include:

- Differences between the actual steady state COP of a particular unit and the nominal ARI value - an error of up to + 5%.

- Uncertainty in loads and balance point. A variation in balance point of $5^{o}F$ can produce a change of up to 10% in HSPF.

- Uncertainty in internal temperatures. A $1^{o}F$ increase in internal temperature is roughly equivalent to a 1% loss in COP.

- The ARI 240-81 method assesses its frost/defrost penalty at a specific temperature and relative humidity. There is reason, and some experimental evidence to suggest that the actual frost/defrost loss varies with relative humidity. Also the selected temperature of $35^{o}F$ may not adequately penalize large exchangers where frosting may tend to be shifted to lower temperatures.

- The ARI 240-81 cycling test is performed at 3 cph whereas actual thermostats have different cycling rates. Some experimental evidence has shown that cycling loss is a function of cycling rate. (The results from one program (RP 1495-1) suggested that the ARI 240-81 procedure overestimates cycling loss - and underestimates frost/defrost loss.)

One factor leading to good agreement between analysis and experiment is that comparisons with test results have frequently involved experimental feed back of measured steady state performance and load which circumvents some of the error which might normally be expected if ARI 240-81 were to be applied using nominal steady state performance and estimated loads. (This type of experimental feed back has some justification since it eliminates some extraneous sources of error not directly related to the ability of ARI 240-81 to deal with dynamic losses.) Therefore while the comparison in Table 11 does appear

TABLE 11

Comparisons Between Experimentally Derived Seasonal Performance Factors and ARI 240-81 Predictions

Program	Season/Site	Parameter[4]	Measured	Predicted	% Error[1]
ORNL II	First Season	HSPF	6.52	6.79	-4.2
		SEER	8.23	7.99	2.9
	Second Season	HSPF	6.76	6.79	-0.5
		SEER	7.85	7.99	-1.7
Lincoln Electric Service	Site 1	HSPF	6.62[2]	--	±10%[3]
	Site 2	HSPF	7.27[2]	--	±10%
RP 1495-1	Site A	HSPF	5.77	5.87	-1.8
	Site C	HSPF	4.61	5.15	-11.9
	Site D	HSPF	5.97	6.52	-9.1
	Site E	HSPF	5.87	6.52	-11.0
	Site F	HSPF	5.77	6.31	-9.5

NOTES

(1) % Error = (Measured - Predicted)/Measured X 100
(2) Values normalized for average weather conditions
(3) Program Manager Estimate based on ARI 240-81 rating for region IV (personal communication)
(4) HSPF and SEER are expressed in BTU/WATT-HR
(5) The sources for ORNL-II are references C-36 and C-30; Lincoln Electric Service, C-20; and RP 1495-1, C-16

encouraging, it should be recognized as representing a relatively small sample of heat pumps in which the analysis and data reductions techniques were not necessarily similar.

All of the Level III programs had some means of defining dynamic performance. The methods varied from measuring energy inputs during defrost (EPRI/Carrier programs) to detailed measurement and partitioning of losses (ORNL-II).

Table 12 illustrates dynamic losses due to part load cycling and frost/defrost reported in Level III programs and some other sources including analysis. The loss - or degradation - parameter used in Table 12 is defined as follows:

$$\text{Degradation in HSPF} = \frac{HSPF' - HSPF}{HSPF'}$$

where:

HSPF = actual heating seasonal performance factor including penalty for dynamic loss(es)

HSPF' = ideal heating seasonal performance factor which would have existed in the absence of dynamic loss(es)

Since: $HSPF = \frac{Q}{KW}$, and $HSPF' = \frac{Q}{KW'}$

where:

Q = seasonal heat output or load
KW = actual seasonal energy output
KW' = ideal seasonal energy input

Therefore, it can be shown algbebraically that:

$$\frac{HSPF' - HSPF}{HSPF'} = \frac{KW - KW'}{KW} = \frac{\text{Loss}}{\text{Actual Input}}$$

TABLE 12

ESTIMATES OF CYCLING AND DEFROST LOSSES FROM VARIOUS SOURCES

Source	Basis	Approximate Degradation in HSPF (%)(1)		
		Part Load Cycling	Frost/ Defrost	Combined Total
Bittle & Goldschmidt(2) (D-13)	Calculated using ARI 240-81 for 6 DOE Regions	2-17	1-2	
Wildin, et. al. (C-26, C-31)	Albuquerque, NM Field Tests, Laboratory Tests, and Analysis	13-17(3)	0-5(4)	
RP 789-1 (C-2)	Field Test Data		3-6(6) (4-9)(5)	
Bullock and Reedy (D-27)	Analysis Based on Laboratory Test Data	5(3)		
EPRI End Use Catalogue pg. 94 (A-8)	General Experience			up to 14
ORNL-I (C-29, C-34)	Knoxville Field Tests '79 - '80			20(7)
ORNL-II (C-36, C-30)	Knoxville Field Tests '81 - '83	12.7(8)	13.8(8)	26.5(8)
NBS I (C-27)	Detailed Evaluation of A-A HP field tests (376 hours)			19(7)

Notes:

(1) Degradation is defined as $\frac{HSPF' - HSPF}{HSPF'}$ where HSPF' and HSPF are ideal and actual values of heating seasonal performance factor (see prior section 7.3 for expanded definition).

Notes (Continued):

(2) The percentages reported are referenced to actual rather ideal. Therefore larger values (i.e., 17%) may overstate degradation by 2-3 percentage points.

(3) These estimates are based on application of laboratory part load factors to field operating conditions.

(4) During initial testing ('75-'76) defrost loss was judged to be negligible based on monitored defrost times. In subsequent tests ('77-'78) the measured consumptions during defrosting (see note 5) were 3.4% and 5.4% for demand and time temperature units respectively. These relatively high values were attributed to abnormally damp weather.

(5) Measured consumption during defrost. Does not include either credit for useful heating or impact (positive or negative) of frosting.

(6) Defrost consumption of (5) minus estimated credit for useful heating.

(7) Measured HSPF compared with ideal value based on manufacturers steady state performance.

(8) Detail measurement of individual loss components.

Experimental results are frequently reported as the ratio of loss to actual input - which as shown above, is equivalent to the degradation in HSPF. In some cases, the numerical values reported are either not strictly consistent with the Table 12 definition of degradation - or represent a type of consumption rather than a true net loss - and these instances are discussed in the following paragraphs.

Methods of determining the degradations reported in Table 12 have varied widely and include:

- Calculation of HSPF with and without losses using ARI 240-81. Bittle and Goldschmidt applied this method to ten heat pumps for each of the six DOE regions and reported the gains in average HSPF which could be achieved in each DOE region by eliminating, in turn, part load cyclic losses and frost/defrost losses. The percentage gains reported are not strictly in accordance with the definition of degradation noted above since the differences in HSPF obtained were reported as percentages of the actual, rather than the ideal HSPF. For degradations or gains of a few percent, this error is insignificant. However, the 17% gain reported probably overstates the corresponding degradation by about 2-3 percentage points.

- Estimation of overall combined loss by comparing actual measured HSPF with ideal HSPF calculated from steady state performance. This method could be applied to many Level II as well as Level III tests. Errors involve experimental measurement of HSPF (primarily the load or output) and calculation of HSPF (errors due to uncertainties in actual installed steady state performance as well as load). Results of this type were reported in the ORNL-I and the NBS-I programs.

- Estimation of part load cyclic loss from laboratory measurement of part load factors applied to the actual part load conditions experienced in the field. This approach was used by Wildin, et al and by Groff and Reedy.

- Direct measurement of individual dynamic losses.

  - In some programs, the total energy consumed during the defrost process was measured which provided a simple, reasonably accurate, upper limit on the defrost loss. These consumption results were either reported "as is" (Wildin, et al) or corrected by an estimated credit for useful heating (RP 789-1). Neither of these two programs measured the impact of frosting.

  - In one program (ORNL-II) detailed direct measurements of individual dynamic losses were obtained including the partitioning of the frost/defrost losses into the the frosting and defrost components as well as the subdivision of the part load cycling losses between start-up transients and off cycle parasitics. In all cases the losses reported were intended to be true losses rather than just a category of consumption. For instance the loss during a defrost cycle (or a start-up transient or frosting period) was obtained from the measured energy input minus the energy input which would have been required to heat the building if the heat pump were operating at steady state COP. This method is algebraically precise but can entail significant error since the desired answer is the difference between two experimental quantities. This error is particularly large, perhaps of the order of one third, in the case of the frosting loss since the steady state energy input is only slightly less than the actual energy input.

As the above discussion and Table 12 indicate, the measurement of dynamic loss has been far from extensive to date. The amount of information available is small and much of it is of questionable accuracy. Very little comparison with analysis is available, although the RP 1495-1 work suggested that ARI 240-81 overestimated cycling loss and underestimated

frost/defrost loss. On the other hand it is our understanding that the individual dynamic losses reported in ORNL-II have been found to be in generally good agreement with predictions based on the ORNL APF model.

Although the accuracy of the Table 12 results is uncertain, they do suggest that dynamic losses can be significant with combined losses approaching or exceeding 20% in some instances - and individual values of part load cycling and frost/defrost approaching 15%. While it is possible that many combinations of installed heat pump equipment and climate may result in substantially lower, and possibly minimal, dynamic losses, the fact that the large losses can occur in some situations is sufficient justification to merit more precise experimental and analytical treatment. In particular since cycling and defrost losses may become a higher percentage of seasonal energy consumption as steady state efficiencies improve, more attention must be given to such effects when developing advanced heat pump equipment.

As a final point it should be noted that percentage losses may be somewhat misleading since they typically are largest when the duty cycle - and total energy consumed - is lowest. In these cases while the percentage loss is high, the absolute loss - and energy cost penalty - may be relatively unimportant.

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D-26 Fan Cycling Effects on air Conditioner Moisture Removal Performance in Warm, Humid Climates. Mukesh K. Khattar, N. Ramanan, M. Swami, Florida Solar Energy Center, presented at the International Symposium on Moisture and Humidity, April 15 - 19, 1985, Washington, D.C.

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APPENDIX A

LIST OF ORGANIZATIONS

AND INDIVIDUALS CONTACTED

A.1 Manufacturers

Carrier Corp.	-	Charles Bullock	(315) 432-6204
		Gerald Groff	(315) 432-6204
Westinghouse Electric Corp.	-	Stephen Veyo	(412) 256-7638
General Electric Co.	-	Heinz Jaster	(518) 385-0162
Trane Co.	-	Floyd Hayes	(608) 787-3404
		Jim Crawford	(214) 581-3603
Owens-Corning Fiberglas Corp.	-	Merl McBride	(614) 587-0610
York Div., Borg-Warner Corp.	-	Jim Harnish	(717) 771-7165
Bard Manufacturing Co.	-	Fred Paepke	(419) 636-1194

A.2 Utilities

Alabama Power	-	Nance Lovvorn	(205) 250-4377
	-	C. Fredrick Will	(205) 250-4443
Tennessee Valley Authority	-	Steve Morrow	(615) 751-5162
		Paul Cooper	(615) 751-5622
American Electric Power	-	Bill Coleman	(614) 223-2705
Ontario Hydro	-	Dave Young	(416) 231-4111
Empire State Electric	-	Herb Kaufmann	(212) 246-4300
Commonwealth Edison	-	Art Barsema	(312) 294-2868
Public Service Gas & Electric	-	Jim Griffith	(201) 761-1007
Central Hudson Gas & Electric	-	W.J. Kelly	(914) 452-2000
Kansas City Power & Light	-	Linda McKinzie	(816) 556-2142
Lincoln Electric System	-	Darryl Brewster	(402) 423-3274
Long Island Lighting	-	Joe Mankowski	(516) 785-5110
Niagara Mohawk	-	Richard O'Neil	(315) 474-1511
Ohio Edison	-	Donald Smith	(216) 384-5826
Orange and Rockland Utilities	-	Cliff Herbst	(914) 352-6000
Union Electric	-	Charles Grandy	(314) 554-3131
Portland General Electric	-	Doug Boleyn	(503) 220-3061
		Ron Genuich	(503) 226-7448
Pacific Power and Light	-	Carl Stulz	(503) 243-4866
Palo Alto Electric Utilities	-	Mike Beanland	(415) 329-2277
Northeast Utilities		Robert Garbe	(203) 665-3484
		Russ Johnson	(203) 665-3469
Puget Sound Power and Light	-	Joel Jackman	(206) 454-6363
Florida Power Corporation	-	Henry Allan	(813) 866-5663
		Mike Anderson	(813) 866-5662
Carolina Power and Light Company	-	Carl Wilkin	(919) 836-7668
Ketchikan Public Utilities	-	Wade Unruh	(907) 225-3111
New England Electric	-	Dorothy Conant	(617) 366-9011

Utilities (Continued)

Detroit Edison Company	-	Larry Kasik	(313) 897-1105
		Richard Popeck	(313) 897-1339
Baltimore Gas & Electric	-	Thomas Humphreys	(301) 298-1941
Mississippi Power & Light	-	Shellie Herrington	(601) 969-2635
Pennsylvania Power & Light	-	P.L. Roberts	(215) 770-5534
Philadelphia Electric	-	John Lowrey	(215) 841-5590
Virginia Electric & Power	-	Don Virgin	(804) 771-3440
Eugene Water & Electric	-	Bob Lorenzen	(503) 484-1125
Wisconsin Electric Power	-	Robert Krubsack	(414) 277-3187
Utah Power & Light	-	Steve Lewis	(801) 535-4169
New York State Electric & Gas	-	Antoinette Tobin	(607) 729-2551
Bonneville Power Administration	-	Brad Miller	(503) 230-5872
	-	Linda Sato	(503) 230-5872
	-	Terry Oliver	(503) 230-5476
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Texas Electric Service	-	Lee Moore	(817) 336-9411
Public Service Company of New Mexico	-	Tom Nesmith	(505) 848-4600
Houston Lighting and Power	-	Jeff Mangum	(713) 966-7065
Texas Power and Light	-	Leo Stambough	(214) 698-7720
Consumers Power Company	-	Bob Albrecht	(517) 788-2200
		Bill Berry	(517) 788-2940
United Power Association	-	Vance Zehringer	(612) 441-3121

A.3 Government Agencies

Oak Ridge National Laboratory	-	Philip Fairchild	(615) 574-2020
		Van Baxter	(615) 574-2104
Brookhaven National Laboratory	-	Philip Metz	(516) 282-2123
National Bureau of Standards	-	David Didion	(301) 921-2994
National Research Council Canada	-	Raymond Chauhan	(613) 993-1421
Solar Energy Research Institute	-	Ron Judkoff	(303) 231-1000
Department of Energy	-	Terry Statt	(202) 252-9127
		Mike McCabe	(202) 252-9130
		John Talbot	(202) 252-9130
Department of Defense	-	Casto de Biasi	(703) 325-0155
		Jerry Williams	(202) 767-6237
Department of Housing and Urban Development	-	David Moore	(202) 755-6900
Department of Army	-	Gary Phetteplace	(603) 646-4464
Cold Regions Research and Development Laboratory			
Florida Solar Energy Center	-	Mukesh Khattar	(305) 783-0300
North Carolina Alternative Energy Corp.	-	Tom Phelps	(919) 549-9046

A.4 Universities

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Purdue	-	Ray Cohen	(317) 494-2128
		David Tree	(317) 494-5694
		Victor Goldschmidt	(317) 494-2130
University of Pittsburgh	-	Richard Dougall	(412) 624-5335
University of Illinois	-	W. Stoecker	(217) 333-0916
University of New Mexico	-	Bud Wildon	(505) 844-6013
University of Oregon	-	Gordon Reistad	(503) 754-2575
University of Texas	-	Bruce Hunn	(512) 471-3104
Princeton University	-	David Harrje	(609) 452-5190

A.5 Installers

Heat Pump Association (PEPCO)	-	Joe Marielli	(202) 872-2468
Home Heating & Air-Conditioning	-	Lionel Boullin	(301) 585-8100
Bennett Air Conditioning	-	Art Bennett	(301) 449-1680
Heat, Inc.		Leon Brassard	(603) 889-0104

A.6 Associations

American Society of Heating Refrigerating and Air Conditioning Engineers, Inc. (ASHRAE)	-	Richard Wright	(404) 636-8400
American Refrigeration Institute (ARI)	-	Mike Woodford	(703) 524-8800
International Energy Agency (IEA) Heat Pump Center	-	Karl-Otto Holzapfel	011-49-7247/824541
American Gas Association (AGA)	-	Ab Rheem	(703) 841-8400
		Mark Menzer	(703) 841-8562
		Michael Kwart	(703) 841-8575
Electric Power Research Institute	-	Arvo Lannus	(415) 855-2398
		Jim Calm	(415) 855-8949
		Carl Hiller	(415) 855-8950
		Gary Purcell	(415) 855-2168
Gas Research Institute (GRI)	-	A.R. Maret	(312) 399-8100
Canadian Electric Association	-	Harvey Douglas	(514) 937-6181
Edison Electric Institute (EEI)	-	Robert Griffin	(202) 828-7514
National Rural Electric Cooperative Assoication (NRECA)	-	Lowell Endahl	(202) 857-9598

A.7 Contractors/Others

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		Bob Fischer	(614) 424-4040
		Frank Jacob	(614) 424-5326
Battelle PNL	-	Bill Sandusky	(509) 376-8343
		Richard Mazzucchi	(509) 376-4737
Synergic Resources Corp.	-	Rich Crane	(215) 667-2160
Dubin-Bloom	-	Robert Sparkes	(203) 236-1654
Vitro Corp.	-	Terry Logee	(301) 231-1407
Karpay & Associates	-	Buzz Karpay	(315) 437-1780
W.S. Flemming & Assoc., Inc.	-	Patrick Hughes	(315) 437-1780
		Harry Misuriello	(202) 543-7212
Watt-Count	-	Don Tebbet	(615) 373-3598
ETL Testing Laboratories, Inc.	-	George Yamamoto	(607) 753-6711

APPENDIX B

TEST PROGRAM SUMMARIES

B.1 Level I Programs

B.1.1 New England Power Service Company

New England Power Service Company (NEPSC) initiated a heat pump (HP) monitoring program from 1982-1984. Six of the HPs monitored were air-to-air (A-A) dual-fired oil and gas; three were air-water (A-W) electric systems. As a baseline group the utility also monitored and compared the performance of these systems to two water-source, and four A-A electric HP systems. The primary objectives of the program were to:

- gain hands on experience of the performance of various types of HP systems;
- verify lab test results;
- better understand HP load management; and
- obtain data that could facilitate the promotion of HPs.

Monitoring of the systems was conducted in the New England region. To obtain the data, NEPSC used watt-hour meters in conjunction with three channel data pulse recorders. Every 15 minutes data were obtained from the total HP system, supplementary heating and outdoor temperature. Temperature sensors were used at only half of the sites and the weather data were taken to be typical of the entire HP sample homes. In one case where the outdoor temperature was not monitored, NEPSC used the available channel to monitor the fan and blower of the HP system separately. Oil and gas consumption were also recorded from the dual-fuel systems. Only one home monitored indoor temperatures.

To assure accuracy of the data acquisition system, manual readings of the watt-hour meters were taken every month. If any data loss were noted, a "Bad Status Code" would be recorded and the data would not be used. Of the 12-14 homes monitored, there were no major problems with the data. NEPSC noted, however, that difficulties were encountered with placement of outdoor temperature sensors. In some instances too much wind protection and inconsistences in placing the sensors resulted in inaccurate

temperature readings due to excessive solar gain. The thermostats were put together in their lab and later found to have inadequate shielding.

Analysis of the data is being done on the six A-A HPs and a report should be available in late Spring of 1985. No conclusions have currently been drawn on any of the systems and no analyses have begun on the three A-W HP systems. It is expected that the study will provide a description of dual fuel and A-W HPs rather than a quantitative, statistically valid analysis. No normalization for the weather was conducted, but the data is being compiled in 5° temperature bins for subsequent analysis.
Preliminary data was provided by staff at NEPSC and through telephone conversations in January - April of 1985 (Reference C-23).

B.1.2 Eugene Water and Electric Board

Engene Water and Electric Board began a HP monitoring program in 1978. Since this time, six electric HPs, five of which were A-A systems, have been monitored along with six other Energy Efficient Homes having electric resistance heating. These 12 homes that are being monitored as part of Energy Efficient Homes (EEH), will be compared to a baseline of 13 electric resistance heated homes and one conventional HP home, that are not part of the EEH program. The main objective of the program has been to validate the use of HPs and EEHs in the Eugene Service Area.

Watt-hour meters and demand meters were installed to monitor space heating, water heating, and total kWh consumption for each house; lighting and appliances kWh were calculated by subtracting space and water heating from the total kWh of the house. A demand meter for the total house kWh, measured peak consumption demand for the month based on 15 minute intervals. The meters were read manually on the first day of each month; no tapes were used. Major operational problems were not encountered with this type of monitoring system. Although weather data was not monitored, data was available from the nearby Eugene Airport. Geographically, the airport site was very similar to the HP sites monitored.

Energy savings were calculated by comparing the average savings of the EEHs with the 14 baseline conventional systems. Eugene Water and Electric Board did some preliminary statistical analysis, but the sample size was not intended to be statistically valid. The study provided general findings and savings that can be expected with HPs in EEHs.

No normalization of the data was conducted by Eugene Water and Electric Board. However, the data obtained by the utility has been sent to Lawrence Berkeley Labs and Ecotope. Ecotope, a Seattle based firm, has calculated confidence factors of the data and is doing research on the data for the Northwest Power Council. No official report is available from the utility, or Ecotope at this time, but monthly summary data has been compiled by Eugene Water and Electric Board (Reference C-25).

B.1.3 Baltimore Gas and Electric

Baltimore Gas and Electric conducted a HP monitoring program of 25 A-A high efficiency HP systems from August 1976 - August 1977. The monitoring program took place in the Baltimore Gas & Electric (BG&E) Service Territory. The primary objectives of the program were to:

- gain a better understanding of the maximum demand HPs have on the utility system;
- conduct economic analyses of HP performance;
- obtain data on load profiles of HPs to facilitate load management; and
- provide consumers with information to educate them about HP systems.

The utility used WR-4C magtape recorders and watt-hour meters to obtain 15 minute intervals of data. An IBM 360-65 computer was used to conduct a

regression analysis. Once a month meters were checked manually with the types to assure accurate readings. For this study, the compressor; combined supplementary heat, compressor, and fan; and total house kWH were monitored with approximately five or six submeters on each house. Ambient temperature data were obtained from the local airport station.

Baltimore Gas & Electric did not feel it was necessary to undertake a sophisticated statistical analysis for their study objectives. To determine the magnitude of the load and shape of the load that HPs might generate from a planned housing development with HPs; the utility chose to sample 11 percent of the heat pump population - 25 single-family homes (12 Ranch, 5 split foyer, 4 Colonial, 2 Split-level and 2 Cottage style). No error bound or confidence interval were calculated. Their study to determine the impact of HPs on load was sufficient to satisfy the utility needs. A detailed statistical analysis was not necessary.

A report has been written by Baltimore Gas & Electric to summarize their HP program. This report however, has only limited availability (Reference C-24).

B.1.4 Tennessee Valley Authority

The Tennessee Valley Authority (TVA) monitored 18 A-A electric HP systems in representative homes in Nashville during the heating season 1982-1983. Their main objectives were to determine the impact of HPs on the utility system demand in the Nashville service area, and estimate energy savings from HPs.

Electric energy consumption of the total house, compressor, and resistance strip heat were monitored on wattmeters and recorded at 15 minute intervals on WR4C magnetic tape recorders. Ambient temperature data were obtained from the Nashville weather station. Data reliability was initially poor, in a preliminary test period (1981 - 1982), due to a variety of equipment and operational problems. However, during the 1982-1983 season reliability was substantially upgraded - to a reported 95%. Manual wattmeter reading

at the time of data pickup were used as a check, and back-up, for the magnetic tape recorders. Where limited data loss did occur, the data was "patched" using other data for similar weather.

A statistical model was used to normalize the data to standard conditions (i.e. a single set of building and heat pump characteristics). The resulting normalized data was used to generate average load profiles and energy savings. These average results were considered useful for approximating the value of heat pumps for reducing demand and energy consumption. However, it was felt that more accurate results, probably involving a larger and more geographically diverse sample and the measurement of internal temperatures, would be required for quantitative utility planning. No attempt was made to use this data to estimate individual - as opposed to average - savings - however it was felt the error band on individual savings would have been very wide.

This program is described in a TVA report (Reference C-13). Further inmformation was obtained in a visit to TVA on May 14, 1985.

B.1.5 Kansas City Power and Light

Kansas City Power and Light (KCPO) monitored 12 HP systems during the heating seasons from 1981-1984. Ten of the HPs were A-A electric add-on systems with gas furnace, and one was an A-A electric add-on system with a propane furnace as the back-up and one other system was an A-A electric add-on system with electric resistance heat. The main objectives of the monitoring program were to gain promotional information for HPs and to better understand load management issues associated with HP systems.

KCPO used magnetic tape recorders with pulse initiated kWH meters and pulse initiated gas meters to monitor each of the 12 homes. The total kWH consumption for the house, kWH for the total HP system, and mcf or kWH for the back-up systems were monitored. Manual checks were conducted once a month, when the tapes were changed to assure accuracy of the data acquisition equipment. Very little data loss were noted and there were no major

operational problems. Weather data were obtained from the local airport station and a station within the KCPO service area. The hourly weather data were adequate for their needs.

The 12 homes monitored were randomly selected by the installing dealers who choose homes where customers were willing to participate in the monitoring program.

No normalization of the data was conducted, but the utility is very satisfied with the accuracy and results of the monitoring. Although the sample size is not statistically valid, they still met their objective by obtaining first hand knowledge and experience with HPs for a descriptive analysis. No report is available; all information was obtained through phone conversations with staff at the utility.

B.1.6 Wisconsin Electric

Wisconsin Electric monitored 7 A-A gas add-on HPs during the 1979-81 heating season. The main objectives of the program were to gain hands on experience as to the HPs performance relative to a conventional gas furnace and the economic analysis/energy savings available from HPs. They also wanted the data to help educate consumers about HPs.

Watt-hour meters (for HPs) and gas flow meters (for gas furnaces) were used to monitor the seven homes. Homeowners would read the meters monthly and utility personnel would check the monitoring occasionally, especially if a particular meter reading appeared inaccurate.

Timeclocks were used for the daily flip-flop between the gas furnace and the HP system. Five of the homes during the 1979-1980 heating season were dropped from the analysis due to severe timeclock control problems. Problems were also encountered with the remote readouts used on the gas meters. The second year of the monitoring program was therefore initiated to obtain reliable data on all of the seven homes.

No normalization of the data was done. Local airport data was available, however, it was not necessary for their analysis. No statistical analysis was conducted, because it was also deemed unnecessary for an adequate economic analysis.

This summary was compiled as a result of telephone interviews with utility personnel and a report available from the utility (Reference C-12).

B.1.7 Florida Power Corporation

Florida Power Corporation conducted two similar monitoring programs. The first program monitored four identical homes from October 1978 - February 1979 in West Country, Florida. Two of the four homes used A-A heat pumps and the other two homes used resistance heat. The main objectives of this program were to identify actual energy savings from particular energy conservation implementation schemes and to help promote the installation of HPs to builders.

To monitor the homes, watt-hour meters and recording temperature monitors were used to measure kWh consumption of the total house, total HP system and hot water. kWh consumption was recorded every 15 minutes. A central programmer was also formulated to simulate people with identical occupancy patterns: lights, ranges, showers, etc., were programmed to operate at the same time. No major operational problems were encountered with the monitoring system. The data were manually checked at least once a month against the recording meters. The kWh data was stated by the utility staff to be very accurate (i.e. within 2%).

The four homes were built and selected by U. S. Homes on the same street, have identical floor plans and have the same orientation. The baseline home incorporated the standard energy features of homes in the test area, the three other homes were much more energy efficient: one with electric resistance heat and the other two with high efficiency A-A HPs with hot water heat recovery.

Data obtained from these four homes was very accurate and adequate for meeting the utilities needs for determining energy savings and promoting HPs. No normalization of the data was necessary. The general conclusion relative to HPs were: the use of HPs for space heating saved 52% of the energy requirements, and using both HP and super insulation reduced energy requirements by 68%.

Florida Power Corporation in conjunction with AMREP, conducted a very similar program to that described above for a ten month period in 1981. Two test homes were constructed to be monitored: a standard home meeting Florida State codes and a home to meet Florida's Power's Energy Saver New Home Award standards. The energy efficient home used an A-A high efficiency heat pump.

Monitoring and calculation of energy savings were basically an elaboration of the early monitoring program. No major difficulties were encountered. Energy saving results of both programs are identified in reports available through staff at the utility (References C-38 and C-39).

B.1.8 Northeast Utilities

Northeast Utilities has conducted several monitoring programs of HPs. From 1979 - 1981 four, three ton GE A-A add-on HPs were monitored in Massachusetts using an oil furnace, ceramic storage, water storage and solar as the supplemental energy sources. The main objective of the program was to evaluate alternative methods for supplying supplemental energy, taking into account load management.

To monitor the homes, the utility used four Westinghouse single phase watthour meters, two WR-4C four-channel logging recorders, and one Hagen Model 111-25 Pulse - Transmitter for temperature. Measurements were taken every 15 minutes of kWhs consumed for the compressor, fan/strip heaters, oil burner, and storage heaters. Controls were implemented to simulate demand on time-of-use pricing structures. The time, load, and temperature pulses obtained from the recorders were translated to a computer program.

This computer program combined the kWH data with solar insolation data. A detailed economic analysis was then done to compare the four supplemental heating types. A report describing this program is available from Northeast Utilities.

From February 1984 - January 1985 Northeast Utilities conducted another monitoring program of 19 A-A HPs in Southbury, CT. JBF Scientific Inc., was the utilities main contractor for this project. All of the HPs were 3 ton, split systems. The objective of the program was to compare kWH consumption from electric baseboard heating and central air conditioning with central A-A HPs in condominiums. All of the condominiums have many energy conservation features and passive solar design. Currently, the data has been compiled, but no report is available from the utility.

Northeast Utilities is also engaged in the monitoring of reversible ground-water HPs in a commercial building. The 46 apartment unit is located in Stamford, CT. Wormser Scientific Corporation has been contracted by Northeast Utilities to monitor the performance of the 48 2-ton water-air HPs. Monitoring of these systems have been conducted from October 1984 - October 1985. The objective of this program is to determine the efficiency of W-A HP systems where the source of water is a subsurface drainage system.

Watthour meters are being used to monitor kWH consumption of the HP compressor and fan. A load recorder measures consumption every 15 minutes. A BTU meter is also being used to measure the energy extracted from the water. Indoor temperature is being measured. The contractor will eventually supply the utility with information related to the cost of operation and energy savings. The load recorders will provide Northeast Utilities with demand profiles on all of the heating systems.

The above information was obtained through phone conversations with utility personnel and selected written material provided by Northeast Utilities (Reference C-22).

B.1.9 Bonneville Power Administration

Bonneville Power Administration (BPA) is undertaking an End-Use Load Conservation Program (ELCAP) with Battelle National Laboratories. This program will monitor approximately 1000 buildings in the Pacific Northwest. It is expected that approximately 700 will be residential units and 300 commercial units. No criteria have been set as to the number of HP systems that will be monitored. The overall objective is to gain a better understanding of load profiles for utilities and to assess the conservation opportunities.

The ELCAP program began in early 1984. Equipment is still being installed and buildings are being built and chosen for the program. Of the 700 residential units, 500 will be chosen from current housing stock and 200 will be built for the program. These homes are called Residential Standards Demonstration (RSDT) Program Houses. Half of the homes will have typical building standards for the area and half will have standards set by the Regional Power Council. Of the 500 residential homes that will be chosen, it is expected that approximately 25-30 of the units will have HPs. Watthour meters will be used to monitor KWh consumption for the total homes, space heating unit, and lighting in all homes.

Of the 300 commercial units, it is expected that approximately 30 will have HP systems. In all of the units, total KWh and resistance heat will be monitored. General characteristics of the units will also be noted. Eighty of the sites in the program will however, be monitored in more detail; including indoor humidity and on-site weather data. Currently, two commercial units have started to be monitored. One unit is a hydronic A-W system and the other is a roof-top A-A HP system.

Metering on some of the ELCAP systems began in January 1985. No report is currently available. Information for this summary was obtained from BPA and Battelle Pacific Northwest Labs personnel.

B.1.10 Alabama Power Company

Alabama Power Company has conducted several monitoring programs for HPs. From April 1974 - April 1975, the utility monitored 15 A-A systems in Anniston, AL. Only 12 of the systems were finally used for data analysis, of which seven were split systems and five were packaged systems. The major objective of this monitoring program was to assess the impact of HPs on load management and gain data in their service area relative to energy and demand requirements of HPs.

The 12 homes were monitored with four dual-channel, demand magnetic tape recorders and impulse watt-hour meters. Manual checks of the data were conducted to locate any unusable data i.e, data that were 2% off during translation. Operational problems were encountered with the recorders and HPs on three of the original 15 HP systems. However, kWH data were monitored in 12 of the homes for the total house, cooling, heating, air handling (for indoor units), and defrost (recorded on cooling meter).

The number of homes chosen for the monitoring program were not similar in construction. All of the homes, however, were totally electric. Although not a statistically valid sample size, COPs were calculated for the homes by comparing baseloads during heating months to the energy loads required for resistance heated homes. Weather data was obtained from 1965 Birmingham, AL data.

From February 1976 - November 1978, Alabama Power Corporation conducted another monitoring program of eight homes in Birmingham, AL. Four of the eight homes monitored had HP systems. The main objective of the program was to look at the impact of attic insulation and storm windows on kWH consumption. This program was basically a continuation of an earlier EPRI Project RP-137 that monitored homes in six cities throughout the U.S.

In this project, the total house kWh, strip heat, dryer, water heater, ODU cooling, ODU heating, range, indoor fan and return air temperature were all monitored separately. For the HP homes, the compressor, outdoor fan, indoor fan, strip heat and defrost kWH were monitored separately.

For future monitoring programs, Alabama Power Company reported that they would test 30 more homes to make study more statistically valid and try to obtain more information related to occupancy patterns. They felt that the analysis of the HP systems would have been more accurate if they were able to separate the heating and cooling kWH metering during the monitoring vs during the analysis. Also, having the kWH monitored on two different channels for the indoor and outdoor HP units made it difficult to separate the compressor use during defrost and separate the indoor fan for the heating and cooling modes.

Alabama Power Company has recently conducted a third monitoring program of 30 Energy Efficient Homes that all have HP systems. These homes are being compared to the Standard Homes monitored in the previous study, in order to gain more updated information about HPs.

The first two monitoring programs discussed above are described in detail in reports available from the utility. The third program is not currently available in report form (Reference C-41 and C-42).

B.1.11 ORNL Residential Energy Storage Project

This project was designed to demonstrate the feasibility of using thermal storage with residential electric heating and/or cooling systems to enhance load management. Eight utilities participated in this program. Each project involved a number of experimental houses utilizing some type of hot or cold storage and a number of control houses with conventional heating and/or cooling systems. In five cases, these control houses provided field performance data on heat pumps (HP) or central air conditioners (CAC). These five utilities and number of control systems involved were as follows:

Long Island Lighting Company	35 CAC
Pacific Gas & Electric Company	30 CAC
Wisconsin Electric Power Company	25 CAC
Arkansas Power & Light Company	31 CAC
Virginia Electric and Power Company	31 HP

Power input to the heat pump or air conditioner was recorded for all control houses in these five projects. In most instances, total house consumption was also monitored and, in some cases, fan power was recorded separately. Power consumption instrumentation was generally some type of magnetic tape recorder. In some instances, indoor temperatures and humidities and outdoor temperatures were also measured. The five projects mentioned above were designed to provide two seasons of data in the 1980 - 1981 time frame, although in some cases, less than the two seasons of useful data was actually obtained.

These projects are described in references C-46 through C-51.

B.1.12 EPRI RP 432-1 (Level I Testing)

This program conducted by Westinghouse involved 120 residential air-to-air heat pumps of 1968 to 1978 vintage ranging in size from 1.5 to 5.0 tons. The test heat pumps were located in 10 occupied homes in each of 12 regions designed to cover a range of climates. Data was obtained for 2 heating and 1 cooling season between October 1975 and March 1977. The objective of this work was to define heat pump performance such as energy consumption, seasonal performance factors,for a range of climates, house size etc. and to compile reliability and maintenance information. Seventy-seven of the 120 heat pumps were monitored with Level I instrumentation. The remaining 43 incorporated Level II measurement of output (by the flip-flop method) and are described in Section B.2.1 below.

The basic data acquisition system in each location consisted of 2 WR4C recorders providing a total of 6 channels of information (plus 2 time channels) at 15 minute intervals. 5 channels were devoted to kilowatt hour readings - compressor heating, compressor cooling, supplementary resisted heat, indoor fan, and total house; 1 channel monitored indoor temperature. A central weather station monitoring outdoor drybulb, total solar radiation and diffuse solar radiation was located in each region. Results were presented on energy use and time of day power demand and peak power demand for both heating and cooling.

This program is described in EPRI Report EA-739 Load and Use Characteristics of Electric Heat Pumps in Single Family Residences (Reference C-1) and also in a paper presented at the Second Heat Pump Technology Conference (Reference C-37).

B.1.13 Other Level I Programs

Carolina Power and Light, Virginia Electric and Power, and Detroit Edison are other utilities that have been identified as having Level I HP monitoring programs. Detailed descriptions have not been provided due to lack of reports or information available from the utility. The programs, however, are included in the overall test summary of Table 2.

B.2 Level II Programs

B.2.1 EPRI RP 432-1 (Level II Testing)

In 43 of the 120 houses of the EPRI RP 432-1 program (described in Section B.1.11 above) the heat pump compressor was bypassed on alternate days during the heating season to obtain a flip-flop measurement of energy output and permit estimates of heating seasonal performance factor.

The resulting heating seasonal performance factors were presented as a function of degree days heating. A linear correlation of this data indicated values ranging from slightly above 2.0 in warm climates (1500 degree

days heating) to about 1.2 in cold climates (7500 degree days heating). These actual results were substantially less than calculated ideal performance (a linear correlation of the calculated "ideal performance" indicated values ranging from 2.4 to 1.8 for the warm and cold regions respectively. Also in a given climatic region the scatter around the correlation line was very large. Attempts to explain this large scatter in terms of common factors such as heat pump age, model, relative size, duct air flow rate were not very successful. On an individual basis only 25% of the data was within 15% of the predicted ideal seasonal performance factor.

B.2.2 EPRI RP 1191-6

This project which was co-sponsored by Oklahoma Gas & Electric and conducted by Oklahoma State University involved 3 residential heat pumps - one air-to-air, one ground coupled, and one solar assisted ground coupled. Results were primarily confined to the air-to-air and ground coupled design since equipment and instrumentation problems prevented meaningful data from the solar assisted unit. Data was obtained for 2 heating and 2 cooling seasons during 1981 through 1983. All units were located in Perkins, Oklahoma, a small town about eleven miles south of Stillwater. A microprocessor base data acquisition system was employed to obtain power consumption measurements for the compressor, resistance heating, inside blower, outside blower and total house as well as power consumption for domestic water heating. An on site weather station provided solar insolation, dry bulb temperature, humidity, and wind speed and direction. In the case of the ground coupled design well water BTU rate was also measured. Measurements were available on time increments as short as 15 minutes, however for analysis purposes most of the information was presented on an hourly or daily or monthly basis.

In this program house load was calculated from a Oklahoma State Dynamic Simulation Program. Heat pump output could also have been obtained from an energy balance using the measured electric input and well water heat input, however this was not done since the dynamic simulation calculation was believed to be more accurate and since the emphasis of the program was on

determining load reduction rather than field measurements of COP or performance factor. This program is described in EPRI Report EM3408 "Performance Comparisons of Air and Ground Coupled Heat Pump System" (Reference C-15).

B.2.3 Lincoln Electric Service

Lincoln Electric Service (LES) has been involved in the testing of residential air-to-air heat pumps since 1974. A well documented study of three such systems was conducted during the winter of 1983-1984. The objective of these programs including the more recent 1984-85 investigations was the determination of seasonal performance factors for as installed residential air-to-air heat pumps. These tests took place in the Lincoln, Nebraska area. Two of the heat pump systems incorporated standard electric resistance banks as supplemental heat while the third employed a Coleman gas fired furnace.

The flip-flop technique was utilized to characterize building load and heat pump energy consumption. The general approach was to operate the resistance heat one week on, two weeks off with the heat pump system operating during this off period. Although one unit had a gas fired supplement, resistance heaters were included so that building load could be characterized.

The data was monitored by conventional kilowatt hour meters and recorded on WR4C mag tape recorders. The tapes were changed approximately every two weeks in order to minimize data handling/recording problems. The energy consumption data was organized into half hour increments for the purpose of analysis. Temperatures for all the sites were taken from the local Lincoln weather bureau office. In addition, internal thermostats were locked and periodical spot checks were made to insure this value remained constant.

Regression techniques were employed to correlate heat pump and resistance heat (i.e.: building load) energy consumption to outdoor temperature. The

correlation coefficients were greater than 0.95 for both the linear building load and the cubic heat pump energy use curve. Hourly temperature occurrence data was derived from a 20 year average of Lincoln winters and was used as the means of adjustment or normalization.

Results obtained from this investigation indicate that conventional air-to-air heat pumps are competitive in LES territory and have seasonal performance factors of the order of 2.0. Comparisons with the ARI procedures indicate that observed performance is approximately 10% below that cited in the directory listings owing to the difference in ARI's general climactic factors and conditions specific to Lincoln. Information on the LES program was obtained from telephone contacts with the program manager and from Reference C-20.

B.2.4 ESEERCO I: Air-to-Air Heat Pump Study

This program represents the first of the ESEERCO heat pump studies. The primary objective of this effort was the measurement of seasonal performance factors of 11 air-to-air heat pump systems located throughout New York State. The monitoring was conducted by Westinghouse with the assistance of a ESEERCO member utilities over the 1976-77, 1977-78, 1978-79 heating seasons.

The measurement of seasonal performance factor was completed via the use of the flip-flop technique. System switch over (between heat pump and resistance heat/electric furnace operation) occurred every one to two days, although at some sites continuous heat pump or resistance heat operation was used to develop building load lines. The data acquisition system incorporated conventional watt hour meters along with two WR4C mag tape recorders. Energy consumption of the total house, compressor/fan during heating and cooling operation (indicating defrost) and supplemental resistance heat was used to characterize heat pump energy usage and individual building load. Weather data was taken directly at only three sites with the remainder developed from nearby weather stations. All installations were completed before program start and the internal house temperature was not measured.

A bin method approach was used to calculate seasonal performance factor. Load lines were developed from regression fits of derived temperature points and measured electrical energy consumption data. The report presents an average SPF of 1.6 $\pm$ 0.16 for all the homes tested. In addition it acknowledges and attempts to address the impact load line variations (i.e.: regression fit standard error) have on SPF calculations.

The information on this program was derived from ESEERCO Report No. EP5-6 (Reference C-14) and telephone contacts with the ESEERCO staff.

B.2.5 <u>ESEERCO II: Water Source Heat Pump Study</u>

This ESEERCO program involved the testing of 15 well water source heat pumps in New York State over the 1983 cooling and 1983-84 heating seasons. The objective of this recently completed program was the determination of seasonal performance factor data for such state of the art ground and water source heat pump designs. In this study particular attention was given to the impact of ground water temperature variations, cycling times and ambient temperature on the performance of these systems.

Unlike the original ESEERCO study this program utilized a micro processor based data acquisition system to record average and integrated parameters occurring over a single heat pump cycle including total heat extracted from ground water, cycle time, and total electric power consumed. These per cycle values were stored along with other cycle values to give a detailed record of heat pump performance. Internal and ambient temperatures were recorded from each site by RTD sensors.

Seasonal performance characterization was completed utilizing a resistance heat based flip-flop approach and a bin analysis procedure. In addition the influence of cycle time ground water flow rate ambient temperatures were examined.

Currently this report is in draft form and should be available from ESEERCO in 1985. Preliminary conclusions of this study indicate that water source heat pumps perform quite well within New York State owing to the near

variations. Information from this program was obtained from telephone constancy of source water temperatures despite ambient temperature contacts with ESEERCO personnel and the Westinghouse monitoring program manager.

B.2.6 Ohio Edison

This program, conducted by Ohio Edison of Akron, Ohio, involved 18 residential air-to-air heat pumps installed in homes of its employees during the period 1971 through 1975. Up to four heating seasons were completed in some homes and only one in others. The objectives of this program were to obtain additional information on heat pumps and familiarize and sell key employees on advantages of heat pumps.

Annual energy delivered by the heat pump systems, and seasonal performance factor, was obtained with a type of annual flip flop. The energy output for any given year was taken to be the same as a prior year's operation on resistance heat adjusted for the ratio of degree days. Seasonal performance for eight homes--some for 73-74, some for 74-75, and some for both years--varied between 1.31 and 2.06. No comparison with prediction was presented.

The source of this information is a document entitled "Heat Pump Test Program - Ohio Edison Company" (Reference C-18).

B.2.7 APA-I

In this program, sponsored by the Alaska Power Administration, two water-to-air heat pumps are being tested in residences in Juneau, Alaska. One system has been in operation since 1981, the other is new and no data is currently available. The objectives of this program were to determine if water-air heat pumps would operate satisfactorily in the Juneau area using sea water at about 45°F as a heat source.

Energy input was determined by monthly readings of watt meters connected to the heat pumps. Energy output was estimated from the heat load

characteristics of the structure, accounting for other heat gains such as passive solar, appliances, etc.

Monthly COP's for the one installation for which data was available varied from 1.5 to 3.6 (the higher readings being the summer) for two years of testing. The overall average heating seasonal performance factor was 2.2.

This program is described in Juneau Water Source Heat Pump Program Final Report (Reference C-21a).

B.2.8 APA-II

The Alaska Power Administration also conducted a two-year field evaluation of 11 air-to-air heat pumps installed in Ketchikan, Alaska. Eight of these units were residential and three were small (4.5-8 ton) commercial units. The objective of this program was to determine if heat pumps would operate acceptably in Ketchikan in terms of performance, reliability and owner acceptance. The emphasis was on qualitative rather than detailed results.

As with the APA-I program, energy input was determined from monthly watt meter readings and output estimated from the building load characteristics. Data presented for one residential and one commercial installation indicated seasonal performance factors for a two-year period of slightly over 2.0.

This program is described in Ketchikan Heat Pump Final Report (Reference 21b).

B.2.9 AGA

Under contract to the American Gas Association, Mueller Associates is designing a program to test 20 to 30 residential air-to-air heat pumps for a period of five years. Primary objective of this work is to determine as installed performance of a given class of residential electric air-to-air heat pumps with electric back-up. Additional objectives are to determine COP as a function of ambient temperature and also to isolate, if possible,

affects of age, model, sizing, degree days heating, supplementary heating, defrost, and cycling. The emphasis is on quality and reliability rather than quantity of information.

Two levels of data collection will be employed. A microprocessor data acquisition system with on-site storage will be the primary data collection method. Additionally, there will be manual back-up on the four watt meters recording energy input to the compressor, fan and crank case heater; indoor electric heater; indoor fan; and whole house, as well as two counters recording heat pump and defrost on-time. Energy input will be measured with the aforementioned watt meters. Provision will be made for measuring energy output by both the duct enthalpy and flip flop methods. In the duct enthalpy method, flow will be measured using a pilot-static tube with differential pressure cell; differential temperature will be measured with a thermopile; and in the cooling mode entering and leaving relative humidities will be measured. Additionally, indoor and outdoor temperatures and humidities will be measured. The current plan is to use the flip flop method as the primary technique for measuring heating output. The duct enthalpy will be used as a back-up (and check) in the heating mode and the primary method of measurement in the cooling mode.

A prototype system in Baltimore is being used to check out the instrumentation and data acquisition techniques. In the planning, much emphasis has been given to developing statistically valid information and to considering the number of sites required to achieve a 95% level of confidence at 10% error band. Initial estimates are that between 10 and 20 sites would be required.

The program plan is described in Mueller Phase I Report (Reference C-9). Although the program plans indicate very extensive instrumentation - even more than some Level III programs - it is considered a Level II program since the measurement and isolation of dynamic losses appears to be a secondary objective.

B.2.10 ORNL - I

The ORNL program is one of two field test evaluations of residential heat pump systems. This organization tested two, as installed, heat pumps in the ACES Complex, located in Knoxville, TN, over the period from 1977 through 1980. These tests were aimed at examining the as installed performance of heat pumps in both heating and cooling modes.

Seasonal performance estimates were completed for a single dwelling, in the TECH facility. Building load was inferred from data acquired on an "identical" building (the ACES house) in the same complex. Monthly load estimates differed by as much as 9%, although only a 2% variation was noticed over the season. Energy input for both the heat pump compressor and the supplemental resistance heat were acquired from watt hour meters and recorded on mag tapes. Weather data, particularly ambient temperature, was recorded at the site.

Measured performance was correlated to outdoor temperature and compared to manufacturer's quoted steady-state COP values. The results indicated that losses caused by duty cycling and frosting/defrosting may exceed 40% in some spring months and cause seasonal performance to fall 20% below steady-state based predictions. In the cooling mode, cycling losses were shown to reduce efficiency approximately 10 to 20%. Information on this program is based on references C-29 and C-34.

B.2.11 City of Palo Alto

The City of Palo Alto monitored one A-A electric HP from December 1980 - April 1981. Initially the goal was to monitor two systems, but noise problems in the suburbs prevented long-term monitoring with one of the systems. The overall objective was to find out if, in fact, HPs are an efficient and viable energy source in Palo Alto, CA.

Watt-hour meters were read weekly and recorded on a log sheet which was later analyzed by an Apple II Computer Program. Total house kWH, supplemental heat, indoor temperature, supply and return HP temperature, the compressor and fan were all monitored separately. The data obtained from

this monitoring program, however, was barely adequate to meet the City of Palo Alto utility's needs. More frequent readings, ideally daily readings, would have provided them with more adequate information.

To calculate energy savings and the heating seasonal performance factor, a flip-flop method was used. The HP would operate for four days and then an electromechanical time clock would switch on resistance heat for three days. This seven day cycle repeated weekly. The weekly data that was collected and averaged for daily data. Weather data was obtained from weather station at the Palo Alto fire station. Normalization of the data was not necessary due to very little temperature swings in the Palo Alto service area.

A report, available from the utility, shows the energy savings generated from the heat pump system along with figures of COP vs. temperature. A statistical analysis of the data was not conducted, because it was unnecessary in order to meet the utilities objectives. The study basically concluded that the energy savings of HPs did not outweight the first cost of the system. In addition, there is low market potential for the systems due to large availability of natural gas and little ducting in homes. In addition, most homes in Palo Alto are also radiant flow or floor furnaces and less than 5% of the homes use air conditioning, which makes HP systems even harder to cost justify (Reference C-19).

B.2.12 Ontario Hydro

Ontario Hydro monitored two add-on A-A HPs in Toronto, Ontario. One HP was added-on to an oil furnace and the other HP was added-on to a gas-fired furnace. Monitoring of these systems began around 1978 and continued through the heating season of 1982. Both systems had a 24 hour flip-flop with electric resistance heating as a control backup. The main objective of the program was to determine the seasonal efficiency of add-on HPs in the field. This information in turn, would be provided to consumers interested in HPs.

To monitor the two residential HP systems, electronic temperature sensors were located at inlet and outlet points on the HP systems. Heat flow pulses were also monitored on separate registers during HP, furnace or defrost operation. The study also compared two control modes of operation:

(1) restricted - HP on only during mild weather and only furnace on during cold weather conditions. An outdoor temperature in this case, provides the information that determines which heating source to use. The freezing point is approximately the change-over point.
(2) unrestricted - HP on continuously.

The seasonal efficiency of both systems were determined by calculating the total output from the furnace or HP and dividing by the total energy input consumed. An error analysis was then conducted on the HP COP, the furnace efficiency and the displacement; both for the restricted and unrestricted operations.

A paper, provided by Ontario Hydro summarizes the results of their study. COP as a function of outdoor temperature, load characteristics as a function of outdoor temperature, and overall energy savings from these add-on HP systems are noted in the paper (Reference C-40).

B.3 Level III Programs

B.3.1 EPRI RP 789-1

In this program 5 air-to-air heat pumps (4 residential and 1 commercial), all of pre-1975 vintage, were tested for one complete heating and cooling season in 1976, by Carrier Corporation. The objective of this program was to determine seasonal efficiencies of heat pumps in northern climates. Residential heat pumps were installed in Boston, Syracuse and Minneapolis; and both a residential and commercial unit was installed in Seattle. The basic data acquisitions system consisted of a multiplexed tape recorder. Energy heat input measured with pulse initiating watt meters, was recorded for the compressor, supplementary resistance heat, and total building

structures. Energy input during defrosting was segregated by means of a defrost channel. Heating load and cooling sensible load were obtained from duct enthalpy measurements based on a calibrated (and periodically re-checked) air flow value and differential temperature from a calibrated thermal pile. Cooling latent load was inferred using a fixed ratio of total capacity to sensible capacity, which was based on prior experience.

A weather station was located in each site recording outdoor dry bulb, relative humidity, barometric pressure and wind speed and direction. Indoor space temperature was measured at the thermostat as well as duct supply and return air temperatures. All of the above information was measured at intervals of 15 minutes or less. Heat pump balance points were stated as well as descriptions of equipment and controls.

Seasonal performance factors were presented for heating and cooling. Based on the actual weather conditions the heating seasonal performance factors ranged from 1.5 to 2.0 and the cooling SEER's from 7.7 to 12.4. For heating these results were also normalized to average weather conditions using a dynamic simulation model. Total defrost energy was quoted as 3 to 8% of total energy input.

This project is described in EPRI report EM-2319 July 1982 (Reference C-2). Information was also obtained from telephone conversation with EPRI and Carrier staff.

B.3.2 <u>EPRI 789-3</u>

This program was also conducted by Carrier Corporation as an extension of 789-1 to other climates and to improved equipment. It employed 7 residential heat pumps: 5 air-to-air units with electric supplement including 2-speed and 2-compressor designs; an air-to-water design with an oil boiler; and an air-to-air unit with a gas furnace. Three units were in New York, the remaining 4 were in Illinois, Texas, Tennessee and Minnesota respectively. The instrumentation system and data acquisition approach was very similar to that discussed above for 789-1. In particular total capacity (including latent contribution) was estimated using a fixed value of total to sensible capacity.

Three types of heating and cooling seasonal performance factors were presented:

- As measured using actual weather.
- Normalized values corrected to average weather using a dynamic simulation model.
- And expected values based on ERI-240-81 for average weather.

This project is described in a pre-publication version of the final report on RP-789-3 (Reference C-3). Additional information was also obtained from telephone calls with EPRI and Carrier staff.

B.3.3 EPRI RP 2033-9

This program is an additional follow-on to RP 789-1 and RP 789-3. Its objectives were to include more variations of heat pumps including additional add-on heat pumps and room heat pumps. The instrumentation and data acquisition system is essentially the same as in previous programs.

This program has been completed. A report is in process but has yet to be released.

B.3.4 EPRI 1495-1

General Electric, under the sponsorship of EPRI conducted the evaluation of 7 conventional air-to-air heat pump systems during the 1981-82 winter season. These field tests were conducted in Albany, New York, Harrisburg, Pennsylvania and Memphis, Tennessee. The purpose of this program was to obtain quantitative information for use in heat pump performance predicting algorithms. As a consequence, the effort involved a significant amount of laboratory investigations in addition to the field tests.

A daily flip-flop method was utilized to characterize pump seasonal performance. Measurements were completed using conventional kilowatt hour meters, timers and event counters with a data acquisition system involving mag tape recorders. Outdoor temperature data was obtained from local airport sources, while internal temperature was fixed at the same value during both heat pump and resistance heat operating modes. Linear regression techniques were employed to correlate resistance heat only energy consumption (i.e.: load) to ambient temperature. General Electric has stated that the correlation for each residence was very good although regression coefficients and standard errors were not specified.

The most interesting conclusion of this program was the fact that defrosting/frosting conditions were observed to have a greater impact than cycling on heat pump performance. GE's data suggest that the Federal Register/ARI procedures do not correctly account for this. Fortuitously, however, seasonal performance factors associated with these former procedures agree quite well with values derived from a computer based bin method developed by General Electric.

The GE report is in draft form and not currently available from EPRI. Information on this program was acquired from telephone contact with the GE program manager and reference C-16.

B.3.5 EPRI 1204-14 (Analysis Funded by ORNL)

This program, conducted for EPRI by the Allegheny Electric Cooperative, involved two residential water-to-air heat pumps--one heating and cooling, the other heating only. Testing was conducted from the fall of 1981 through August 1983 (two heating and cooling seasons) at sites in or near East Freedom and Bedford--two towns in the vicinity of Altoona, PA. The objective of this program was to measure the thermal performance of residential water source heat pumps in retrofit rural systems and to compare the performance and costs with other heating options such as air-to-air heat pumps, gas furnaces, etc. Analysis of the data was conducted by the University of Pittsburgh under separate contract to Oak Ridge National Laboratory.

A microprocessor-based data acquisition, backed up by manual readings (primarily longer-term watt meter readings), was employed. Energy input was recorded separately for the compressor, indoor fan, water pump, resistance heat and the total house. Heat pump energy output was obtained both directly from duct airflow in delta T measurements and also from some of the electrical and water source heat inputs to the system. The results were in at least approximate agreement, but did not agree exactly due to duct losses and basement heat leakage. Temperatures and humidity were measured indoors and outdoors. Three sets of data were obtained at each site: (1) information averaged over an hour, (2) 15 minute electrical demand, and (3) selected readings at peak scanning rates (approximately every 10 seconds).

Energy consumption and heating seasonal performance factor are presented for both systems with and without water pump energy. With typical water pump energy the heating seasonal performance factor of the heating only system was about 3, whereas that of the heating and cooling unit (optimized for the cooling mode) was less than 2.0. Both had near constant COP's throughout the winter regardless of outside temperature. Cooling energy was not an important factor in this climate and SEER was not reported. Typical response curves for capacity COP and electric input are presented for the first few minutes of typical cycles. However, losses due to cycling are not presented.

This program is described in a draft report prepared by the University of Pittsburgh (Reference C-8). Information was also obtained from telephone contact with the University of Pittsburgh.

B.3.6 NBS-I

Under contract to the Federal Energy Administration, the National Bureau of Standards conducted field tests on a five-ton residential air-to-air heat pump in Washington, DC, during the winter of 1974 through 1975 and the summer of 1975. The actual period of useful data acquisition was limited to 373 hours in the winter and four days in the summer. The objective of this testing was to gain quantitative information on dynamic performance of air-to-air heat pumps.

Watt-hour meters were used to measure the energy inputs to the compressor, outdoor fan, and indoor blower, and during winter to the supplemental resistance heating. The meters used in the winter test were equipped with pulse counters for automatic readout; those used in the summer were read manually. Energy output was obtained from flow and differential temperature measurements incorporating a pilot tube airflow monitoring system and thermopile differential temperature. In summer, condensate was weighed hourly. Indoor and outdoor temperatures and relative humidities were recorded on strip chart recorders. Seasonal performance factors could not be obtained because of the short time period of the testing. However, data on cycling loss with and without defrost was obtained in the form of curves of the ratio of COP to steady state COP as a function of load factor.

This program is described in a paper presented at the Second Annual Heat Pump Technology Conference (Reference C-27).

B.3.7 NBS-II

Under sponsorship of the Department of Energy, the National Bureau of Standards tested 3 residential air-to-air heat pumps during heating and cooling seasons of 1980 and 1981 in the Washington D.C. area. The objective of this work was to obtain realistic field performance data, compare laboratory and field results to determine how well the ARI standard predicted actual field performance; to develop analytical methods for thermostat cycling and overall performance; and to evaluate data and data acquisition methods for complete field testing.

An extensive micro-processor based data acquisition was employed having the ability to record and store a variety of instantaneous and integrated values over different time periods. Watt meter ratings of energy input were reported for compressor and outdoor fan, indoor fan and first stage resistance heat and second stage resistance heat. Energy output we measured by the duct enthalpy method. Sensible heat was obtained from pilot tube flow measurements and thermopile differential temperature. Latent

heat was determined from a calibrated condensate metering pump. Dry bulb temperatures are measured in the supply and return air and outside ambient. Dew points were measured in the return air and outdoor ambient. Operating modes were continually recorded from optical coupler on-off sensors. Compressor on-time and defrost on-time were recorded for each cycle.

Results are currently available only for the first cooling season. This data shows experimental steady-state EER's within about 10% of laboratory results. Data is also presented for part load factor (ratio of cyclic to steady-state EER) as a function of cooling load factor (the ratio of cyclic to steady-state capacity). From these results C_D was determined as a function of cycling rate and found to agree with laboratory results for comparable cycling times.

The cooling work is reported in NBS Report NBSIR85-3107 (Reference C-10). The data acquisition approach is described in NBSIR81-2285 (Reference C-11). The heating data is being reduced and a report and is expected to be available within 1985. Additional information was obtained from telephone conversations and a visit to the National Bureau of Standards.

B.3.8 ORNL-II

Oak Ridge National Laboratory field tested an air-to-air residential heat pump in an unoccupied house at the TECH complex in Nashville, Tennessee for two heating and two cooling seasons during 1981 through 1983. The objective of this work was to characterize dynamic losses in capacity and efficiency due to cycling, frosting, and defrosting. A micro-processor based data acquisition system monitored hourly integrated totals of space heating and sensible cooling heat flows; energy consumption by compressor, indoor and outdoor fans, back-up electric resistance heat, and condensate collection during the cooling system. An on-site weather station monitored dry bulb and dew point temperatures as well as barometric pressure, rain fall, solar radiation, and windspeed and direction. Energy input was obtained with integrating watt meters. Sensible space heat and cooling heat flows were determined from flow measured with a vane anemometer and differential temperature measured with two averaging resistance temperature

devices. Condensate collection was measured with a recording rain guage. Energy input and output were stored by mode of operation--i.e., start-up transient, normal operation, defrost.

Seasonal performance factors for heating and cooling were presented and compared with ARI results. Heating seasonal performance factor was found to be about 6.8 which agreed very well with ARI projections based on a similar heat pump. Cooling seasonal performance factors were measured at 8.2 and 7.9 for the 1982 and 1983 cooling seasons. The ARI result for a similar unit was 10.1. However, it was felt that the difference was primarily due to performance degradation in the cooling mode due to refrigeration leakage. (The ARI rating for heat pump having a steady-state performance similar to the actual degraded steady-state performance was 7.99.) Detail measurements of the losses due to part load cycling and frosting/defrosting were presented. These results indicated a total loss during the heating season equivalent to 26.5% of the total energy consumed exclusive of second stage resistance heating. Heating and cooling C_D were reported as .24 and .2 - .25 respectively.

This program is described in ORNL/CON-150 (Reference C-30) and an ASHRAE paper (Reference C-36). Additional information was obtained in a site visit on May 15, 1985.

B.3.9 University of New Mexico

As part of the Westinghouse RP 432 program, the University of New Mexico examined 10 residential heat pumps in Albuquerque, New Mexico during the 1975-76 heating season. Although ten heat pumps were monitored, only four were studied in great depth to ascertain the major factors affecting as installed performance.

Load/heat pump characterizations were completed by use of a flip-flop technique occurring every third day. Data was recorded by conventional kilowatt hour meters and stored on WR4C recorders in 15 minute increments. Weather conditions, including ambient temperature and incident solar radiation were monitored at a central location in the city. Although

internal temperature was not controlled, it was recorded at an air register outlet within each home so that the temperature difference between the interior space and outside ambient was known. The analysis of energy and weather data to derive a seasonal performance factor was completed using a bin method approach.

Due to the arid climate of New Mexico, the frosting/defrosting effects did not significantly impact heat pump performance. Solar gain, however, was observed to markedly affect cycling rates as well as heat pump on-time. Correlations of cycling data with load factors were developed based on the methods advanced by Kelley and Bean in the NBS-I study (Section B.3.6). Two of the four units tested showed the impact of cycling on seasonal performance, with one unit exhibiting an approximate 17% performance degradation as compared with seasonal performance estimates based on manufacturers' data.

Information concerning this program was developed from references C-26 and C-31.

B.3.10 Purdue University

This program involved a rigorous experimental evaluation of a 3 ton air-to-air heat pump system operating as the primary heating element of a mobile home. The tests were conducted at Purdue University, West LaFayette, Indiana during the 1978-79 heating season. The primary objective of this program was to develop data documenting the steady state, transient, and defrosting performance of a heat pump system operating under winter conditions. In addition the heat pump interaction with the warm air distribution system was explored and quantified.

A computer based data acquisition system was utilized to record important parameters for use in analysis. Ambient temperature measurements were collected from an on-site meteorological station and monitored within the mobile home at a number of points. Duct enthalpy measurements were used exclusively by the researchers. Seasonal performance evaluations, however, were not completed since the heat pump did not include supplemental heaters.

The measurements obtained were used to examine and correlate a variety of fundamental interactions. These interactions included cycle time and steady state condenser temperature as well as frosting and its relationship to relative humidity levels at the coil. The investigations also demonstrated the serious impact the mobile home duct losses had on overall heat pump performance.

Information concerning this program and its numerous results may be found in Reference C-43. Additional sources of information include Herricks Laboratory publications as well as Purdue University graduate theses.

B.3.11 Ohio State University

As part of a larger program investigating a wide range of residential heating equipment, researchers at Ohio State University examined the performance of two residential air-to-air heat pumps in the Columbus, Ohio area. This program was sponsored by the Electric Power Research Institute in 1974. Its primary objective was the modelling of building/heating equipment dynamic interactions for use as a predictive energy consumption tool. The heat pump model did not include provisions for simulating the frosting/defrosting operation and therefore did not track measured performance. Other systems however including gas and electric furnaces were modelled quite well as evidenced by the good correspondence between calculated and measured data. More detailed information on this program is available from EPRI Report No. EA-894 (Reference C-44).

B.3.12 Princeton University

During the Fall of 1975 to Fall of 1976, heating and cooling seasons, the Center for Environmental Studies, Princeton University, conducted a program, sponsored by Public Service Electric and Gas Company, to determine realistic performance of heat pumps in the northern United States. This program involved ten air-to-air residential heat pumps with electric back up in central New Jersey. Seven units were in houses; three were in apartments. The data collection system consisted of magnetic tape recorders. The cassettes from these recorders were picked up monthly and the

information contained therein transferred to, and analyzed on, a computerized data reduction system. Electric usage was measured at 15 minute intervals for the compressor, auxiliary heat, defrost (cooling mode at compressor during heating season), and the total house. Measured temperatures included outside temperatures, house temperature (duct return), downstream (supply) duct temperature, basement temperature and coil temperature. Complete weather data was obtained from a dedicated local weather station. Energy output in the heating mode was determined from direct measurement of the temperature change across the heat pump unit combined with the known (or calibrated) duct flow. Alternate estimation of output (or load) was obtained from the assumption that building load was a linear function of building outdoor ambient temperature difference. Results included compressor heating COP as a function of outdoor ambient, heating seasonal performance factors, defrost performance penalty, and cooling energy input profiles. Cooling COP was not measured due to lack of data on latent load.

This program is described in reference C-52.

B.4 Other Programs

The programs summarized above are believed to be representative of the existing data base and to include most of the major field test projects. However there are clearly other programs which did not come to our attention (such as additional utility Level I programs) and others which were identified but not incorporated in the above Appendix B summaries or in the text tables, due to unavailability of reports, timing, or other reasons. Some of the activities in the latter category are as follows:

- Westinghouse Electric Corporation has conducted advanced heat pump testing as part of an ORNL contract which included detailed laboratory measurements on a developmental unit (Reference D-2).

- Watt-Count and the University of Tennessee are studying field performance of air to air heat pumps in Nashville, Tennessee. This program includes review of utility kwh consumption previously obtained on about 200 heat pumps plus more recent daily kwh data. Reports will be available in 1985.

- Consumers Power has conducted detailed field tests on four ground water heat pumps, three of which were solar assisted (Reference C-45). Consumers Power is also testing over 50 air to air heat pumps using Level I methods - a report is expected in early 1986.

- The North Carolina Alternative Energy Corporation has obtained semi-weekly kwh data on 4 dual fuel air to air heat pumps - a report is expected soon. They have also conducted laboratory type tests on 4 ground coupled heat pumps to investigate the effect of different ground cooling schemes.

- The Cold Regions Research and Engineering Laboratory (CRREL) is field testing several water source (or ground coupled) heat pumps. The commercial projects include a 440 KW water-to-water heat pump at CRREC and a 47 KW water-to-air heat pump at Ft. Greely, AK. Residential projects include 3 ground water heat pumps at Ft. Dix, NJ and Fort Devens, MA; two ground coupled heat pumps at CRREL; and a water source heat pump at Ft. Greeley, AK.

- United Power Association, a wholesale power supplier located in Elk River, MN instrumented a well water heat pump which was operated for one heating season and one and one half cooling seasons. Parameters measured included electric energy consumption and heat and water flows. The data has not been analyzed and it is uncertain whether a report will be prepared.

- The National Solar Data Network, managed by the VITRO Corporation for the Department of Energy, includes data on about 25 sites which had residential or commercial heat pumps - either air-to-air or water-to-air. These heat pumps were carefully instrumented with power meters and usually air flow or liquid flow meters and temperature sensors on the load side. Monthly and Seasonal reports are available although the emphasis of the reports is on the solar systems and therefore contain only a small mention of the heat pump systems.

- The Florida Solar Energy Center (FSEC) has conducted analytical and experimental work on heat pump performance with particular emphasis on cooling and dehumidification (References D-25 and D-26). Based on this work FSEC believes that the interaction between heat pump performance and building demand is both very important (particularly in the cooling mode) and relatively unexplored to date.

- In the Hood River Project, conducted by Bonneville Power Administration, all electrically heated homes (3000) in an entire community are being weatherized to reduce heating energy requirements. The energy savings will be inferred from monthly electric bills before and after weatherization. In four houses, where major measures of weatherization were not feasible, heat pumps were installed as an alternate means of energy savings. This project was initiated in 1982. Retrofit weatherization began in 1984 and will be complete by the end of 1985. The evaluation will continue through 1986 after which a report will be forthcoming.

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