

## U.S. HVAC&R RESEACH PROGRAMS

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**Abstract:** This paper presents an overview of public and public-private sector HVAC&R research programs in the United States; identifying key HVAC&R research program sponsors, goals, and research organizations.

**Key Words:** *HVAC&R research programs, ARI Alternative Refrigerants Evaluation Program (AREP), ARTI 21<sup>st</sup> Century (21CR) Program, ARTI Materials Compatibility and Lubricants Research (MCLR) Program, ARTI Research Program, ASHRAE Research Program, CEC Public Interest Energy Research (PIER) Program, CEC PIER-Building Energy Research Grant (BERG), DOE Building America Partnership, DOE High Performance Building, DOE Zero Energy Building, NCEMBT, NYSERDA, Technology Roadmaps, and USGBC.*

### 1 INTRODUCTION

In reviewing HVAC&R research programs in the U.S. it is important to understand the roles of and relationships between funding organizations and organizations that actually perform the research. The funding organizations generally define what areas of research are to be funded - while the research organizations generally perform the research for the funding organizations. There is of course some interplay between the two in defining research to be conducted. Many funding organizations have developed technology roadmaps outlining the path from research to product development and market transformation. In many cases these roadmaps are developed with input from the research, manufacturing and regulatory sectors.

Funding organizations are generally federal or state governmental agencies, technical societies, or trade organizations. The U.S. Department of Energy (DOE), the U.S. Environmental Protection Agency (EPA), the U.S. Department of Housing and Urban Development (HUD), and the U.S. Department of Defense (DoD) are examples of federal funding agencies. The California Energy Commission (CEC) and the New York State Energy Research and Development Authority (NYSERDA) are examples of state funding agencies. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and AHRI's research arm the Air-Conditioning and Refrigeration Technology Institute (ARTI) are examples of technical society and trade association funding organizations.

Each funding organization may have its own focus or slant on the research to be conducted. The U.S. Department of Energy and state energy agencies, like CEC and NYSERDA, generally focus on energy. Their HVAC&R research programs are targeted toward development of more energy efficient systems, systems that reduce peak electric power loads, or systems that integrate onsite renewable energy generation. The EPA on the other hand might focus more on indoor air quality in buildings, and HUD might focus more on affordable housing. Technical societies, such as ASHRAE, tend to have a broader range of research interests. Trade associations tend to support research that will prepare their members for developing successful products for tomorrow's market place.

Research organizations generally include the national laboratories, universities, private-sector research laboratories and engineering consulting firms.

DOE has a number of national laboratories that have performed HVAC&R research.

- Brookhaven National Laboratory (BNL)
- Lawrence Berkeley National Laboratory (LBNL)
- Oak Ridge National Laboratory (ORNL)
- National Renewable Energy Laboratory (NREL)
- National Energy Technology Laboratory (NETL)
- Pacific Northwest Laboratory (PNL)

The U.S. Department of Commerce also has a “national” laboratory, the National Institute of Standards and Technology (NIST) with campuses at Gaithersburg, Maryland, and Boulder, Colorado. Much of NIST’s work on HVAC&R and building systems research is conducted by the Building and Fire Research Laboratory in Gaithersburg. Thermophysical and transport properties measurements of refrigerants are conducted at NIST’s Boulder campus.

The General Services Administration is responsible for most of the buildings occupied by the federal government and typically sponsors research to characterize the performance and/or indoor air quality of those buildings. The Department of Defense also has a number of laboratories. The Army Corps of Engineers is generally responsible for the planning and construction of buildings on government installations, while much of the research on air-conditioning and refrigeration systems for ground tactical vehicles and equipment is done within the U.S. Army Research, Development and Engineering Command (RDECOM). NASA, the U.S. Navy, and the U.S. Air Force also conduct research and develop specialized heating and cooling systems or thermal management systems for use in electronic equipment, aircraft, spacecraft and naval vessels.

Many universities in the U.S. have capabilities to conduct a broad range of HVAC&R research and are often utilized for industry and industry-government sponsored research.

In recent years there have been a number of driving factors for collaborative HVAC&R research. They can be grouped into three general categories - environmental concerns, electric power grid reliability concerns, and indoor environmental quality concerns. These drivers have spawned collaborative research in several specific areas as identified below.

Environment Concerns – Climate Change: Ozone Depleting Substances (ODS), Greenhouse Gases and Global Warming Potential (GWP)

- Development and use of more environmentally benign refrigerants
- Systems with smaller refrigerant charges
- Tighter systems and leak detection equipment
- Development of recovery and recycling equipment
- Assessment of alternative cooling technologies – thermoacoustic, thermoelectric, water vapor compression, magnetocaloric, etc.
- Energy efficiency improvements to HVAC&R components - compressors, heat exchangers and other components

Electric Power Grid Reliability - Peak Electric Load

- Higher efficiency of HVAC&R equipment at high temperature/peak load conditions
- Load shifting to alternative energy sources
- Load shifting through thermal storage
- Better integration of HVAC with buildings/homes
  - Load reduction through tighter insulated building envelopes
  - More efficient thermal distribution systems

- Reducing internal heating/cooling loads
- Integration of on-site power generation/renewal energy

#### Indoor Environmental Quality – Comfort, Productivity, and Health of Building Occupants

- Moisture and condensation control for control of indoor mold
- Mold detection technology
- Detection and inactivation, neutralization, dilution or removal of indoor air pollutants:
  - Bio-aerosols and allergens
  - Carbon dioxide
  - Carbon monoxide from combustion appliances
  - Volatile organic compounds (VOC)
  - Fine particulates
- Reduced indoor noise levels
- Thermal comfort
- Energy efficient means of providing increased ventilation rates

## 2 KEY HVAC&R RESEARCH PROGRAMS AND FUNDING ORGANIZATIONS

### 2.1 Federal Programs

**U.S. Department of Energy (DOE)** is the federal government's largest funder for public-private collaborative HVAC&R research. That effort is centered in the Office of Energy Efficiency and Renewable Energy's (EERE) Building Technologies (BT) Program. The BT program works with the building industry and HVAC&R manufacturers to sponsor research and development on energy efficient technologies and practices. The strategic goal of the BT program is to develop net-zero energy buildings (ZEB) (referred to as zero energy homes (ZEH) in the residential sector) to reduce national energy demand (DOE 2008). This goal is defined more specifically as:

*"To create technologies and design approaches that enable net-zero energy buildings at low incremental cost by 2025. A net-zero energy building is a residential or commercial building with greatly reduced needs for energy through efficiency gains (60% to 70% less than conventional practice), with the balance of energy needs supplied by renewable technologies. These efficiency gains will have application to buildings constructed before 2025 resulting in a substantial reduction in energy use throughout the sector."*

In support of this strategic goal HVAC&R research under this program may be conducted by several national laboratories, universities, commercial research organizations, or research consortia through open solicitations, grants and cooperative agreements. Current R&D activities supported by DOE include:

- Diagnostic and real-time monitoring tools
- Design tools for heat pumps and air conditioners
- Improvements in supermarket refrigeration
- Energy service (space conditioning, water heating, etc.) equipment for low or zero energy buildings
- Combined cooling, heating, and power (CHP) equipment for buildings
- Residential thermal distribution systems

The BT Program also supports programs, initiatives, and projects that optimize building energy performance and savings through integration of new technologies with innovative building practices.

Building America advocates a systems engineering approach to home building. The program has several research teams that have worked with over 577 industry partners. The Building Industry Research Alliance works with six national builders, each to produce a prototype single-family homes that use 40 to 70% less energy than comparable homes. It also seeks to integrate onsite power generation systems leading to ZEH designs that produce as much energy as they use. Cost-effective, highly efficient space conditioning and water heating systems are critical in achieving this goal. DOE/BT's HVAC, Water Heating, and Residential Integration subprograms are working to ensure that research and development is closely aligned with the evolving needs; that those new technologies can be rapidly field-tested; and then transitioned to the market in cooperation with Building America industry partners.

High Performance Buildings works with architects, engineers, builders, contractors, owners, and occupants to optimize commercial building performance, occupant comfort, and savings through a whole building approach to design and construction. To assist these efforts, DOE sponsors development of building energy software and simulation tools, advance controls, indoor air quality, and commissioning tools for residential and commercial buildings.

### Research Roadmaps

DOE, working with industry and other stakeholders, facilitates the development of technology roadmaps to guide research in selected technology areas. These roadmaps are incorporated into DOE's Multi Year Plan, a planning document which DOE updates each year (DOE 2008). The technology roadmaps help to align government resources with high priority needs. They provide a framework for partnerships and act as a starting point for ongoing dialogue for guiding continued cooperation and research.

- *Vision 2020: The Lighting Technology Roadmap*
- *The Promise of Solid-State Lighting for General Illumination: Light Emitting Diodes and Organic Light Emitting Diodes*
- *High Performance Commercial Buildings - A Technology Roadmap*
- *Building Envelope Technology Roadmap*
- *Window Industry Technology Program*
- *Basic Research Driving the Future of America's Heating, Ventilation, Air Conditioning and Refrigeration Technologies*
- *Residential Buildings Technology Roadmap*

Open solicitations under the Building Technologies Program are normally issued by the National Energy Technology Laboratory (NETL). Those solicitations seek proposals for innovative technologies that have the potential for significant energy savings in residential and commercial buildings, by supporting projects that advance energy efficient equipment, envelope, and whole building technologies. The objective of this program is to accelerate high-payoff technologies that, because of their risk, are unlikely to be developed in a timely manner without a partnership between industry and the federal government.

## **2.2 State Programs**

**California Energy Commission (CEC)** sponsors one of the largest state run research programs, the Public Interest Energy Research (PIER) program. The PIER program initiated in 1998 supports energy research, development and demonstration (RD&D) projects that will help improve the quality of life in California by bringing environmentally safe, affordable and reliable energy services and products to the marketplace. The PIER program annually awards up to \$62 million for research through partnerships with RD&D organizations including individuals, businesses, utilities, and public or private research institutions. PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grant Program
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally-Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies

HVAC&R research under the PIER program normally falls within the area of Building End-use Energy Efficiency. In 2006 the PIER Building total portfolio was valued at \$78.1 million with 113 active projects. About 42% of the buildings portfolio was on HVAC. In October 2006 CEC announced establishment of the PIER Building Energy Efficiency Grant (BERG) program. This program had a budget of \$1 million and was set up to award multiple grants with a maximum of up to \$200,000 each or \$50,000 for co-funding of ASHRAE projects.

**New York State Energy Research and Development Authority (NYSERDA)** is a public benefit corporation created by the New York State Legislature. NYSERDA has conducted a multifaceted energy and environmental research and development program since its inception in 1975. NYSERDA's research and development program supports the development and commercialization of innovative energy and environmental products, technologies, and processes that improve the quality of life for New York's citizens and help New York businesses to compete and grow in the global economy.

NYSERDA research and development activities in five primary program areas:

- Energy Resources
- Transportation and Power Systems
- Environment
- Industry
- Buildings

NYSERDA issues annual or periodic project solicitations for innovative building technologies in the following areas:

- Heating and Cooling - to develop and commercialize innovative, energy efficient environmentally-friendly heating and cooling technologies for the home and business. New products include a high-efficiency, pulse combustion, gas-fired, commercial boiler; a 95% efficient, aluminum, gas-fired residential boiler; fluorescent leak detection technologies for air conditioning systems; and an electric heat pump water heater.
- Lighting - to develop energy-efficient lighting products, such as fixtures to accommodate high efficiency light sources, fiber-based plasma display panels, photovoltaic-powered exterior fixtures, and ultraviolet germicidal systems. NYSERDA also partners with the Rensselaer Polytechnic Institute's Lighting Research Center (LRC), assisting manufacturers with programs such as the National Lighting Product Information Program (NLPIP), Design and Evaluation of Lighting Technologies and Applications (DELTA), the Hybrid Skylight Program, and numerous training seminars.
- Building Envelope – to develop new building construction products, such as advanced windows, panelized wall systems, and industrialized construction methods. Other projects include integrated systems to optimize building energy and environmental impacts, such as building integrated solar technologies and advanced indoor air quality systems.
- Controls and Meters – to develop and demonstrate innovative control, sensor, and metering technologies for residential and commercial building systems. Technologies seek to improve power quality, reliability, and efficiency, as well as the indoor environment, such as variable speed air conditioners, wireless submeters, remote

HVAC diagnostic equipment, advanced indoor environmental quality monitors, web-enabled systems for price sensitive load management, and power quality and conditioning equipment.

- Distributed Generation/Combined Heat and Power – to promote innovative distributed generation applications - the on-site generation of electricity. In particular, the program promotes combined heating and power (CHP) -- electric generation from heat recaptured from space or domestic water heating.

**Association of State Energy Research and Technology Transfer Institutions** Several other states also have their own research programs or work jointly on federally funded cooperative programs, or through research consortia such as the Association of State Energy Research and Technology Transfer Institutions (ASERTTI). ASERTTI was established in 1990. Its mission is to increase the effectiveness of energy research efforts in contribution to economic growth, environmental quality, and energy security. ASERTTI does this by collaborating on research projects with state, federal, and private partners and by sharing technical and operational information among members and associates. ASERTTI activities include applied research, technology development, demonstration and deployment, with a strong interest in end use efficiency and conservation and supply side interests, including fossil fuels and renewable resources.

## 2.3 Industry Association and Technical Society Programs

### **The American Society of Heating, Refrigerating, and Air Conditioning Engineers**

(ASHRAE) is a technical society whose mission is to advance the arts and sciences of heating, ventilation, air conditioning, refrigeration, and related human factors to serve the evolving needs of the public and ASHRAE members. ASHRAE membership is comprised of individuals. ASHRAE has been a long standing sponsor of HVAC&R research. Since the 1960's, ASHRAE has funded more than 1400 research projects. ASHRAE's annual research budget is between \$2 and \$3 million per year. Funding for ASHRAE research is also supplemented through co-funding from other organizations on a project-by-project basis. ASHRAE has already funded twenty-two new projects this year. In January 2008, 11 projects totaling \$1.6 million were awarded. In March 2008, four additional projects totaling \$471,885 were recommended for award and seven more projects with total budget of just under \$1 million were opened for bids.

The ASHRAE research program supports the needs of over 100 ASHRAE technical committees. ASHRAE's Research Strategic Plan provides a framework for the society's research priorities for 2005 to 2010. The plan is centered on the concept of sustainability and identifies goals and a number of possible research topics for five broad opportunity themes.

#### Energy and Resources Theme Goals:

- Provide guidance to reach 30, 50 & 70% reductions in building energy use
- Produce by 2015 residential and light commercial buildings that use 70% less energy
- Develop economically viable renewable energy applications that reduce energy use by 25% by 2015
- Develop systems & components that reduce energy use in supermarkets by 30% by 2015
- Optimize and make consistent ASHRAE Standards. 55, 62.1 and 90.1 to achieve energy efficient buildings with high Indoor Environmental Quality (IEQ)
- Develop integrated, best practice design methods that minimize energy consumption and life cycle costs while maximizing system life span and IEQ.
- Develop evaluation methods for energy, cost, emission, IEQ, health and productivity
- Establish benchmark data on energy use in industrial refrigeration

Indoor Environmental Quality Theme Goals:

- Make improvements in occupant health and comfort that can yield a 20% increase in productivity by 2015
- Provide an optimal indoor environment for buildings, vehicles, and facilities with respect to comfort, productivity, health, and safety
- Provide better understanding of how contagious viruses such as SARS, influenza, tuberculosis, hemorrhagic fevers, and other respiratory diseases are transmitted in an indoor environment and develop remediation techniques and equipment to minimize exposure
- Develop self-diagnostic inspection methods for HVAC systems that minimize negative impacts on comfort, health, and productivity

Tools and Applications Theme Goals:

- Develop more effective tools that will provide a 25% improvement in the productivity of the design process by 2015
- Develop dual path standards that are prescriptive and performance based
- Develop methods to allow a designer to accurately and confidently model a building in virtual reality in no more than one week by 2010
- Develop a measurement-based rating system to establish the environmental performance of a building and its system.
- Develop self-calibrating and inexpensive sensor systems to measure control variables, comfort, health, and productivity
- Establish design tools to improve the installed energy efficiency of heating, ventilating, cooling, and refrigeration systems and their components
- Provide design guidance for buildings and systems to address the past and expected change in climatic conditions

The Equipment, Components and Materials Theme Goals:

- Establish techniques to improve energy efficiency and reliability of HVACR system components
- Continue research into new alternative and natural refrigerants
- Improve performance and reliability and minimize the environmental impacts of working fluids and materials
- Advance ASHRAE's role in the safety and security of food distribution
- Develop reliable, durable and self-correcting sensor technology for monitoring IEQ, pollutants, energy conservation, and fault detection and diagnostics
- Move one or more non-traditional technologies with comparable performance and cost to traditional vapor compression systems to market readiness by 2010
- Develop techniques that provide a 50% reduction in the installed HVAC&R energy by 2015

Education and Outreach Theme Goals:

- Make results of ASHRAE research available to the technical community
- Ensure that ASHRAE research has an international impact

ASHRAE has reconstituted its Research Advisory Panel to review and update the research plan for 2010 and beyond.

In January 2008, the ASHRAE published a special report *ASHRAE Vision 2020: Producing Net Zero Energy Buildings*. This document outlines the society's vision and strategy to assist the building community in introducing viable Near Zero Energy Buildings (NZEB) by the year 2030. ASHRAE plans to achieve this by providing its members with the tools needed by 2020. The strategy involves coordination of research activities, educational products and publications among ASHRAE committees and a number of outside organizations. ASHRAE

intends to swiftly address the highest priority research items working through its Research Advisory Panel and the US Green Building Council's Research Committee. ASHRAE will add emphasis to user-friendly energy modeling tools and interfaces included in ASHRAE's Research Strategic Plan.

**U.S. Green Buildings Council (USGBC)** issued in November 2007 *A National Green Building Research Agenda*. It calls for greater investment in research for green building practices and technology. The document cites that in the U.S. buildings account for 38% of carbon emissions; 71% of electricity consumption; 39% of energy use; 12% of water consumption and 40% of non-industrial waste. Yet research on green building practices and technologies amounted to only 0.2% of all federally funded research from 2002 through 2004. The U.S. federal agencies providing the most research funding for green buildings are the Department of Energy (DOE) and the Environmental Protection Agency (EPA), but that funding constitutes less than 4% of their respective research budgets.

The Agenda's research program areas are organized in four systems-based categories: Delivery Process and Performance Evaluation; Integrated Building Designs; Buildings' Interaction with Local Environments and Buildings' Interactions with Occupants. One of the subcategories under Integrated Building Design is "Passive, Active and Hybrid HVAC and Controls." Research priorities in this subcategory include:

- Development, enhancement and optimization of climate-based HVAC strategies (e.g. radiant systems, evaporative cooling, natural and mixed-mode ventilation); and
- Comparison, evaluation and optimization of centralized and personal control options for advanced HVAC systems.

Other research topics include:

- Test and develop innovative thermal energy and air distribution systems that enable distributed environmental control
- Develop techniques and tools to evaluate, characterize and benchmark overall performance of advanced HVAC strategies
- Produce improved design tools for passive and hybrid components and systems
- Demonstrate performance of low energy cooling and dehumidification
- Improve understanding of delivered efficiency rather than component efficiency for HVAC equipment
- Advanced technology transfer – finding effective ways of parlaying research results into industry practice

**Air-Conditioning, Heating, and Refrigeration Institute (AHRI)** was formed on 1 January 2008, with the merger of the Air-Conditioning and Refrigeration Institute (ARI) and the Gas Appliance Manufacturers Association (GAMA). AHRI is a North American association of HVAC&R equipment manufacturers with over 350 member companies. Primarily formed for the establishment of industry performance standards, certification programs, and industry advocacy, AHRI also supports and directs industry cooperative research. This research may be wholly funded by its own members or jointly funded in public-private programs managed by the Air-Conditioning and Refrigeration Technology Institute (ARTI). Since 1991 the North American HVAC&R industry and ARTI have directed a number of major research efforts.

The ARTI *Material Compatibility and Lubricants Research (MCLR) Program* was a 10-year, \$10.8 million cooperative research program between industry and the U.S. Department of Energy that began in 1991. Its objective was to provide basic research needed to assist the HVAC&R industry in phasing out the use of ozone depleting CFC refrigerants. As the name indicates, the primarily focus of this program was to examine and solve material compatibility and lubricant issues associated with the introduction of HCFC and HFC refrigerants. An industry Advisory Committee provided the direction and oversight of research that was subcontracted to universities, national laboratories and commercial research organizations.



Forty-seven projects were completed under the MCLR program leading the way for the successful phase out of CFC refrigerants in the U.S.

The ARI *Alternative Refrigerant Evaluation Program (AREP)* was an industry cooperative research program from 1993 through 1997. It included HVAC&R equipment manufacturers from North America, Asia, and Europe. Under this program manufacturers conducted performance screening tests on a number of proposed refrigerants and refrigerant blends designed to replace R-22 and R-502 in a broad range of applications. This program was unique in that manufacturers divided up the refrigerants to be tested among themselves for in-house performance testing, and then shared results with each other. This program identified several refrigerants and refrigerant blends that have since gained widespread acceptance by manufacturers to include R-134a, R-407C, R-404A, and R-410A.

The ARTI *HVAC&R Research for the 21st Century (21CR) Program* was an industry-government cooperative research program with funding provided by industry associations, state energy agencies and the U.S. Department of Energy. This \$8.7 million, eight-year program (1999-2007) addressed a broad range research in five areas: energy efficient equipment, working fluids, system integration, indoor environmental quality and emerging technologies. An industry-government Steering Committee and over 80 technical experts provided the direction and oversight of research that was subcontracted to a number of universities, national laboratories and commercial research organizations. Forty-five projects were launched under this program. The final report for the last project funded under this program was approved for release in September 2007.

The *ARTI Research Program*, launched in 1995, is industry's latest program for cooperative research. It is funded from contributions provided by the Air-Conditioning, Heating, and Refrigeration Institute (AHRI), the Copper Development Association (CDA), the Heating, Refrigeration and Air Conditioning Institute of Canada (HRAI) and the New York State Energy Research and Development Authority (NYSERDA). The ARTI Research Roadmap outlines ambitious goals for 2020 in four market sectors:

- Residential Buildings: 50% reduction in HVAC&R annual energy consumption and peak energy demand
- Commercial Buildings: 25% reduction in energy consumption and peak energy demand
- Refrigeration: 90% reduction of refrigerant leakage in supermarket refrigeration systems and 25% reduction in energy consumption
- Emerging Technologies: review and monitor research in the HVAC&R arena and elsewhere for technological breakthroughs that could contribute to achieving the above goals.

The roadmap serves as a guide, not only for ARTI sponsored projects, but also for others as well. Under the *ARTI Research Program*, a concerted effort is being made to co-sponsor research projects with other organizations. To date, twenty-two projects have been funded under this program, eleven of which are ARTI co-funded ASHRAE projects.

The *ARTI Research Program* is also supporting IEA Heat Pump Program Annex 33 with four projects applicable to the efficient design of compact heat exchangers:

- Novel Materials for Heat Exchangers
- Optimizing Refrigerant Distribution in Evaporators
- Void Fraction Measurement and Modeling for Condensing Refrigerant Flows in Small Diameter Tubes
- Near Critical and Supercritical Heat Transfer of R-410A in Small Diameter Tubes

ARTI 21CR and ARTI Research Program project final reports and summaries can be downloaded free from the ARTI Research website [www.arti-research.org](http://www.arti-research.org). Reports from the ARTI MCLR program are available upon request.

**National Center for Energy Management and Building Technologies** (NCEMBT) is a not-for-profit research organization that focuses on building energy performance, indoor environmental quality, and building security. The NCEMBT was organized in 1999. Its founding partners are: International Training Institute (ITI); National Energy Management Institute (NEMI); Sheet Metal Workers' International Association (SMWIA); Sheet Metal and Air Conditioning Contractors National Association (SMACNA); University of Nevada at Las Vegas. Its research partners include: Advanced Energy; ASHRAE; Building Diagnostics Research Institute; California Energy Commission; Construction Specifications Institute; The Chelsea Group; Florida Solar Energy Center; Iowa Energy Center; Linric Company; Pennsylvania State University; Syracuse University; University of Illinois; U.S. Department of Energy; and Washington State University.

The mission of the NCEMBT is to:

- Transform the built environment by delivering applied research and education that result in sustainable building systems which are efficient, productive, secure, and healthy.
- Coordinate the application of research with partners and sponsors to get the research to market.

Goals of the program are by 2012

- Achieve 70% building energy efficiency
- Reduce envelope and load energy required by 20%
- Reduce design and construction energy waste by 20%
- Overall accuracy of 80% in procedures to diagnosis and evaluated the performance of buildings

Areas of research are:

- Building Characterization
- Building Systems
- Building Services
- Building Security and Resilience

As reported in its *2006-2007 Annual Review*, NCEMBT has 34 tasks or projects completed or ongoing. Those projects tend to focus on energy impacts of ventilation, air distribution systems, humidity control, and indoor environmental quality along with development of overall building energy performance standards and metrics. The *2006-2007 Annual Review* and other reports can be downloaded from the NCEMBT website <http://www.ncembt.org/downloads.html>.

### 3 DISCUSSION AND CONCLUSIONS

Even though federal funding for HVAC&R research programs has been declining since the events of 9/11/2001, the U.S. still has vibrant and active programs for collaborative public-industry HVAC&R research. The federal government, state governments, industry associations, professional societies, and academia all play a vital role in furthering the development of more efficient and environmentally friendly heat pumps and HVAC&R equipment.

Much of the work in the early 1990's focused on addressing a high priority environmental issue of the day - stratospheric ozone depletion. Several of the earlier research programs described in this paper focused on developing new non-ozone depleting HFC refrigerants and developing equipment and lubricants that were compatible with the newly developed refrigerants. Today we face new environmental issues; climate change from global warming resulting from increase greenhouse gas concentrations in the atmosphere and a growing worldwide demand for more energy as more regions of the world become industrialized. Research not only continues on developing more environmentally friendly refrigerants with low global warming potentials, but also on safe and more efficient systems designs that use less refrigerant or natural refrigerants that are more hazardous. General improvement in energy efficiency of HVAC&R equipment and its efficient integration into more energy efficient buildings and homes also continues to be a major area of research.

The development of industry technology roadmaps has helped to articulate and focus those research programs. The expanding use of internet-based websites have aided in rapidly disseminating research information and made coordination efforts among the various research sponsors much easier.

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