CONF-840266--1

DE84 007561

OVERVIEW OF DOE-SPONSORED HEAT PUMP RESEARCH

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For presentation at the

Heat Pumps: An Update On Research
and Applications Seminar

Sponsored by the
Electric Power Research Institute

February 23-24, 1984

Sheraton New Orleans Hotel
New Orleans, Louisana

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Overview of DOE-Sponsored Heat Pump Research

DOE research activities related to residential and commercial heat pump technology are supported by the Office of Building Energy Research and Development, Building Equipment Division (under the DOE Assistant Secretary for Conservation and Renewables). Technical management is assigned to the Oak Ridge National Laboratory (ORNL), located in Oak Ridge, Tennessee. In-house expertise at ORNL is used to identify and evaluate R&D opportunities, to conduct selected research tasks, and to assist DOE in managing contracted activities. Program planning is coordinated with the Electric Power Research Institute (EPRI) and benefits from active interaction with equipment manufacturers and utilities. More than half of the project funding is passed through to contractors, most of which are industrial organizations.

Program Size and Research Emphasis

The budget for the Building Equipment Research (BER) program at ORNL is about $6.3 million per year, with the major share (~85%) allocated to electric and heat-actuated heat pump research. The remaining 15% is allocated to appliance-related research and program support activities (administration, foreign liaison, industry interaction, and project evaluation). Table 1 shows a percentage breakdown of the heat pump research budget for FY-83 through FY-85 (FY-84 and 85 are proposed allocations assuming level funding). As shown, the trend is toward a decreasing emphasis on the research areas we have been working in and increasing emphasis in several new areas which I will describe later in the overview. The new research areas are intended to be generic (i.e., not oriented specifically toward electric or heat-actuated equipment); however, most of the near-term focus will be on electric equipment due to availability of information (for analytical projects) and hardware (for experimental projects).

Table 1. Heat Pump Research Budget Allocation Trends

	FY-84	FY-85[1]	FY-86[1]
Heat-Actuated	48%	38%	28%
Electric[2]	41%	29%	21%
New Areas (Generic)	11%	33%	51%

[1]Proposed allocation, based on assumed level funding.

[2]Ongoing areas of research as listed in following paragraph.

Major areas of ongoing research associated with electric heat pump technology include:

- Advanced Heat Pump Design Analysis and Optimization
- Dynamic Loss Phenomena
- Heat Pump Capacity Modulation
- Ground-Coupled Heat Pump Technology
- Nonazeotropic Refrigerant Mixtures

Highlights of recent activities in these areas are described in the following paragraphs.

Design Analysis and Optimization

Work on advanced computer-aided design analysis, tools, and techniques has been conducted at ORNL for several years.[1,2] The computer programs have been developed and current efforts are focused on validation, technology transfer (to heat pump manufacturers), and documentation. Included are codes to provide steady-state and seasonal performance analyses or design configurations optimized for best (cost-effective) performance. Cooperative working arrangements with industry will provide guidance for extending the usefulness of existing programs and data for validation and will facilitate the transfer of this technology to manufacturers.

Dynamic Loss Phenomena

A two-year test of a conventional air-source heat pump to characterize dynamic losses in capacity and efficiency (due to cycling, frosting and defrosting) under real-world field conditions (in TECH site house near Knoxville, TN) was concluded in September 1983.[3] A summary of the findings for the heating season is presented in Table 2. "Cycling losses" (i.e., startup transient loss plus off-cycle parasitics) and frosting/defrosting losses were found to be nearly equal, comprising 12.7% and 13.8% respectively, of the heat pump performance degradation (overall degradation 26.5%). The heat pump has been modified with solenoid valves installed to prevent refrigerant migration during the "off" cycle in preparation for cycling-loss-reduction tests to be conducted in FY 1984. Concurrent testing in the ORNL laboratory environmental chambers under closely controlled conditions is aimed at examining these dynamic loss phenomena in more detail. By relating these losses to key design parameters and component features, design analysis can more effectively address performance optimization on a seasonal basis. Also, from understanding why and how these losses occur, techniques for eliminating or reducing them may be developed.

Table 2. Dynamic Loss Measurements
1981-83 Heating Seasons

Rated performance characteristics:

	47°F	17°F
Capacity (Btuh)	34,000	18,000
COP	3.1	2.1

Normalized steady-state COP 2.7

Heating Seasonal Performance Factor 2.0

Breakdown of Dynamic Losses*:

Startup transient loss	8.4%	
Off-cycle parasitics	4.3%	
Frosting losses	3.7%	
Defrosting energy	10.1%	
(incl. I^2R "tempering" heat)		(5.6%)
Overall degradation in HP performance	26.5%	

*Note: base heat pump only total energy, excluding supplemental I^2R below balance point

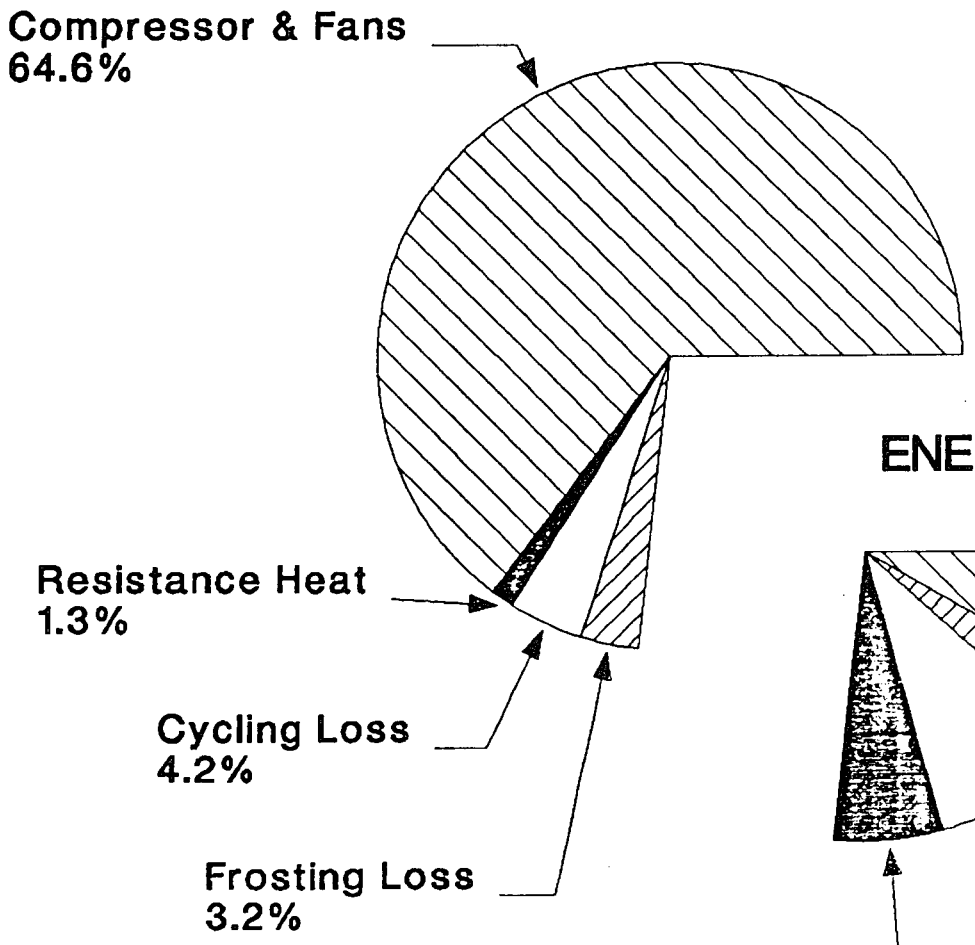
Heat Pump Capacity Modulation

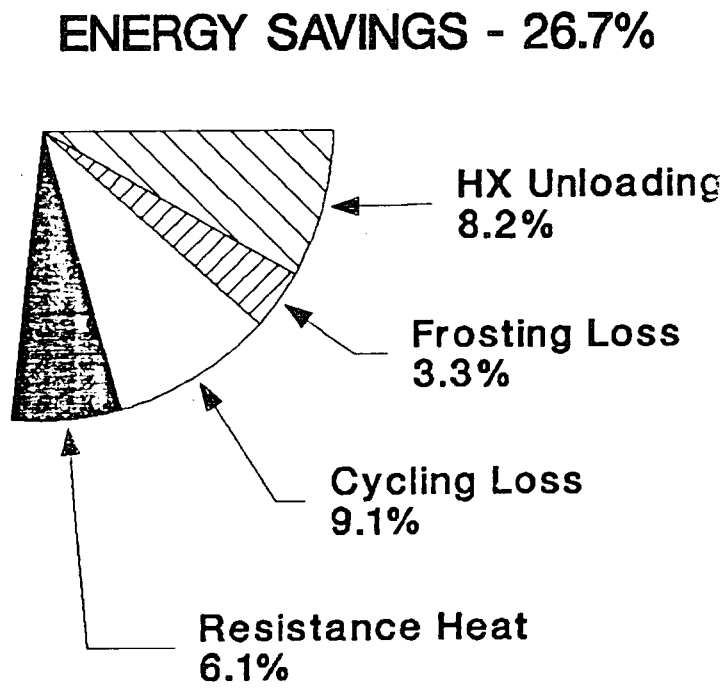
Work on heat pump capacity-modulation has also been a major DOE/ORNL activity for several years. A dual-stroke (capacity-modulated) heat pump was developed to the preprototype stage by Westinghouse* under a previous cost-shared ORNL contract.[4] Field evaluation testing of the preprototype unit has been conducted for the past year in a residence in the Pittsburgh area. Preliminary cooling performance data showed cooling seasonal performance factor (SPFC) of 3.3 (SEER of 11.4 Btu/h-W), even though the unit was optimized for northern climate to provide its best performance in the heating mode. Testing is scheduled to conclude at the end of March.

ORNL has also conducted in-house analytical studies on capacity modulation to quantify the potential seasonal performance benefits. These recent studies considered typical dynamic losses and advanced, continuously variable speed control methods. Energy use and savings for a continuously-modulating heat pump are compared to those for a non-modulating one in Figure 1. Both configurations were optimized for best annual performance (for an 1800 ft^2 house in Nashville, TN) using a newly-developed Annual

* Note: Much of the Westinghouse system analysis utilized in the preprototype development had its roots in an EPRI project (RP-544) conducted by Westinghouse in the late 1970's.[5]

ENERGY USE & SAVINGS FOR A CONTINUOUSLY MODULATING HEAT PUMP





Performance Model .[6] As illustrated, benefits such as heat exchanger unloading and reduced use of supplementary resistance heaters combine to give about twice the energy savings as is attributable to the more obvious cycling loss reduction. For a more northerly climate, the cycling loss fraction could be even smaller.

Ground-Coupled Heat Pump Technology

In the ground-coupled heat pump area, experimental testing and analytical evaluations are underway to establish the technical limitations and preferred ground coil design configurations for various soil and weather conditions. Work is in progress to derive a comprehensive ground coil heat exchanger analytical design method which accounts for soil freezing and moisture migration effects based on the theories of heat and mass transfer, coupled with phase change, in porous media. Model development and validation work is proceeding progressively, starting with a heat transfer only model for single coils and eventually to include soil freezing, moisture migration, surface effects, and thermal interaction of adjacent coils. The heat transfer (only) model is completed and has been validated against laboratory data .[7] Its application is limited to conditions in which the soil is saturated with moisture and no phase change occurs. The model which considers heat transfer coupled with phase change was also completed recently and is now being validated. In this connection, a cooperative working arrangement has been implemented with Niagara Mohawk to provide them technical assistance with instrumentation on their GCHP project (jointly funded by New York State Research and Development Authority and Rochester Gas and Electric) in return for experimental data we can use for validation of these models.

Experimental projects are also being conducted on two horizontal-coil and one vertical-coil experimental ground-coupled heat pump (GCHP) installations. Results are summarized in Table 3 .[8,9,10] Heating mode tests of the horizontal-coil installation at the TECH site showed a seasonal heating performance about 30% better than an air-source heat pump system with equivalent technology (SPFH 2.6 vs 2.0). However, the experimentally observed seasonal cooling performance with these horizontal-coil systems showed a performance degradation, particularly at the TECH site. The sandy soil at BNL apparently provides good earth-to-coil contact for heat transfer without any special precautions in backfilling, whereas we found evidence that the clay soil at the TECH site did not, even after extended ground settling. In contrast to the horizontal coil results, the vertical-coil experiment at the TECH site showed an SPFC of 2.0. This improved performance is largely due to better coil-earth heat transfer since the vertical coil extends below the water table into saturated soil.

Table 3. Experimental results on GCHP projects

Project	Seasonal Performance Factor Heating (SPFH)	Cooling (SPFC)
TECH site[a] horizontal coil, 213m	2.6	1.3
BNL site[b] horizontal coil	2.5	1.9
TECH site vertical coil,[d] 140m	–[c]	2.0

[a]Tennessee Energy Conservation in Housing (TECH) site near Knoxville, Tenn.
[b]Brookhaven National Laboratory (BNL) site on Long Island, New York.
[c]No data available, testing started summer 1983.
[d]Comprising six coils (holes) ranging from 18 to 30 m deep.

Efforts are also underway to develop a water-source heat pump mechanical package design optimized for ground-coupled application. Initial activities the past year have focused on software development. Water (brine)-to-refrigerant heat exchanger models were developed by BNL and incorporated into the heat pump model previously developed at ORNL, and a methodology was developed to relate heat pump entering brine temperature to the load history (ground temperature effected by preceding heat extraction). Friedrich was selected as the industry contractor to work with BNL and ORNL on this project.

Nonazeotropic Refrigerant Mixtures

This area is a relatively new area of major emphasis in our program, although we have had a small contracted effort with the University of Illinois (Prof. W. F. Stoecker) for several years.[11,12] We have tried to coordinate our expanded research in this area with EPRI, first by supporting complementary work at NBS (experimental measurements of heat pump performance with a mixture of R-13B1/R-152a), and more recently by working with EPRI to develop a joint EPRI/DOE plan for fluids research. Our evaluation of R&D opportunities has identified heat pump capacity modulation via mixture composition control as one of the most promising applications for the use of nonazeotropic refrigerant mixtures. Therefore, this will be the focus of our work in this area during the coming year.

Future Directions: New Areas of Research

As mentioned at the beginning of this overview, several new areas of generic research with wide applicability in both present and developmental heat pump equipment are proposed to receive increasing emphasis in the future. Some of these areas in which the assessed R&D opportunities seem the greatest and on which we plan to focus in FY-84 include:

- Stirling-Cycle Heat Pump Technology
- Advanced HVAC Distribution Systems
  - Zone control concepts (residential)
  - Concepts for providing human thermal comfort with reduced energy input
- Commercial Building Systems
  - Envision a national program involving the private sector

The Stirling-refrigeration-cycle heat pump (SCHP) concept is one of the high-risk research efforts that has promise, but will probably require several years of R&D to reach proof-of-concept suitable to gain manufacturer interest. A preliminary assessment has shown the advantage of this concept for use in cold climates, since the capacity does not drop significantly when the ambient temperature is reduced. It also identified the need for further experimental work to determine the technical feasibility of achieving nearly isothermalized cycle heat transfer processes, which may be critical to improving SCHP performance sufficiently to show potential economic viability. This work has been initiated.

Assessment of specific priority research needs in the other two areas is still underway. We expect our planning and project scoping studies in these areas to be closely coordinated with industry.

The outlook seems very promising for expanded use of heat pump equipment and for further improvements in performance. Continuing research to advance heat pump technology, together with the cooperative efforts of HVAC equipment manufacturers, research organizations, government, universities, and utilities will assure that new heat pump products will be available to meet the future needs of the end-use customer and the utility.

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