Survey of Heat Pump R&D in the United States

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A number of organizations that fund and manage research have been surveyed to ascertain their efforts on heat pump and heat pump related issues. The emphasis was to discover the type of work currently being performed and the institutions involved. This article summarizes heat pump research under the categories alternative refrigerants, controls, ground and water-source heat pumps, alternative cycles, and other heat pump issues. Tables 1-5 list research projects with numbers in brackets indicating contact persons listed in References.

Table 1: Research in alternative refrigerants.

Funded by	Research Project Title [Research Organization]	Start - End [Contact]*
ARI	Alternative Refrigerant Evaluation Program (AREP) [over 30 equipment manufacturing companies in North America, Japan and Europe]	1/92 - 3/94 [1]
ASHRAE	Capillary Tube Performance with Alternative Refrigerants [Iowa State University]	9/93 - 3/95 [2]
EPRI	Alternative Refrigerants Evaluation Program (AREP) [University of Illinois, Iowa State, Lehigh University]	11/92 - 4/94 [3]
EPRI	The Measurement of Evaporative Heat Transfer Coefficients of Refrigerant Mixtures, R32/R134a and R32/R125/R134a With and Without Lubricant [NIST]	11/92 - 12/93 [3]
EPRI	Novel HFC Propanes, HFC Butanes, and HFC Ethers as Alternatives to CFCs [Clemson University]	7/92 - 4/94 [4]
EPRI	Development of Zero-ODP Refrigerant for Centrifugal Chillers [Allied-Signal, Inc.]	7/91 - 7/94 [4]
EPRI/ US EPA	Testing of Environmentally Safe Refrigerants/ Refrigerant Mixtures in Heating and Cooling Equipment [University of Maryland]	7/92 - 9/94 [4/5]
GRI	Materials Research for Improved Ammonia Heat Pump Application.	91 - 96 [6]
US DOE	New Refrigerants [NIST, ORNL]	ongoing [7]
US DOE/ ARTI	Materials Compatibility and Lubricants Research (MCLR) Program [~40 separate contracts]	9/91 - 9/95 [8]
US EPA	Evaluation of a Residential Heat Pump Using a Rectifier for Refrigerant Mixture Separation [NIST]	9/92 - 9/93 [5]
US EPA	Improving Air-Conditioner and Heat Pump Performance with R-22 Replacement Refrigerants [pending]	9/93 - 9/96 [5]
US EPA	Modeling Evaluation of R-22 Replacement Blends [Research Triangle Park]	4/93 - 8/94 [5]
US EPA	Use of Non-Chlorine Refrigerants and Refrigerant Mixtures in Heat Pumps and Air-Conditioning [pending]	9/93 - 9/96 [5]

*See References

Research Project [Research Organization]	Start - End [Contact]*
Funded by EPRI:	
Microprocessor control system design for a variable-speed ground-source heat pump [University of Alabama]	6/91 - 9/93 [9]
Water-loop heat pump system evaluation and development of control and operation strategies [ClimateMaster, Inc.]	1/86 - 12/93 [10]
Heat pump thermal distribution system study, including determination of the best zonal approach for residential systems [Tecogen, Inc.]	10/87 - 3/93 [11]
Funded by GRI:	
Development of improved emission controls for a residential reciprocating-engine-driven gas heat pump	Ongoing [6]
Advanced heat pump controls development	84 - 94 [6]
*See References	

Table 2: Examples of controls research.

In this survey are responses from the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE), the Air-Conditioning and Refrigeration Institute (ARI), the Air-Conditioning and Refrigeration Technology Institute (ARTI), the Electric Power Research Institute (EPRI), the Gas Research Institute (GRI), the US Department of Energy (US DOE), and the US Environmental Protection Agency (US EPA). However, the survey is not to be construed as an exhaustive accounting of on-going research effort within the US. There are numerous projects funded by other interested stakeholders that are not included in this survey. Additionally, research within private manufacturing firms, by its very nature proprietary, is not publicly available; no attempt was made to summarize that research here. Hence, the investigations noted within this article are meant to be representative of the types of work that are underway to satisfy the needs of US equipment manufacturers and their customers.

Research Drivers

There are a number of drivers in the US that influence research on heat pumps utilized in heating and cooling applications:

- occupancy comfort requirements;
- equipment economics (e.g., installation and operating costs);
- efficiency demands of the US National Appliance Energy Conservation Act (NAECA regulates single-phase heat pumps with cooling capacities of 65,000 Btu/h [19 kW] and smaller) and the US 1992 Energy Policy Act (EPAct regulates three-phase heat pumps of 65,000 Btu/h [19 kW] cooling capacity and smaller, heat pumps with cooling capacities between 135,000 Btu/h and 240,000 Btu/h [40 and 70 kW], and packaged terminal heat pump equipment);
- environmental effects of air-conditioning on stratospheric ozone levels and on global warming.

Equipment costs are a key factor in determining heat pump acceptance. In the US, the air-conditioning industry is a mature market, and comfort conditioning and refrigerating products are considered commodities. The market is very sensitive to pricing; market demand gravitates to the lowest cost equipment. Utility rebate and incentive schemes that reward higher efficiency equipment can, and do, alter market dynamics and affect heat pump sales over other types of equipment.

Some of the drivers act at odds with each other. As manufacturers seek to comply with DOE efficiency requirements, the US Clean Air Act of 1990 (which accelerated the phase-out of CFCs and detailed the future ban of HCFCs) has forced manufacturers to also plan for the simultaneous development of units that will use non-chlorinated working fluids. In nearly all instances, it will be a challenging redesign just to regain the efficiency levels of the original HCFC-22 units.

Hence, the previous objective of US R&D to provide cost-effective equipment that satisfies load demand has been superseded by government-mandated efficiency levels and refrigerant obsolescence regulations. This has led to a new focus where the industry is striving to develop and market equipment that efficiently utilizes environmentally-friendly working fluids while also satisfying customer needs. This is a tough balancing act to achieve.

Table 3: Ground- or water-source heat pump research.

Research Project [Research Organization]	Start - End [Contact]*
Funded by EPRI:	
Slinky/spiral ground coil development [Oklahoma State University]	3/92 - 1/94 [9]
Design and development of a triple function two-speed ground-source heat pump [Water Furnace International]	12/88 - 12/93 [9]
Advanced water-loop heat pump equipment development [The Trane Company]	8/88 - 6/95 [13]
*See References	

Research Project [Research Organization]	Start - End [Contact]*
Funded by GRI:	
Advanced gas heat pump development based on chemisorption technology	87 - 97 [6]
Sorption technology and component development	91 - 96 [6]
Dual-cycle absorption heat pump development	96 - 98 [6]
Generator-absorber heat exchange (GAX) heat pump development	92 - 97 [6]
Funded by US DOE:	
Development and commercialization of advanced cycle concepts in absorption and engine-driven heat pumps for residential and small commercial buildings [Phillips Engineering]	82 - ongoing [12]
Development and commercialization of highly-efficient large commercial absorption chillers using advanced cycles with water as the working fluid	82 - ongoing [12]
*See References	

Table 4: Non-vapour-compressor cycle research.

R&D Organizations

There are a number of organizations within the US that are involved in developing and supporting research on heat pump components or their working fluids. These organizations include private equipment manufacturers, chemical producers, industry trade associations, federal agencies and departments (e.g., US DOE and US EPA), national laboratories (e.g., Oak Ridge National Laboratory and National Institute of Standards and Technology), and a myriad of state and local agencies. These entities provide significant funding and in-kind support to many private and university research facilities for the furthering of heat pump technologies.

Alternative Refrigerants

As a result of the mandated final phase-out date of HCFC-22 (the primary refrigerant in US unitary heat pumps) by 2030, increasing levels of effort are being applied to investigating alternative working fluids. In Table 1, it can be seen that there are numerous research programmes geared towards uncovering alternative working fluids, investigating thermo-physical properties, ascertaining compatibility with materials, characterizing heat transfer mechanisms, and comparing performance against HCFC-22 in existing and optimized equipment and cycles.

Many of the replacement candidates under evaluation are blends with two or more constituents. Of these the majority of the fluids are zeotropic mixtures having fractionation concerns that need to be resolved. These concerns are related to temperature glide characteristics, possible flammability scenarios, equipment control and operation requirements, and equipment servicing in the field.

However, zeotropic blends potentially offer large efficiency gains if their temperature glides can be utilized in future innovative heat pumps. Research is in its infancy on whether composition shifting can be advantageously utilized to provide efficiency improvements over the basic cycle during cooling and heating modes. Composition shifting would permit different circulating mixtures for summer cooling operation and for winter heating operation. Optimization of the compositions for both operating modes will be very challenging, but could yield large efficiency gains. Also of particular challenge will be the development of counter-flow air-to-refrigerant heat exchangers that benefit from the resultant refrigerant temperature glides.

Controls

Another key research area is in the development and application of new controls to produce heat pumps that are more responsive to load conditions. Table 2 notes several on-going projects geared towards efficiently applying enhanced controls to heat pumps. Equipment manufacturers are also investigating the use of electronic expansion valves (utilizing algorithms to provide tighter bandwidth), better sequencing of compressors (using microprocessors) and utilization of electronically-controlled variable-speed motors.

Currently, heat pump equipment utilizing two-speed compressor motors and multi-speed blower motors are available in the marketplace. Additionally, variable-speed motors and their associated drive packages have been available for many years. However, as a result of higher first cost, these enhancements were not easily accepted in the US market. Much research is still needed to cost-effectively apply custom design motor and drive packages to specific applications.

Another trend in the US market has been the increased usage of multi-zoning to obtain better thermal comfort and energy utilization. Generally, this was accomplished via multiple units to serve multiple zones. However, newer controls have allowed multi-zone control on a single unitary heat pump. Some sectors of the US market are willing to pay slightly more for the resultant benefits of better comfort matching.

Ground & Water Source

There are a number of ground/water-source applications in the US, with more added every day. The research effort in this area is focusing on providing

Research Project [Research Organization]	Start - End [Contact]*
Funded by ASHRAE:	
Study to determine heat loads due to coil-defrosting and to develop design tools [University of Florida]	4/92 - 7/94 [14]
Design procedure development for thermal energy storage tanks which separate the manufacture of ice from the storage of ice [University of Missouri - Kansas City]	9/91 - 9/93 [15]
Funded by EPRI:	
Development of a dual-fuel heat pump for residential and small commercial buildings [Tecogen, Inc.]	2/87 - 12/93 [9]
Development of a cost-effective heat pump with integrated dedicated year-round water heating capability [Nordyne, Inc.]	8/90 - 3/93 [16]
Development of advanced off-peak or base -loaded heat pump water heaters [E-Tech Division; Crispaire Corporation]	9/89 - 12/93 [9]
Funded by GRI:	
Residential reciprocating engine-driven heat pump development	84 - 94 [6]
Development of an 88 kW (heating) engine -driven heat pump with a heating COP of 1.8 at 8.3°C, a unit cost of US$ 25,000, and a service life of 20 years	93 - 97 [6]
Funded by USDOE	9/91 - 6/95
Domestic refrigerator-freezers with 50% lower energy use	[17]
*See References	

Table 5: Other research.

better components and installation methods. As with the air-source heat pumps, efforts continue to improve efficiencies and to uncover optimal working fluids. High-efficiency ground-source heat pumps offer the potential to lower energy consumption, thereby reducing pollution while saving money for the customer. Refer to Table 3 for a representative example of some of the work in this area.

Alternative Cycles

There are a number of alternative technologies and alternative cycles that are being assessed by US manufacturers. These include systems that use linear free-piston compression, acoustical compression, electrodynamic compression, and Stirling cycle compression. With regard to some of these long-term technologies, manufacturers of unitary equipment are anxiously waiting to see how well the concepts are implemented in smaller applications such as household refrigerators, freezers, and window-unit room air-conditioners. Table 4 illustrates some research on non-vapour-compression cycles.

Other Heat Pump Issues

Table 5 provides examples of other heat pump research under consideration. These types of research are associated with new coil-defrosting strategies, thermal storage, dual-fuel usage, and engine-driven heat pumps. Also of interest is the water-heating capability of heat pumps to provide hot water for domestic needs.

Optimal Results

In conclusion, these very diverse research projects are well-coordinated with the sponsoring entities - government, industry, and utilities - cooperating to achieve optimal results. The government-sponsored research is aimed at ensuring better utilization of natural resources. Industry's research is directed towards providing products that satisfy customer requirements. The utilities provide strong support to air-conditioning and refrigeration issues to improve the efficiency of their energy-distribution networks. Ultimately, the research will lead to even more efficient heat pumps that satisfy requirements using environmentally-friendly working fluids.

References:

Ref. No.	*Contact*	*Telephone No.*
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