HVAC&R Research For the 21st Century (21-CR)

A heating, ventilation, air-conditioning and refrigeration (HVAC&R) research mission with a theme of harmonizing energy efficiency, comfort, and environmental concerns with technical objectives that support the U.S. National Construction Goals.

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The Air-Conditioning and Refrigeration Technology Institute (ARTI) is a not-for-profit organization established to undertake scientific research in the public interest. ARTI strives to be responsive to the research needs of the HVAC&R community with an emphasis placed on precompetitive investigations. It is ARTI=s role to provide guidance and cohesiveness to research efforts while providing an umbrella for related research by others. ARTI is an entity associated with the Air-Conditioning and Refrigeration Institute.

The Air-Conditioning and Refrigeration Institute (ARI) is the national trade association representing manufacturers of more than 90 percent of U.S.-produced central air-conditioning and commercial refrigeration equipment. ARI strives to be responsive to its member companies and to the air-conditioning and refrigeration community by providing services and managing or coordinating activities of value to the industry. ARI continuously seeks opportunities to cooperatively interact with domestic and foreign industry, government, and academia.

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PREFACE

Background on the 21-CR Initiation:

To build on the successes of the recently-completed ARI R-22 Alternative Refrigerants Evaluation Program (AREP) and the nearly-completed ARTI Materials Compatibility and Lubricant Research (MCLR) Program[1], ARI's Research and Technology (R&T) Committee began exploring in 1996 future research needs. By the end of 1996 the R&T Committee had identified a number of drivers and issues that impact the industry and identified research to overcome these challenges. To further aid in this endeavor, the R&T Committee sponsored a two-day industry workshop (R*esearch for the 21st Century*) in Chicago, Illinois on 21-22 April 1997 to refine/define the drivers (Exhibit C) impacting the industry and to outline research areas (Exhibit D) of value to the heating, ventilation, air-conditioning and refrigeration (HVAC&R) community. The workshop was structured around four topical breakout sessions:

- commercial buildings (e.g., chiller systems),
- residential buildings (e.g., small unitary equipment),
- light commercial buildings (e.g., unitary rooftop package equipment), and
- supermarket (e.g., commercial refrigeration) and transport refrigeration (e.g., truck/rail/ship equipment).

The participants in the individual breakout sessions were challenged to:

- Take note of the drivers on the industry coming from external changes.
- Identify specific areas of research to satisfy these drivers.
- Prioritize the research areas.

The R&T Committee utilized the workshop's output to define a ***new industry R&D mission with a theme of harmonizing energy efficiency, comfort, and environmental concerns with technical objectives that support the U. S. National Construction Goals***.

Support for the 21-CR Program:

The research highlighted in the balance of this document represents a consensus position of the U.S. HVAC&R industry. To initiate the effort, significant funding have currently been pledged by the:

Air-Conditioning and Refrigeration Institute (ARI),
Copper Development Association (CDA),
Heating, Refrigeration, and Air-Conditioning Institute (HRAI) of Canada,
Refrigeration Services Engineers Society (RSES).

Endorsements of the 21-CR program have currently been made by the:

Canadian Heat Pump Council (CHPC),
Commercial Refrigerator Manufacturers Association (CRMA),
Geothermal Heat Pump Consortium (GHPC),
Iowa Energy Center,
Thermal Technology Centre (TTC), National Research Council Canada.

Early in 1998, the U.S. Department of Energy expressed enthusiastic support for the initiative and indicated that it will be a strong financial contributor to the 21-CR effort. Additionally, there are a number of industry associations (e.g., ACCA, AGA, ASHRAE, GAMA, GRI, SMACNA), state energy offices (e.g., California Energy Commission, Energy Center of Wisconsin, New York State Energy Research and Development Authority) that are ascertaining how they can best contribute to the success of the 21-CR program.

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[1] Refer to Exhibits A and B for background briefings on the AREP and MCLR programs.

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INTRODUCTION

The overall emphasis of this initiative is to identify areas of precompetitive research that will enable U.S. manufacturers to offer equipment in the next decade that, once integrated into building and process applications, will utilize dramatically less energy (as compared to today's applications) while addressing the comfort and indoor environmental quality (IEQ)[2] needs of building occupants. Some of these energy and IEQ improvements will accrue by innovative advancements in the heating, ventilation, air-conditioning and refrigeration (HVAC&R) equipment itself. Still additional benefits will be garnered by better incorporation of these improved systems into applications -- buildings or refrigeration processes.

The goals of the program are very aggressive! The program is not seeking incremental improvements. Nor is the program aimed at assisting near-term commercialization efforts. Both of these are better left to individual equipment manufacturers as they each strive to satisfy market needs through their own competitive strengths. The proposed program is focused on precompetitive research efforts that resolve hurdles and difficulties that prevent or impede HVAC&R manufacturers from introducing new systems and components. Once these technical challenges have been addressed, it is then up to individual manufacturers to apply the research results and to produce products that satisfy market needs. When carried out as part of a coherent plan, this emphasis on precompetitive investigations will advance the capabilities of industry to meet the broader objectives of decreasing energy consumption, increasing IEQ, and safeguarding the environment.

ARTI is uniquely positioned to champion this research initiative since, through its extensive committee structure, ARTI has access to unpublished studies, has a large base of industry experts to draw upon, and possesses an ability to assess research needs that are consistent with market realities. These items are important points as any product development resulting from research knowledge must be executed by industry. Industry can more easily speed the implementation of this knowledge into new products and processes if it is intimately involved in the planning and development of the research.

The new initiative seeks to *foster an environment where technical barriers can be identified, solutions investigated, and information shared*. The type of research outlined herein is generally capital intensive and of such sufficient risk that no one company can perform the work on its own. Undertaking this effort is in the strategic interest of U.S. manufacturers, their customers, and of overall benefit to the entire U.S. economy.

U.S. National Construction Goals

The objectives of this HVAC&R initiative support the U.S. National Construction Goals developed by the Construction and Building Subcommittee[3] of the National Science and Technology Council

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[2] IEQ includes sound, comfort (e.g., temperature, airflow, humidity), lighting, etc.

[3] Starting in 1993, a number of federal agencies joined the Construction and Building Subcommittee of the National Science and Technology Council: Department of Agriculture (Forest Service), Department of Commerce (National Institute of Standards and Technology), Department of Defense (Army Corps of Engineers), Department of Energy, Department of Health and Human Services (National Institute for Occupational Safety and Health), Department of Housing and Urban Development, Department of Interior (Bureau of Mines and U.S. Geological Survey), Department of Labor (Occupational Safety and

(a cabinet-level group charged with setting technology policy) to define priorities for federal research, development, and deployment related to the industries that produce, operate, and maintain constructed facilities, including buildings and infrastructure. The National Construction Goals represent the U.S. government's strategy to guide and support the building industry. The ten-year goals relevant to the HVAC&R industry are:

Better Buildings and Homes:
- 50% reduction in operation, maintenance, and energy costs,
- 50% less waste and pollution,
- 50% more durability and flexibility,
- 50% reduction in delivery times.

Health and Safety:
- 30% increase in occupant productivity and comfort,
- 50% fewer occupant related illnesses and injuries,
- 50% reduction in construction worker illnesses and injuries.

Benefits of the Initiative

The U.S. HVAC&R industry is a mature one in which product innovations have been gradually accepted by the marketplace. Achieving rapid marketplace acceptance of new innovations is difficult in that HVAC&R products generally are viewed as commodities where sales are extremely price sensitive; a small price difference can sway a purchase decision. As a result, industry is not well-capitalized to perform long-term research in high-risk areas. Yet, industry's long-term viability, as well as the needs of its customer base, is dependent upon the development of novel, breakthrough technologies. Implementation of innovative ideas into HVAC&R products will serve to offer customers added benefits by reducing energy consumption costs, improving indoor comfort for building occupants, and further reducing the impact that operation of HVAC&R equipment has on the environment. Additionally, innovative breakthroughs offer U.S. manufacturers the opportunity to expand international sales and to stave-off sales of foreign-manufactured products in the $17 billion/yr U.S. market.[4]

Energy reduction is a large component of this HVAC&R initiative. Some statistics on site-consumed energy[5] usage within the U.S. are:

Health Administration), Department of Transportation (Federal Highway Administration), Department of Veterans Affairs, Consumer Product Safety Commission, Environmental Protection Agency, Federal Emergency Management Agency, General Services Administration, National Aeronautics and Space Administration, and National Science Foundation.

[4] Equipment manufactured by the U.S. HVAC&R industry consists of unitary air conditioners and heat pumps, heat transfer equipment, chillers (absorption, centrifugal, screw, etc.), gas furnaces, commercial and residential refrigeration equipment, compressors, and a variety of component products. The value of U.S. industry shipments for 1995 was over $17 billion, roughly 40% of the world's total production of HVAC&R equipment. Source: Bureau of the Census, Current Industrial Reports, MA35M(95)-1

[5] Energy utilized on site is without consideration of conversion and distribution losses.

- U.S. Commercial Buildings[6]
  - Approximately 5.5 quads[7] of energy (i.e., electricity, natural gas, fuel oil, and district steam or hot water from a central plant or utility) are consumed in commercial buildings each year at an annual cost of $71.8 billion.[8]
  - Comfort conditioning (e.g., heating, cooling, and ventilation) and refrigeration is the single largest component of this overall requirement and uses 48% (2.67 quads/yr) of the site-consumed energy.[9]

- U.S. Residential Households[10]
  - Approximately 10 quads of energy (i.e., electricity, natural gas, fuel oil, and liquefied gas) are consumed in residential applications each year at an annual cost of $124 billion.
  - Comfort conditioning (e.g., heating and cooling) is the single largest component of this overall requirement and uses 45% (4.54 quads/yr) of the site-consumed energy.

  - U.S. buildings consume about 35% of the country's total energy (all fuel types).

  - Including fuel used to generate electricity, commercial buildings account for over 15% of the U.S. carbon dioxide emissions; residential buildings account for 19%.

The direct payback from improved HVAC&R products is dramatic. Annual U.S. energy bills for comfort conditioning and refrigeration equipment are approximately $90 billion. Increasing overall HVAC&R equipment efficiency by 25% (a reasonable goal if a concentrated research program is pursued) could ultimately yield an annual energy savings of $22 billion. There would also be a proportionate decrease in the emissions of gases that are associated with global warming, as carbon dioxide emissions from power plants would decrease by nearly 60 million metric tons per year.[11] Additionally, as a result of improved

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6 Includes buildings used for assembly, education, food sales, food services, health care, lodging, mercantile and service, office, warehouse, and other.

7 1 quad of energy = 1 quadrillion (1×10^{15}) BTUs.

8 Source: Errata, Commercial Buildings Energy Consumption and Expenditures 1992, U.S. DOE Energy Information Administration, Office of Energy Markets and End Use, Report # DOE/EIA-0318 (92), October 1995.

9 Source: Energy End-Use Intensities in Commercial Buildings, U.S. DOE Energy Information Administration, Office of Energy Markets and End Use, Report # DOE/EIA-0555 (94), September 1995

10 Source: Household Energy Consumption and Expenditures 1993, U.S. DOE Energy Information Administration, Office of Energy Markets and End Use, Report # DOE/EIA-0321(93), 5 October 1995.

11 In 1992, carbon dioxide emissions from a generic building (including emissions occurring at the utility power plant for electricity) totalled 15.32 million metric tons per quad of site-consumed energy. (Source: Core Databook, U.S. Department of Energy, Office of Building Technology, Table 8, 24 June 1994) 25% of 15.5 quads of energy (for commercial and residential buildings in 1992) x 15.32 = 59.4.

indoor environmental quality (IEQ), worker absenteeism can be reduced significantly, thereby improving productivity.

It is worth noting that any process, application, or operation that depends on heating, ventilation, air-conditioning or refrigeration will benefit from enhancements in HVAC&R equipment. Additionally, a number of improvements developed by the industry have applications to other sectors of the U.S. economy. Hence, advances in the HVAC&R industry will have a profound impact on the overall U.S. economy and the international competitiveness of numerous U.S. industries.

Challenge

The equipment and refrigerants that have been successfully utilized for decades are now undergoing radical changes caused by regulations and market forces.

Energy Conservation Regulations:

In the United States, the National Appliance Energy Conservation Act (NAECA) and the Energy Policy Act of 1992 (EPACT) stipulate minimum energy efficiency requirements for residential equipment and light commercial heating, ventilation, and air-conditioning equipment. The U.S. Department of Energy soon will be reviewing these efficiency regulations with the intent of increasing the minimum efficiency levels for various equipment.

Environmental Regulations:

The Montreal Protocol calls for a phaseout of chlorofluorocarbon (CFC) production in developed countries effective 31 December 1995, and in developing countries by 31 December 2005. Although several candidates have been identified as replacements for CFCs (e.g., HCFC-123 replaces CFC-11, and hydrofluorocarbon HFC-134a replaces CFC-12 in many applications), some alternatives (such as the HCFCs) are intermediate-term solutions. In the U.S., production of HVAC&R equipment using hydrochlorofluorocarbon (HCFC) refrigerants are to be ceased in 2010 (i.e., HCFC-22) and 2020 (i.e., HCFC-123).[12] Replacements for HCFCs (e.g., R-410A, R-407C, etc.) are also coming under closer scrutiny due to global warming concerns. Uncertainty will continue into the next century as the world's governments discuss further modifications to the Montreal Protocol and undertake national programs to reduce greenhouse gas emissions as required by the Climate Change Convention.

Market Forces:

The U.S. economy has become highly dependent on air-conditioning and refrigeration equipment. Whether for comfort conditioning individual homes or office buildings, preserving food, maintaining environmental conditions for manufacturing processes, or the safe storage of medical supplies, HVAC&R products have become ubiquitous in the marketplace. The marketplace demands equipment that is safe, reliable, effective, and affordable.

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[12] Under the U.S. Clean Air Act, limited production of HCFC refrigerants will be permitted for ten years following the equipment usage bans for a "servicing tail" of existing equipment in the field.

It is expected that HVAC&R products will continue to find new applications in the U.S. market. Foreign markets will also expand dramatically as developing countries capitalize on the benefits of HVAC&R products. As the world's demand for such equipment expands, it is anticipated that foreign manufacturers will seek a larger foothold in the new markets while continuing to seek an opportunity to exploit the U.S. market. Hence, competition will become intense worldwide!

U.S. industry must move quickly to deal with the demands of satisfying environmental laws and energy concerns in a business environment where some existing technologies are now viewed as temporary solutions. Some of the alternative working fluids that appear to be environmentally benign are less energy efficient than the substances they replace.[13] Hence, either considerable cost must be added to today's equipment to maintain efficiency levels, or considerably more money will have to be spent controlling stack gas emissions of carbon dioxide (a greenhouse gas) if the alternative technologies are to have the same environmental impact.

The challenge is to develop equipment that balances the various requirements of environmental sustainability while responding to the needs of the marketplace -- safe, reliable, effective, and affordable systems. It should be recognized that these are not unrelated issues. The consumer wants equipment that satisfies his varied applications in a cost-effective manner and does not utilize excessive energy nor causes undue stress on the environment.

TECHNICAL IDEAS

Figure 1 summarizes the research needs of the industry. A number of project areas have been characterized to address long-term drivers of energy efficiency, comfort and health, environmental sustainability, safety, and marketplace appeal.

Through this new HVAC&R initiative, it is anticipated that the development and marketplace introduction of advanced equipment will be greatly accelerated. In recognition of the needs for energy efficiency and minimal adverse environmental impact (i.e., global climate change), alternative technologies and concepts must be evaluated on a basis of their *total equivalent warming impact* (TEWI).[14] Over the lifetime of today's well-constructed vapor compression equipment, 97-99% of the TEWI is due to the release of carbon dioxide that is produced by the provision of power needed

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[13] Additionally, some of the proposed environmentally benign alternatives are more hazardous to occupants and service technicians than the fluids they are replacing.

[14] TEWI has two primary contributors: the portion which is dependent on the working fluid chosen and its application (e.g., release of refrigerant to the atmosphere), and the portion associated with the amount of carbon dioxide released into the atmosphere during the creation of energy from combusting fossil fuels (e.g., coal, oil, or natural gas).

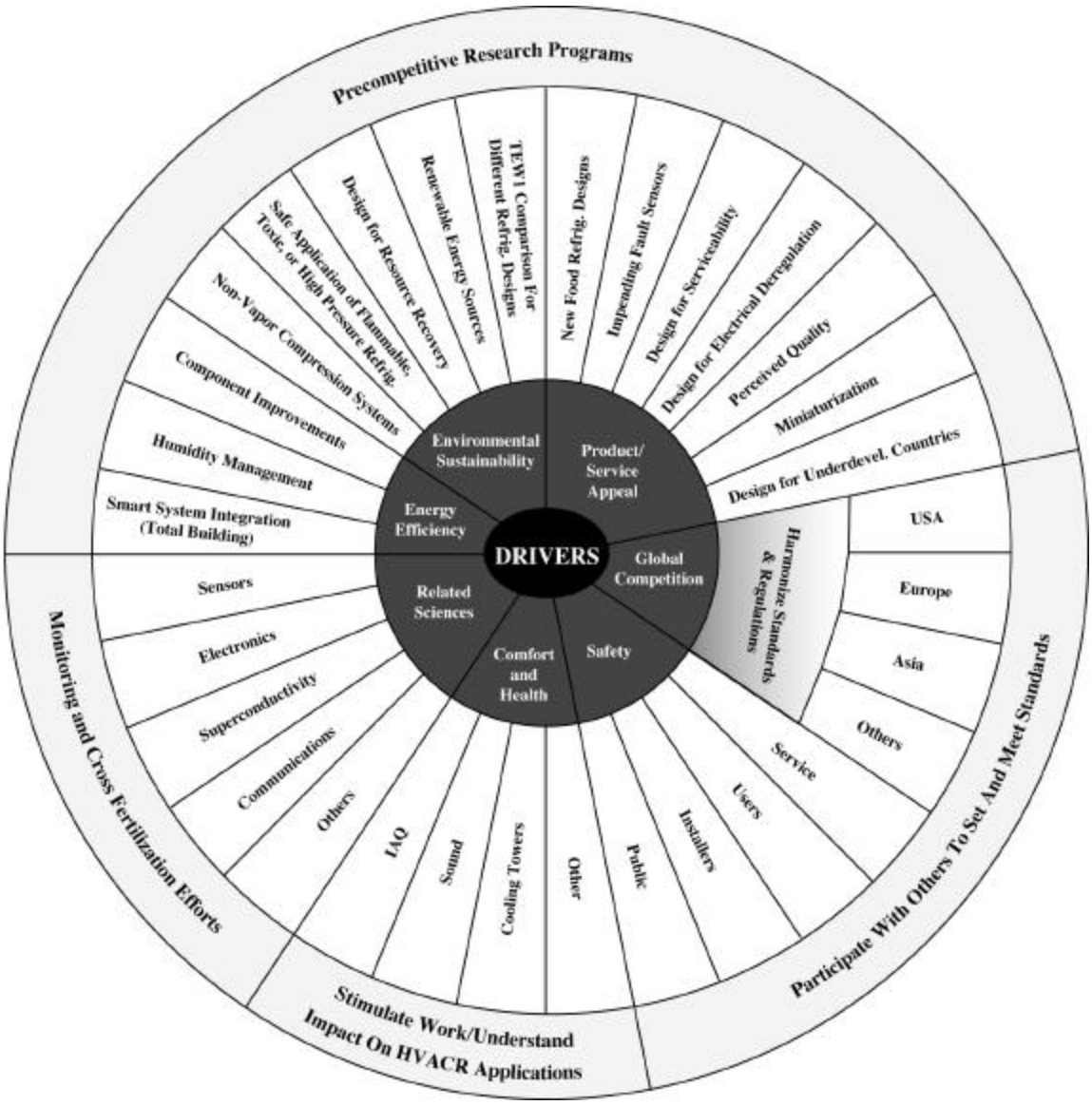

***Figure 1**: Long-Term Industry Research Needs*

to drive the equipment. Hence, improvement in overall efficiency is the most important goal when selecting alternative components, working fluids, or technologies.[15]

Specific examples of the types of product-related goals that manufacturers will be positioned to offer as a result of undertaking this program are:

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15 Refer to the TEWI evaluations undertaken by Oak Ridge National Laboratory, the latest being -- James R. Sand, Steven K. Fischer, Van D. Baxter, Energy and Global Warming Impacts of HFC Refrigerants and Emerging Technologies: TEWI Phase III, 1997, ORNL, Oak Ridge, TN

(1) Alternative Systems

The vast majority of air-conditioning and refrigeration equipment utilizes reverse Rankine-cycle vapor compression technology. Over the years, improvements in the performance, reliability, and serviceability of vapor compression systems have made them the most economically viable HVAC&R products. However, as a result of new materials and other technological advances, older alternatives and newer concepts may now be feasible.[16]

Many types of alternative systems have been suggested and preliminary analysis to varying degrees have been performed by various universities, government research facilities, and industry.[17] These technologies include absorption[18] and adsorption cycles, Brayton cycles, Lorentz cycles, Malone cycles, Stirling cycles, thermoacoustic refrigeration, thermoelectric refrigeration, and many others. Each has specific limitations that could be reexamined against the materials and manufacturing technology available today (or anticipated in the future) to evaluate its feasibility of meeting the advanced efficiency targets.

Analyses are needed to screen new concepts and, for those that appear to be more promising, research undertaken to resolve specific limitations that preclude their commercialization. Adsorption cycles, for example, are receiving attention because of their apparent simplicity compared to engine-driven heat pumps. However, the control problems associated with cycling solid adsorbent beds between adsorption and desorption portions of the cycle are not easy to solve in a cost effective manner. Other problems include cost and long-term reliability of the adsorbent material. A concerted research effort may solve these technological difficulties. Systems that do not use fluorocarbons and systems that utilize waste heat effectively are both of interest. New or hybrid cycles are sought that are inherently efficient, reducible to practical hardware without unacceptable loss of efficiency, and use a reasonably-priced, benign working fluid.

(2) Ultra-high efficiency equipment

Energy efficiency improvements in HVAC&R equipment have been steady, but incremental, in nature. To greatly accelerate the rate of efficiency improvements, a significant effort in energy research is needed.

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[16] However, it should be noted that the objectives to be achieved are a moving target -- the alternative technologies need to be compared after factoring in future improvements to the vapor compression technologies.

[17] For brief discussions on several of these, refer to: S. K. Fischer, J. J. Tomlinson, P. J. Hughes, Energy and Global Warming Impacts of Not-In-Kind and Next Generation CFC and HCFC Alternatives, Oak Ridge National Laboratory (ORNL), Oak Ridge, TN, 1994.

[18] The Gas Research Institute (GRI; Chicago, Illinois) has sponsored an extensive program to improve absorption equipment. Manufacturers interested in absorption equipment are currently improving their systems individually.

2a). *Improved unitary efficiency*: About 95% of all residential air-conditioners and heat pumps sold today have cooling seasonal energy efficiency ratios (SEERs) between 10 and 12.5[19]. Since efficiency improvements generally mean higher equipment costs to the consumer, and when it comes to purchasing HVAC&R equipment most consumer decisions are based on first costs, the weighted average shipment efficiency of unitary equipment sold in 1996 was 10.68 SEER for air-conditioners and 11.0 SEER for heat pumps. For the installed based of unitary equipment in the field (average life of 15-20 years), the average efficiency is less than 9 SEER. Figure 2 shows the seasonal energy efficiency ratios of heat pumps manufactured in the U.S. for the last fifteen years. Growth in the weighted average shipment efficiency can be expected to gradually increase each year. However, given relatively low energy costs and the paucity of consumer rebates or other incentives, there is little consumer demand for the more expensive, top-of-the-line high efficiency units that are currently available. Targeting a cooling SEER of 20 in a cost-effective system will require an impressive effort and could revolutionize the HVAC&R market. Also of revolutionary value is the development of a heat pump cycle that will have better heating capacity during low outdoor temperatures while supplying higher discharge temperatures to the occupied space.

Can We Do Better?
While average efficiencies have increased by nearly 40% since 1981, the increase has been gradual.

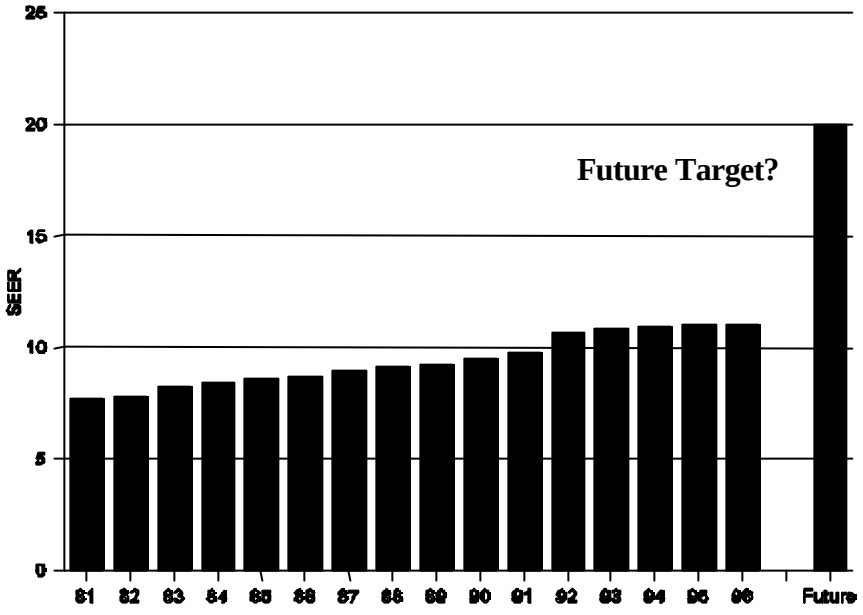

Figure 2. *Shipment-Weighted Seasonal Energy Efficiency Ratings (SEER)*

[19] Top of the line unitary products can achieve efficiencies of nearly 18 SEER. However, market forces for unitary products have not greatly supported the added cost of these higher efficiency units.

of Unitary Air-Source Heat Pumps. (Source: ARI)

2b). *Improved chiller efficiency*: Water chilling equipment (used to condition large commercial, institutional, and industrial facilities) has steadily improved in efficiency and performance in recent years. Over the past 20 years average efficiencies of centrifugal chillers have increased by 34%, jumping from 0.83 kW/ton to 0.62 kW/ton.[20] The relatively easy design changes have been accomplished and further improvements may require a departure from conventional technology. The goal is to enable the development of *state-of-the-art* chilling systems so that overall annual energy consumption can be reduced by an additional 30% (over today's high-end systems).

2c). *Improved refrigeration equipment* : Current supermarket refrigeration systems have the potential for significant refrigerant leak rates and high power consumption. In transportation refrigeration, system size, efficiency, and weight are a compromise to meet "pull-down" and "steady-state" operation requirements.[21] Better cost-effective, reliable capacity modulation methodologies are needed. Additionally, the industry may need a radical departure from previous construction practices, away from built-up systems with long refrigerant piping, towards packaged systems with a secondary fluid (either to affect cooling of the load, or to extract heat from the systems).[22] The goal is to develop new refrigeration systems that offer an overall energy efficiency improvement of 30% (over today's state-of-the-art systems) and dramatically reduced leakage rates.

Achieving the efficiency and goals outlined above will require long-term, high risk, massive research efforts. However, if accomplished, it will result in substantial energy savings. To develop these higher efficiency HVAC&R products, a number of significant hurdles must be surmounted. Some specific examples are:

- *New heat exchanger concepts/fabrication techniques*: Established manufacturing methods are relatively high cost and result in large-sized heat exchangers. Precompetitive research in such areas as integral tube/fin designs (all copper for corrosion resistance), plate-and-tube designs, or micro-channels may offer an opportunity to increase system efficiency while reducing overall component size. Miniaturization of heat exchangers and related components offer advantages of less cost to build (less material should be less expensive), less cost to transport, and less cost to install while requiring less floor space at the job site. Research on optimizing the flow configurations and surface geometries of heat

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[20] For today's most advanced centrifugal chillers, efficiencies are in the 0.48 - 0.52 kW/ton range.

[21] For stationary applications (e.g,. supermarkets and cold storage warehouses), size and weight limitations are not generally issues of concern provided that food display/storage requirements are not impacted.

[22] It should be acknowledged that some of the larger supermarket chains have begun to explore alternative design options (e.g., greater consideration of secondary loop systems, distributed loads, etc.).

exchangers is also vitally important for obtaining more efficient operation.

- *Heat transfer research*: Preliminary research by Japanese and American researchers indicate that electrohydrodynamic (EHD) heat transfer augmentation techniques may be a cost-effective way to achieve ultra-high efficiency products. Also needed are methodologies for minimizing the energy losses in heat exchangers caused by water-side fouling in tubes and air-side depositions on fins. Additionally, research is in its infancy on whether refrigerant composition shifting in heat pumps can be advantageously utilized to permit different circulating mixtures for summer cooling and winter heating operations. Optimizing equipment to use differing refrigerant compositions for the cooling and heating modes will be challenging, but if successful, could yield large efficiency gains.

- *Affordable high-efficiency motor systems*: Improvements are desired in efficiency, compactness, and cost effectiveness of motor systems (i.e., motors, drives, and controls). Variable-speed drives can reduce energy consumption at part load conditions (by varying compressor speed), thereby saving energy on a seasonal basis. New types of motors (e.g., reluctance and permanent magnet) and drives may improve efficiency in variable-speed systems. Present barriers include costly components for power handling, assurance of power-line quality (e.g., harmonics, power factors, and transients), and reduction of electromagnetic interference (EMI). Additionally, it is possible that other improvements to motor efficiencies can be obtained by using non-traditional materials in the construction of the motors. Research is needed in developing these cost-effective high-efficiency motor systems.

- *Oil-free compressors*: HVAC&R equipment utilize compressors that require oil for lubrication, compression sealing, heat absorption, and noise abatement. However, the lubricant adds a number of complex technical problems to the operation of a system:
    * numerous materials compatibility concerns arise from the interaction of the lubricant with the materials present,
    * excessive oil degrades the performance of heat exchangers,
    * complicated and expensive oil return/equalization schemes are necessary, and
    * power consumption is increased due to the oil's viscous shear.

  The elimination of the oil from the operating system could greatly enhance equipment performance and allow the reliable use of new materials. Revolutionary advances in HVAC&R equipment could occur if compressors are developed that require no oils or lubricants to operate; perhaps the refrigerant could satisfy the role of lubrication oils.

- *Improved technologies for humidity control*: Better technologies may allow systems to adapt for optimal latent heat or sensible heat removal. To maintain humidity control, many of today's applications have to "over-cool" and then "re-heat" to a comfortable setting. Integration of alternative technologies (e.g., heat pipes, sorption, filtration/wicking, desiccants, membranes, etc.) may offer better moisture control while also offering advantages in condensate management. Better condensate and frost management

techniques will reduce losses associated with heat transfer interference and decrease pressure drops.

- *Controls and sensors*: An entire new suite of sensors and controls will be required to enable optimum operation of HVAC&R systems. Present sensors in some applications are expensive, large, and invasive. New sensors/controls to ascertain/correct a system that is drifting from efficient operation (e.g., low refrigerant charge, heat exchanger fouling, composition shift of the working fluid, increased pressure drop on the air-side or refrigerant side, etc.), or that is facing an impending failure (e.g., refrigerant system blockage, fan and compressor failure, excessive refrigerant leak, chemical changes within the system, loss of lubrication, etc.) will improve system efficiency and reliability in the field. These same controls and sensors may permit equipment to become easier to diagnose and service. In supermarket applications, sensors could be used to ascertain frost buildup (for subsequent implementation of frost elimination steps) and to sense odor (representative of food spoilage). Fuzzy logic, neural networks, multiple input-multiple output (MIMO), as well as technological advances in digital signal processing offer substantial opportunities for HVAC&R systems.

- *More efficient air handlers*: High-efficiency fans are relatively expensive and compact designs corrupt the optimum air flow. There is a need to quantify fan losses and evaluate alternative designs and configurations.

(3) Smart System Integration

To provide substantial improvements in energy consumption and comfort levels, there is a need to treat buildings, with their individual subsystems, as complete entities, not as the sum of a number of separately-designed and separately-optimized components. This entails that future HVAC&R equipment be better integrated into the various applications. "Whole building" modeling will assist in capturing "waste heat" and in assessing optimum "off-design" or alternative "set-points." Specific areas needing attention are:

3a). *Advanced building distribution systems* : Improvement in the delivery of conditioned air or water is necessary to ensure that advances in equipment efficiencies are not negated by inefficient distribution systems.

- *Improved duct systems*: The majority of residential[23] and commercial buildings built in the U.S. today utilize central HVAC&R systems with ducted air distribution networks. Improvements in duct design, fabrication, installation, and insulation techniques are required to maximize the effectiveness of high efficiency HVAC&R

[23] In 1994, approximately 79% of newly constructed single family homes in the U.S. were built with central air conditioning (includes heat pumps). Source: Characteristics of New Housing. C25 Reports. Bureau of the Census.

equipment. Development and marketplace acceptance of cost-effective zoning techniques will ensure that energy is not needlessly wasted on the conditioning of unoccupied rooms.

- *Advanced controllers*: Sensors and controllers are increasingly being utilized by the industry to make HVAC&R equipment more energy efficient, reliable, and to provide improved diagnostic capability. Hardware and software improvements enable larger systems to be remotely operated and diagnosed. Building automation software that is adaptive and easy to implement needs to be advanced. The development of "fuzzy logic" controls that adapt and respond to different operating constraints within buildings offer further opportunities to improve the effectiveness of HVAC&R equipment.

3b). *Identify and quantify building energy losses* : There is a lack of knowledge on where and how energy is lost (wasted) in typical buildings. Better quantification of these energy losses (real-time energy usage for all building types) may assist industry in identifying techniques to successfully recover useful benefits from low grade energy and heat losses.

3c). *Building rating methods* : Identify and evaluate options to rate whole building energy efficiency and then recommend preferred options and procedures for applying appropriate credits and offsets for systems and components.

3d). *Standard external communications information for HVAC&R equipment* : In light of the current trend of utility deregulation, it can be expected that consumers will be offered more options for utility control of the load during high-peak (and high-cost) hours. It is beneficial for the HVAC&R industry to assess and provide the form of information and signal type best suited for controlling equipment operation for such load management activities. Tieing HVAC&R communications with other building operations (e.g., lighting, elevators, alarms, etc.), in a unified manner, may offer efficiency benefits. A number of standardized communication protocols have been introduced to the market to control HVAC&R equipment (e.g., BACnet™, LonWorks™, etc.).[24] However, these have differing conformance classes that are not fully compatible with each other. An opportunity may exist to standardize the protocols; enabling building operators to more easily control diverse building equipment and service personnel to more easily diagnose and service HVAC&R equipment and components.

(4) Indoor Environmental Quality

Indoor air quality (IAQ) and its relationship to occupant comfort, health, and productivity has

[24] BACnet --> Building Automation and Control networks, is trademarked by the American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc. (ASHRAE).
LonWork --> Local operating network, is trademarked by Echelon Company.

received increased attention in recent years. As a result, defining, recognizing, measuring, and controlling indoor air contaminants are now becoming significant issues. A more complete understanding of which, and how, contaminants affect occupants, and how these contaminants are introduced to occupied areas, is urgently needed. It is envisioned that advanced control and sensor technologies could allow space conditions to be adjusted for individual comfort and for differing activities in occupied areas. Breakthroughs in this area could enable HVAC&R equipment to play a larger role in monitoring and reducing the levels of indoor air pollutants and other airborne irritants. It also is anticipated that better understanding of airborne contaminants will allow for the development and application of more effective control and mitigation techniques (i.e., beyond today's ventilation and filtration methods). Reliable, cost-effective, energy efficient solutions to the complex problems of indoor environmental control are needed. Recommended project areas include:

4a). *General comfort*: Determine the effect of IAQ control strategies on health and comfort, including benefits of improved particulate filtration, gas-phase filtration, use of anti-microbial materials, and ventilation. An assessment is needed to ascertain how advanced sensors and controls can enhance IAQ (e.g., better control of humidity, particulate, and gas phase contaminants). Also needed is information that enables the design and fabrication of equipment (e.g., specific materials) that can absorb/adsorb/filter the identified contaminants.

4b). *HVAC&R materials* : Research to identify construction materials that inhibit the growth of microbes inside HVAC&R systems, This includes drain pans, insulations, blowers, coils, duct materials and filters. Investigations on cost-effective anti-microbial materials to assess their impact on IAQ are also required.

4c). *Filtration and air cleaning methods* : Develop cost-effective absorption, adsorption and catalytic reduction air cleaning systems for commercial and residential applications. Also important is the development of cost-effective, highly-efficient mechanical air filters with low air pressure resistance.

In addition to the above, there are other issues that are associated with occupant comfort and productivity. Objectional noise, vibration, lighting, and air drafts are other factors that affect occupants. These items, taken in concert with IAQ issues, comprise the larger issue of Indoor Environmental Quality (IEQ).

(5) New Environmentally-Friendly Working Fluids

As the industry shifts its focus from CFCs and HCFCs, global warming concerns are causing HFCs to undergo close scrutiny.[25] If the usage of today's accepted working fluids were sharply curtailed,

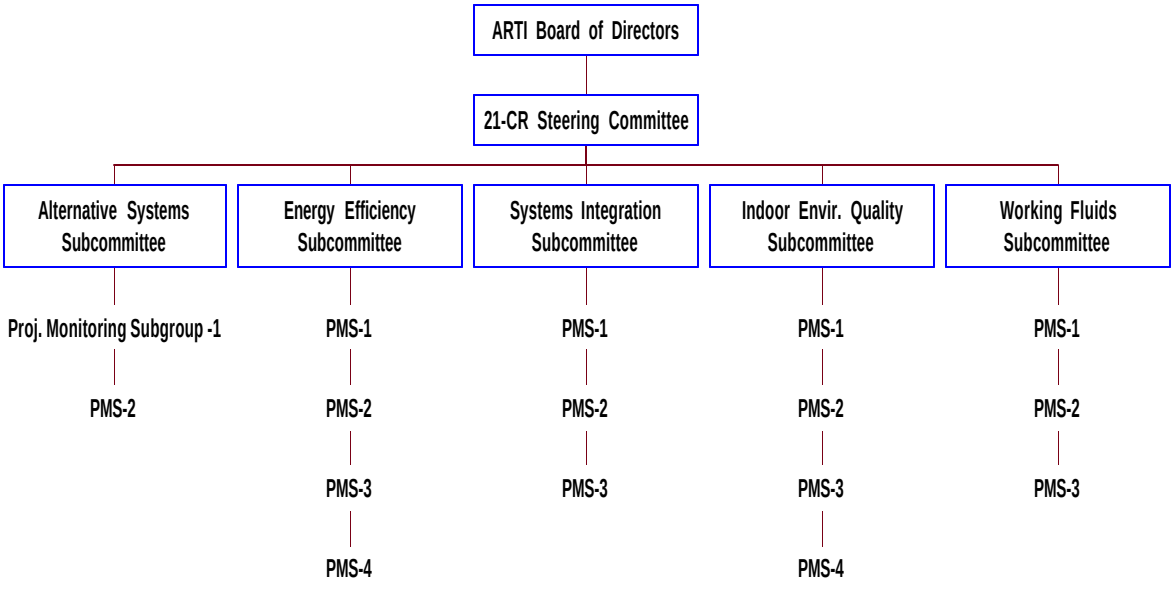
[25] Although life-cycle operation of HVAC&R equipment represents less than 2% of the overall contribution to global warming gases in an industrialized society, the HVAC&R industry is now a relatively easy one to regulate as a result of the existing international protocols related to the ozone depletion issue.

new chemicals would have to be developed and investigated for many HVAC&R applications. These chemicals may be familiar "natural" species such as hydrocarbons or ammonia, or new synthetic ones such as fluorinated ethers. As noted earlier, the TEWI concept needs to serve as the screening method for comparing tradeoffs between the efficiency of various fluids with their direct global warming potentials.

Many issues are associated with the use of these chemicals in new applications, the most crucial of which is safety. The toxicity, flammability, and long-term breakdown products must be carefully determined. Studies on refrigerant toxicity and flammability, and how to safely apply such working fluids in HVAC&R applications, are required to open the market for many products containing alternative chemicals.[26] A myriad of material compatibility issues, reliability concerns, and performance evaluations would also have to be undertaken.

IMPLEMENTATION STRUCTURE

A committee structure has been established under the Air-Conditioning and Refrigeration Technology Institute[27] (ARTI; an entity associated with ARI) to guide the initiative and to monitor the undertaken research. The committee membership comprises authorities in the research area drawn from industry, research organizations, universities, and government. The overall goal of drawing individuals from a broad spectrum is to ensure that strategic technologies are addressed, and to increase the benefits of the resultant research to the industry and the public.



[26] Usage of these chemicals entails research in obtaining "zero-leak" systems, refrigerant charge minimization, and evaluating secondary fluids and systems.

[27] ARTI, a not-for-profit organization for scientific research in the public interest, incorporated in Delaware; its principal offices are in Arlington, Virginia. ARTI holds tax-exempt status under Section 501(c)(3) of the Internal Revenue Code.

Steering Committee

A Steering Committee, comprising senior industry executives (mostly at the vice presidential and higher levels), assure both the appropriateness of the work, relative to industry needs, and access to necessary information, support, and personnel. The Steering Committee assigns priority levels and approves funding support of individual projects recommended by its five newly formed Subcommittees (refer to Exhibit E for the Subcommittee scopes):

- Alternative Equipment,
- Equipment Energy Efficiency,
- System Integration,
- Indoor Environmental Quality (IEQ), and
- Working Fluids.

Subcommittees:

The five 21-CR Subcommittees, comprising senior industry engineers and technologists as well as competent, knowledgeable persons from pertinent industry sectors, identify specific project needs, prepare work statements, prioritize the research, and identify contractors capable of performing the individual research. Once individual projects have been approved for funding by the Steering Committee, the pertinent Subcommittees provide technical review of the submitted proposals, recommend contractor selection, monitor and oversee the on-going research, perform site reviews, and review the submitted final reports.

The Subcommittees also review/monitor and coordinate (where possible) industry/public-sector pre-competitive research. The purpose of this ancillary focus is to encourage other entities (e.g., government laboratories, university researchers, etc.) to perform work of interest to the industry while also striving to minimize duplication of effort.

HVAC&R industry participants have already demonstrated that they are capable and willing to oversee substantial efforts of this type. Two specific examples are the *Materials Compatibility and Lubricants Research (MCLR) Program* and the ARI *R-22 Alternative Refrigerants Evaluation Program* (AREP); refer to Exhibits A and B for background briefings.

OPPORTUNITY TO MAKE A SIGNIFICANT DIFFERENCE

Industry currently performs a great deal of research on HVAC&R issues, alone or in consortium with other interested parties. However, these endeavors generally are aimed at obtaining incremental product improvements. The subject program is needed for the high-risk research that individual industry participants cannot afford to fully fund on their own.

The envisioned research is on the "cutting-edge" of the HVAC&R industry, and entails a high degree of technical risk. Currently, personnel and testing resources within individual companies are spread thin

because of the pace of product changes necessitated by CFC phaseouts and efficiency improvement requirements, with global warming implications to come. In general, HVAC&R companies do not have the capabilities to fully develop the project areas on their own. Collaboration among HVAC&R companies and other interested entities would enable significant resources to be applied to the desired product development goals.

By providing a solid basis for industry collaboration in precompetitive technology areas, this program can catalyze progress in a range of developments that individual U.S. companies otherwise are unable to undertake. If successful, substantial savings should be realized by building owners and operators as a result of reduced operating costs, even greater equipment reliability, and improved comfort levels.

CONCLUSION

The HVAC&R industry, which has been experiencing evolutionary growth for the last 40 years, has suddenly undergone a period of unprecedented change. The pressures driving these changes -- protection of the environment and conservation of our natural resources -- will only become more severe in the future. The development of new technologies needed to meet these rigid environmental requirements will necessitate a large concerted effort. No single company has the resources to accomplish the development of these new technologies alone. A joint, cooperative effort between industry, academia and government is required to solve many of the large problems currently before the industry.

Exhibit A:
Background Information on the Industry-Sponsored MCLR Program

The Materials Compatibility and Lubricant Research (MCLR) program is a multi-year research grant administered by the Air-Conditioning and Refrigeration Technology Institute (ARTI, an entity associated with ARI), a not-for-profit organization for scientific research in the public interest. The MCLR program supports critical research to accelerate the introduction of CFC and HCFC refrigerant substitutes. The MCLR program addresses refrigerant and lubricant properties, materials compatibility, system related issues, and test methods development.

The MCLR program has conducted extensive research on the properties and materials compatibility of HCFC-123, HCFC-124, HCFC-142b, HFC-32, HFC-125, HFC-134a, HFC-143a, HFC-152a and HFC-245ca with a number of lubricants. Although HCFC refrigerants with alkylbenzene and polyglycol lubricants were included in the initial screening tests, most of the work has since centered on HFC refrigerants with polyolester (POE) lubricants. Baseline comparative measurements were also conducted with CFC-11, CFC-12 and HCFC-22 with mineral oil. Properties examined included thermophysical and transport properties and infrared spectra of refrigerants; miscibility, viscosity, and foaming characteristics of refrigerant-lubricant mixtures. Compatibility of refrigerant-lubricant mixtures were tested with metals, motor insulating materials, elastomers, plastics, desiccants, process fluids, and lubricant additives. System related issues studied included lubricant circulation, fractionation of blends, effects of system contaminants, products of motor burn-outs, flushing and clean-out methods, the effectiveness of desiccant driers, and limited efforts in heat transfer enhancement technologies. Methods development research has focused on the development of an accelerated method for screening the compatibility of motor insulating materials with new refrigerant-lubricant mixtures and research to improve methods for testing the flammability of refrigerants and refrigerant blends.

Tieing the whole program together is the ARTI Refrigerant Database, which contains refrigerant summary tables that provide basic comparative data on refrigerants properties. The database also contains searchable citations and abstracts of thousands of research papers on alternative refrigerants. All final reports from the MCLR projects are available from the database administrator.

Since its initiation in 1991, the MCLR has completed twenty-nine research projects. Another eleven projects are currently underway and three more projects are in the planning phase. At the conclusion of the MCLR program, expected to draw to a close by December 1999, over $10 million will have been invested in the research.[28]

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[28] This program is supported, in part, by U.S. Department of Energy grant number DE-FG02-91CE23810. Federal funding supporting the program constitutes 93.57% of allowable costs. Funding from non-government sources supporting this program consists of direct cost sharing totaling 6.43% of allowable costs, and significant in-kind contributions from the air-conditioning and refrigeration industry.

Exhibit B:
Background Information on the Industry-Sponsored R-22 AREP

ARI's R-22 Alternative Refrigerant Evaluation Program (AREP) was a five-year international effort undertaken by the HVAC&R community at an estimated cost of $5 million. The original objectives of the AREP effort were established at the start of the program in 1992:

To identify possible alternatives to R-22 and R-502 for major ARI product categories;
To establish testing protocols for evaluating the candidate replacements;
To conduct tests using the candidate refrigerants; and,
To review and release the results of these tests.

In 1994 the AREP effort was extended to cover a number of application-related issues:

Practical Experiences with New Refrigerants
Data Sharing from New Optimized Compressors
Data Sharing from New Optimized Systems
Calorimeter Tests of New Geometry Tube Heat Exchangers
System Tests with New Geometry Tube Heat Exchangers
Calorimeter Tests of Recircuited Heat Exchangers
System Tests with Recircuited Heat Exchangers
Performance Tests with Future Refrigerants
Public Release of Thermophysical Property Data
Performance and Reliability Tests with Immiscible Lubricants
Component Redesign

All of the program objectives were met to a satisfactory level and the AREP activity was drawn to a close in January 1997. A large volume of data was generated on a number of alternative refrigerants in an efficient manner. Data were made available from tests of many types of compressors, including reciprocating, rotary, screw, and scrolls, and from tests of several classes of equipment, including split-system heat pumps (various sizes, air- and water-cooled), packaged heat pumps, window units, refrigerated transport units, condensing units, freezer chests (display cases), and reciprocating, screw, scroll and centrifugal chillers.

The AREP has been an unqualified success, thanks to the conscientious, dedicated efforts of all the program participants. The industry has demonstrated that it can work together for mutual benefit to address environmental and technological challenges that it faces world-wide.

Exhibit C:
Listing of External Drivers Impacting the HVAC&R Community

During the 21-22 April 1997 Workshop (*Research for the 21st Century*, Chicago, IL), a number of external factors were identified that are expected to have an influence on the HVAC&R community. A list of external drivers was developed by the participants in each of the four workshop breakout sessions:

- commercial buildings (e.g., chiller systems),
- residential buildings (e.g., small unitary equipment),
- light commercial buildings (e.g., unitary rooftop package equipment), and
- supermarket (e.g., commercial refrigeration) and transport refrigeration (e.g., truck/rail/ship equipment)

Since the residential unitary equipment and the light commercial unitary equipment are somewhat similar in performance requirements and construction, the drivers are essentially the same. Hence, these two areas are summarized as one.

DRIVERS / ISSUES FOR UNITARY EQUIPMENT
(Residential and Light Commercial Buildings)

Energy Efficiency Considerations

Controls and equipment for deregulated energy
and changing energy sources
High efficiency - technology needs
- NIK technologies (e.g., non-vapor compression systems)
- Other ideas (CO_2, thermal storage, desiccants, geothermal, etc)

Integrated systems (e.g., hot water generation, etc.)
Utilization of waste heat from other sources w/in the building
Power quality
Equipment mistreatment/abuse

Environment Considerations

Environmental sustainability (ODP / GWP / TEWI)
- energy
- design for resource recovery (e.g., recycling)
- refrigerant containment / charge minimization

Energy storage for load shifting
Design for long-life
- corrosion resistance
- UV resistance

Comfort Considerations

Who controls the temperature (building operator or occupant?)
Sound/acoustics for comfort/productivity (e.g., sound quality)
Realistic sound measurement techniques that match requirements
Flexible systems for varying IAQ needs as occupancy changes
Active ventilation needs in light commercial
Individualized comfort control
Air distribution and zone control
Occupancy sensing
Building "comfort" rating
Temperature / air velocity / relative humidity
Air cleanliness
- what to sense and control
- filtration/absorption

Odor control
Design for comfort and health

Safety Considerations

Year-round maintenance needs
Flammability of refrigerants
Toxicity of working fluids
Safe use of hydrocarbons
Material selection/toxicity
Technician training and overcoming resistance to change

Codes and Regulations

Changes needed in codes/regulations
ASHRAE Standard 62 and impact on industry
Global harmonization of codes and standards (e.g., ISO Standards)

Other Considerations

Communication channels are different between supplier and
manufacturer for light commercial and residential applications
(e.g., specifying engineer vs. contractor)
Low-ambient cooling requirements for light commercial applications
Design for seismic event
Communication control protocols
Technology transfer
Miniaturization
- smaller heat exchangers
- smaller and smarter controls and interfaces
- design optimization

Trade-offs between lubricant choice, HX effectiveness and cost
Robust, fault-tolerant design (service free design?)
Creative financing
Special needs for underdeveloped countries
Educating consumers / users to make informed buying decisions
Design for installation ease (e.g., fool-proof installation)
Design for serviceability
Design for control/diagnostics
Design for condensate management
Design for reliability/durability (perceived quality)
Packaging

DRIVERS / ISSUES FOR COMMERCIAL BUILDINGS

Energy Efficiency Considerations

Controls and equipment for deregulated energy
High efficiency - technology needs
- NIKs
- Other ideas (thermal storage, desiccants, geothermal, etc).

Integrated systems (e.g., hot water generation)
Inter-operability of equipment (and communication protocols)
Modified district heating and cooling systems
Water system optimization (i.e., cooling tower, chilled water loop)
Real-time energy pricing hybrid chillers (electric & gas)

Environment Considerations

Environ. Sustainability (global warming, regulations, utility dereg.)
Limits on electric power generation capacity (& retail wheeling)
Lower utility bills
Compatibility of power systems
ODP
GWP
TEWI
Refrigerant containment/minimization
Material selection/ease of recovery
Design for long-life (corrosion resistance, UV resistance)
Design for resource recovery
Cooling tower make up
Cooling tower treatment chemicals

Safety Considerations

Safety and liability concerns
Flammability/toxicity of refrigerants
Technician training of shop personnel (design and manufacturing)
Technician resistance to change
Equipment mistreatment/abuse
Cooling tower health issues

Comfort Considerations

Comfort (temperature, air flow, acoustics, IAQ)
Design for flexibility in application
Design for comfort & health
Improved occupant productivity
Individual comfort control
Equipment noise
Relative humidity
Air cleanliness (What to sense and control, Filtration/absorption)
Odor control

Other Considerations

Global manufacturing / global competitiveness
Equipment costs
Profit motive
Impacts of related sciences
Information retrieval
Adequate service work force
Fear of chemicals
Engineers design --- architects "art it up"
Component standardization
Design for seismic activity
Increased coastal applications
Wireless communications
Changing demographics (developed vs. developing nations)
Withdrawal of utilities from product development/commercialization
Increased design life of products
Master construction schedules are moving to "just-in-time" concepts
Changes needed in codes/regulations
Special needs for developing countries
Design for installation/maintenance ease
Design for zero maintenance
Design for serviceability
Design for control/diagnostics
Design for condensate management
Design for reliability/durability (perceived quality)

DRIVERS / ISSUES FOR
COMMERCIAL REFRIGERATION & TRANSPORT REFRIGERATION

Energy Efficiency Considerations

System integration (use of waste heat)
High efficiency technology needs
- Not in kind
- Component improvements
- Thermal storage
- Building environment
  - temperature control
  - humidity control

Needs in a deregulated energy environment

Environment Considerations

Environmental sustainability
Limits on electric power generation capacity
Limits on fossil fuel emissions (engine-driven equipment/transport)
Noise emitting from machinery to nearby communities
Refrigerant containment/minimization
- Factory leak testing
- Field leak testing
- Non-leak joining methods
  - Fixed joints
  - Accessible joints

Secondary refrigerant systems
- Low temperature materials
- Reduced pumping power
- High pressure refrigerants

International/federal requirements
- ODP
- GWP
- Other

The acceptance of TEWI in buying decisions
Design for resource recovery
Sound reduction

Safety / Legal Considerations

Safety and liability constraints
Flammability of Refrigerants
Toxicity of Working Fluids
High Pressure Refrigerants
Technician training
Cooling tower health issues

Quality/Performance Considerations

Food merchandising techniques and distribution
Changes in supermarket building condition
US FDA Food Code 1997 (e.g., food quality requirements)
Alternative Technologies to preserve food
International/ANSI Approval Requirements
Improved Product Temperature Within Display Case
Change in Health & Sanitation Codes/Regulations
Change in Performance Codes/Regulations (Canada)

Other Considerations

Global competitiveness
Costs
Impact of related sciences
Improved user productivity
Population growth in warmer climates (changing demographics and lifestyles)
Expansion of the "cold chain" in developing countries (refrigeration from the field to market)
Utility deregulation
Lack of skilled service personnel
Human interface -- complexity of control systems
Changes needed in building/equipment and codes/regulations
System serviceability
Design for system control/diagnostics
Capacity to weight and size (transport)
Ease of consumer access (cases)

Exhibit D:
Ideas Arising from the 21-22 April 1997 Industry Workshop

Research areas responding to the external drivers (refer to Exhibit C) were identified by the participants in each of the four workshop breakout sessions:

- commercial buildings (COM.BLDGS);
- residential buildings;
- light commercial buildings; and
- supermarket and transport refrigeration (REFR & TR)

Again, since the residential unitary equipment and the light commercial unitary equipment are somewhat similar in performance requirements and construction, the research areas were combined (RES & LC).

The workshop participants identified a large number of items in keeping with the workshop challenge. In true "brain storming" mode, these ideas were recorded without detailed discussion or attempt to qualify their usefulness or validity. Near the conclusion of each session the participants ranked the items and, for a limited number, had greater discussion on the relative values of the initiatives.

To enable quick group prioritization of the suggestions, each session participant had a number of colored red stickers to place on items deemed to be of higher importance. Once this initial screening was completed, each participant was given a lessor number of blue stickers to indicate the highest priority for those that were previously marked with red decals. In this manner, the thirty (nominal) participants in each session were quickly able to rank the research needs.

The details of the selection process are shown on the next three pages where the total number of RED (R) and BLUE (B) "votes" are tallied. Those with the largest number of BLUE and then RED votes are considered to be of higher priority. Although, some items received few or no votes, many of those research issues are subsets of a higher priority category.

ENERGY EFFICIENCY

Com. Bldgs		Res & LC		Refr & Tr.		
Systems/component related						
				27R	**21B**	Optimize fast pull-down temperature technology (use of wide glide refrigerants or use of use of variable capacity components).
19R	**18B**	5R	2B			Improve air-moving efficiency (e.g., fan efficiency); especially important for commercial applications due to higher duty cycles.
7R	--	**8R**	**4B**			New heat exchangers/fabrication techniques.
		7R	4B			Low-cost, reliable lubricants (or compressors redesigned for lower-cost lubricants).
				15R	2B	System integration to reduce energy use (use A/C to lower refrigeration load?).
		6R	1B			Need design tools to optimize systems within a building.
		5R	1B			HX design (advanced surfaces).
				9R	--	Frost management technology (also, frost-free surfaces and frost avoidance strategies).
				4R	--	Super efficient thermal insulating material.
		3R	--			Efficient filter design (Currently, system are not optimized for the higher levels of static pressure drop that high efficiency filters need).
				1R	--	Improvements of multi-temperature compartmented systems.
				1R	--	Super robust, durable systems.
--	--					Energy variabilities influence of high lift vs low lift.
--	--					Water treatment for zero fouling & corrosion.
--	--					Reduction of bearing losses in equipment.
--	--					Wetability of heat exchanger surfaces (absorption systems).
		--	--			Efficiency deterioration with age.
				--	--	Engine robustness to poor quality fuels.
Building related						
17R	**16B**	**30R**	**20B**			50% energy reduction in buildings (quantum leap required, interaction w/ non-AC&R trades needed as well).
16R	**16B**					Improved systems, smart systems with total system integration.
		18R	**13B**			Whole building ratings (trade-off/combining energy uses/ integrate with other uses).
		7R	3B			Need R&D to better utilize waste heat from the building and from the compression process (integration of building. energy functions).
2R	--					Building energy strategy.

		2R	--			Should ARI assess viability of an "Energy Budget" .... bench marking and tracking actual measurements?
		1R	--			In-house gauge for component power usage (tie to electricity deregulation) --decision tool.
		--	--			There is a need for whole building monitoring.
		--	--			Active control of infiltration.

Controls

4R		**19R**	**8B**			Sensors and adaptive controls are needed for HVAC sensing/control with better monitoring protocols/algorithms for faulty and impending fault conditions of power, chemistry (e.g., excessive acid/moisture, composition change), charge loss, poor airflow, high power draw, etc. that effect reliability and energy efficiency.
				3R	--	Sensor technologies (humidity, frost, odor/spoilage).
				1R	--	Inter-operability of system protocols.
				1R	--	Power electronics (smart motors, variable-speed motors).
		--	--			Need to assess what signals are needed from utilities to permit systems to "power-down" during peak demand periods.
		--	--			Smart sensors.
		--	--			Standard, open, communication protocol.
				--	--	Information technology for transport refrigeration.
				--	--	Composition sensor for zeotropes.

Research into Alternative and/or Not-in-Kind Technologies

10R	8B	**22R**	**14B**	**16R**	**14B**	Need a project to assess viability of the numerous NIK cycles based on thermodynamics, theoretical performance limits, with identification of technological barriers. This to be on all cycles including heat actuated (e.g., adsorption, absorption, desiccants) and electrically driven (e.g., peltier effect, etc.). Individual projects resulting from this study to be undertaken.
18R	**20B**	6R	--	7R	--	Humidity reduction with separation technology (i.e., independent control of humidity and temperature).
				11R	**16B**	Alternative refrigerants - high pressure refrigerants (e.g., CO_2).
				13R	10B	Secondary Systems (e.g., low temperature fluids, optimized performance).
10R	9B					Heat exchanger design for matching high glide refrigerants.
12R	8B					Better secondary refrigerants (i.e., ice slurry that is less corrosive and has a higher specific heat).
		6R	**5B**			Need investigations to determine how to obtain system

						miniaturization (e.g., use higher pressure fluids, optimize airflow/components/systems, higher speed compressors).
		3R	2B			Glide matching w/ zeotropic refrigerants.
		5R	--			Energy/thermal storage.
		4R	--			Is there a benefit to change systems from the typical air-side (say, to hydronic?)
2R	--					Air-cooling vs water-cooling for heat rejection.
2R	--					Electrohydrodynamic (EHD) heat transfer.
		1R	--			Photo voltonic cells efficiency.
		1R	--			48 F thermal storage material (better latent heat than ice).
		1R	--			Need better "energy recovery" when ventilating and supplying make-up air.
				1R	--	Alternative transport technologies.
				1R	--	Better thermal storage materials (will also minimize engine emissions & noise and will provide backup cooling to primary power).
--	--					Integration of fuel-cell technology.
--	--					Superconducting motors.
		--	--			EHD enhancement.
				--	--	District heating & cooling.

ENVIRONMENTAL

Com. Bldgs		Res & LC		Refr & Tr.		
6R	--	2R	--	**20R**	**16B**	Wider acceptance of TEWI. Analysis & verification of TEWI for various systems (direct expansion vs secondary loop systems). Need to actively promote the TEWI story (consumer commercials?)
18R	9B					Zero global warming system.
8R		**9R**	**7B**			Need info to better design zero-leak systems (e.g., "fool-proof" tube joining, zero leak seals).
--	--	14R	5B			Need info for charge minimization, leak detection, assembly for no-leak.
6R	--			12R	3B	Integrate alternative (renewable?) power sources (fuel cells, solar/photovoltaic for transport & stationary, geothermal for commercial refrigeration, wind powered generators, co-generation, backup & supplemental power) into buildings.
4R	--					On-site power generation.
		3R	--			Corrosion Resistance (especially for coastal).
		3R	--			Alternative refrigerants --- are R-410A and R-407C the answer?
2R	--	1R	--			Elimination of oil in systems (e.g., oil-less compressors, development of refrigerants with lubricating properties).
1R	--					New materials (technology breakthroughs).

--	--					Fiberglass alternative insulating materials.
		--	--	--	--	How can the industry improve its recovery (at disposal) of various materials of construction? What needs to be done to improve recovery and reuse of engineered plastics?

COMFORT & IAQ

Com. Bldgs		Res & LC		Refr & Tr.		
		17R	**14B**			Definition of comfort including Air Quality is a problem. Can this be assessed via academia? Should R&T establish an ARI S/C devoted to this issue?
		10R	**8B**			Need better understanding of occupant IAQ issues ---- odor, organisms, noise, ---- for health ventilation needs, filtration needs, condensate removal, controls, etc.
--	--	5R	3B	5R	--	Noise control via better sound absorbing materials or active noise cancellation. Sound is a transmission problem via air supply (ducting) and via equipment supports.
		2R	3B			Need to establish individualized controls vs level of occupancy and comfort of same.
		13R	1B			Do we establish a "research building/lab" to identify impact of various contaminant control methods?
		15R	--			Comfort definition - how can system designs improve?
		7R	--			Need a new control methodology (e.g., sense skin temperature, or temperature of the walls or other radiant surfaces, use IR technology?).
		--	--			What is a contaminant?
		--	--			Need an assessment comparing the differences between ducted and non-ducted equipment from the perspectives of IAQ and energy use.
		--	--			How design equipment to be flexible for widely changing requirements as tenant requirements change?

SAFETY

Com. Bldgs		Res & LC		Refr & Tr.		
9R	5B	**10**	**7B**	**20R**	**16B**	How can natural, flammable, toxic refrigerants safely be applied to AC&R equipment?
				5R	--	Accurate measurement of product temperatures and data storage of same.
		3R	--			What additional work is needed to use HCs in systems?
				3R	--	Temperature uniformity (control of airflow).
		2R	--			Need better hydronic system designs.

		2R	--			Need improvements to offset losses from secondary heat exchangers.
				1R	--	Minimize product shock due to defrost.
				--	--	Higher quality methods to control pests (better control of temperatures and atmospheres).
				--	--	Organic chemistry of food spoilage.

Other

Com. Bldgs		Res & LC		Refr & Tr.		
		2R	2B			Design for easier maintenance/no maintenance.
7R	--					Serviceability (simplicity & design for diagnostics).
5R	--					Monitoring & awareness of global research & technological advances.
		3R	--			Need improved methodologies to assess and improve system reliability.
		2R	--			Evaluate impact of de-reg. on industry.
		2R	--			System designs for developing country needs.
				1R	--	Adaptability to local power sources.
1R	--					Tolerance for poor power quality.
		1R	--			Need to establish an ARI guideline for "refrigerant grade" materials.
		--	--			Certification of high ambient operation ratings.
		--	--			Resistance to use of non-metallic materials (plastic etc.).

ISSUES NOT DIRECTLY ASSOCIATED W/ PRECOMPETITIVE RESEARCH

Com. Bldgs		Res & LC		Refr & Tr.		
Global Competitiveness						
14R	**11B**	9R	3B	13R	10B	Need to harmonize international standards and regulations (e.g., ISO, IEC, UL & TUV, ASME material specifications with CE, etc.). Is there a need for ARI to form an International Standards Committee to assist in this activity?
				4R	--	Develop/promote U.S. "green" strategy.
1R	--					Certification of standards, labs and test procedures.
--	--					Reduction of trade barriers.
--	--					Use of internet (training, diagnostics & technology transfer).
		--	--			Need to coordinate numerous national regulations, including ... component regulations vs. system regulations, ISO, DOE, EPACT, etc.
				--	--	Monitor worldwide power generation capacity vs. load, distribution and quality.
"Food Chain" Issues						
				7R	--	Monitor global food production & distribution trends.
				5R	--	Monitor developments in alternative food preservation technologies.
				--	--	Early packaging in the cold chain.
				--	--	Food merchandising techniques.
Cost						
8R	--					Real-time energy price impact on operational costs.
5R	--					ARI standards to support total system cost analysis.
2R	--					Cost-effective variable frequency drive.
				1R	--	Light weight systems.
				1R	--	Compact, low-cost heat exchangers.
		--	--			Utility rebates to encourage higher SEER/EER units.
				--	--	Low-cost/light-weight compressors.
				--	--	Low-cost/light-weight engines.
				--	--	Ease and speed of equipment installation.

Lack of Skilled Engineers, Servicemen & Users

		4R	1B			Technician training needs on refrigerant handling, system maintenance (communication protocol, system integration, servicing and diagnostics).
		9R	--			How do we "demo" good practices? Need to develop guidelines on proper system design/installation and maintenance and communicate same widely (e.g., download via internet).
				9R	--	Unmanned systems (e.g., self optimizing systems, zero maintenance systems).
5R	--					Technology gatekeeper (extranet for ARI).
		--	--			Benchmark good HVAC Design Practices (work w/ SMACNA?).
		--	--			Need to better transmit application info on systems tech. to users.
		--	--			How to increase skill level of technicians?
		--	--			How to actively promote NATE?
				--	--	Accessing maintenance information from the internet.
				--	--	Common on-board/off-board diagnostics to assist servicemen.
				--	--	Standardize reporting interface.
				--	--	Knowledged based systems.

EXHIBIT E:
21-CR Subcommittee Scopes

Alternative Equipment:
This Subcommittee advocates R&D aimed at developing and understanding the underlying concepts, benefits and challenges of promising HVAC/R system technologies other than traditional electrically driven mechanical vapor compression equipment with conventional refrigerants. Examples could include transcritical CO_2, thermoacoustic cooling, advanced absorption concepts, hybrid systems, etc. The Subcommittee's focus is on technologies that could be commercialized in 10 to 20 years, that are environmentally friendly, and provide benefits to society.

Equipment Energy Efficiency:
This Subcommittee focuses on research needed to improve the efficiency of existing HVAC&R equipment used in various applications (e.g., unitary, chillers, refrigeration, etc). Heat exchangers, motor systems, compressors, controls and sensors, air handlers, application of working fluids (cycle analysis, heat transfer, etc.), testing, diagnostics, efficiencies across the operating range, pumps and pump controls are examples of specific areas falling under the Subcommittee.

System Integration:
To provide substantial improvements in energy consumption and comfort levels, there is a need to treat buildings, with their individual subsystems, as complete optimized entities, not as the sum of a number of separately-designed and individually-optimized components. This Subcommittee identifies precompetitive research that will facilitate better integration of HVAC&R equipment with other related systems for the various applications. Examples of project interests are distribution systems (e.g., air duct systems and water circulation systems), zone control, advanced application and equipment controllers, identification of ways to recover and reuse waste energy within buildings and refrigeration processes, standardized external communications (i.e., for standardized diagnostics, utility control, mating with building systems, etc.), and influences and impacts of lighting, thermal envelope, etc. on HVAC&R equipment.

Indoor Environmental Quality:
The IEQ Subcommittee fosters investigations that support industry's ability to provide high quality indoor environments for comfort, health, and productivity. This encompasses air quality, sound quality (i.e., noise control), etc. The primary concern is in undertaking research that will position manufacturers to offer equipment that recognizes, measures, and controls defined indoor environmental concerns. Emphasis areas would include indoor air quality control strategies, identification of anti-microbial materials, improved concepts for particulate or gas-phase filtration, and enhanced control of temperature, moisture and humidity, ventilation, sound, and air velocity.

Working Fluids:
Refrigerants, absorption fluids, lubricants, and secondary heat transfer fluids are required for the successful operation of HVAC&R equipment. Contaminates (including cutting oils, detergents, lubricants, and anti-rust compounds used to manufacture component parts) can affect the reliability of HVAC&R equipment. New refrigerants, absorption fluids, lubricants, and secondary heat transfer fluids and new process fluids are likely to be needed in the future. This Subcommittee anticipates the need for precompetitive research to provide and apply new working fluids. In assessing new fluids and applications the Subcommittee

considers issues including system efficiency, equipment reliability, compatibility, safety, and environmental impacts.