U.S. DOE's Air Conditioning R&D Projects

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Introduction

Program Goals:

BTO's ultimate goal is to reduce the average energy use per square foot of all U.S. buildings by 50% from 2010 levels. Emerging Technologies Program's goal is to enable the development of cost-effective technologies capable of reducing a building's energy use per square foot by 30% by 2020 and cutting a building's use by 45% by 2030, relative to 2010 high-efficiency technologies.

HVAC/WH/Appliances goals require by 2020 that the potential energy use intensity (EUI) for:

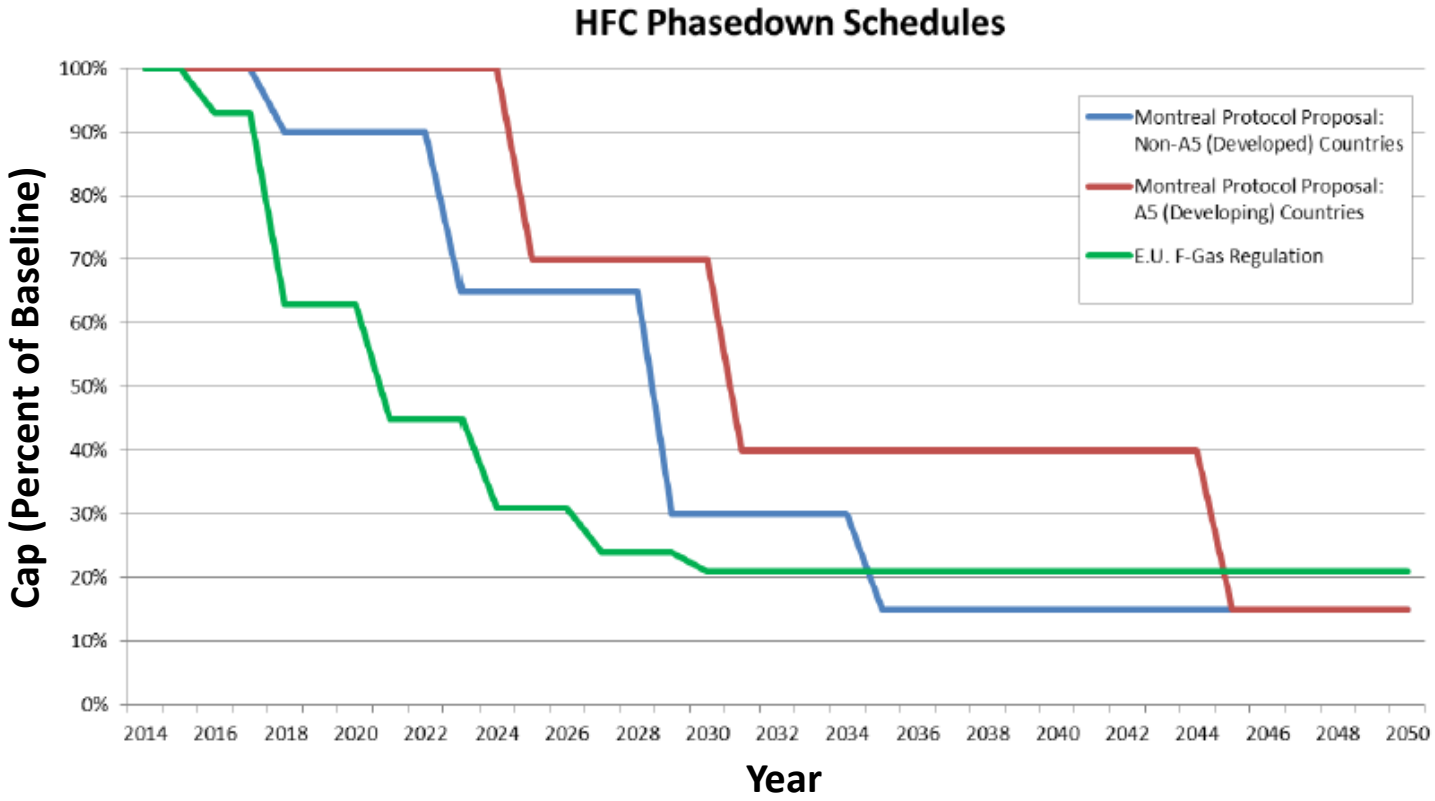
- HVAC would be 60% lower
- WH would be 25% lower
- Appliances would be 15% lower
- All relative to 2010 energy-efficient baseline

Two-pronged approach to accelerate the development of new technologies:

1) Accelerate the development of **near term** technologies that have the potential to save significant amount of energy (including cost reduction activities, bending the cost curve)
2) Accelerate the development of the **next generation** of technologies that have the potential of "leapfrogging" existing technologies by pursuing entirely new approaches (including crosscutting efforts)

The goal is to develop technologies that save energy and reduce our environment burden while *introducing them in the simplest application first*, *highest probability of success*.

Low-GWP Cooling R&D Plays Major Role in International Agreements



Source: Goetzler et al., 2014, "Research & Development Roadmap for Next-Generation Low Global Warming Potential Refrigerants, http://energy.gov/eere/buildings/downloads/research-development-roadmap-next-generation-low-global-warming-potential

- In response to questions that some countries have raised about whether such refrigerants are viable in high-ambient conditions
- Tested the performance of AC units that use low-GWP refrigerants in high-ambient temperatures at Oak Ridge National Lab
- ORNL designed a test matrix of 84 tests
- http://info.ornl.gov/sites/publications/files/Pub59157.pdf

Air Conditioning

World set to use more energy for cooling than heating, *theguardian.com Oct 26, 2015*

- Demand for air conditioning and refrigeration growing so fast that it threatens to smash pledges and targets for global warming.
- Worldwide power consumption for air conditioning alone is forecast to surge 33-fold by 2100 as developing world incomes rise and urbanization advances.
- Already, the US uses as much electricity to keep buildings cool as the whole of Africa uses on everything; China and India are fast catching up.
- By mid-century people will use more energy for cooling than heating.

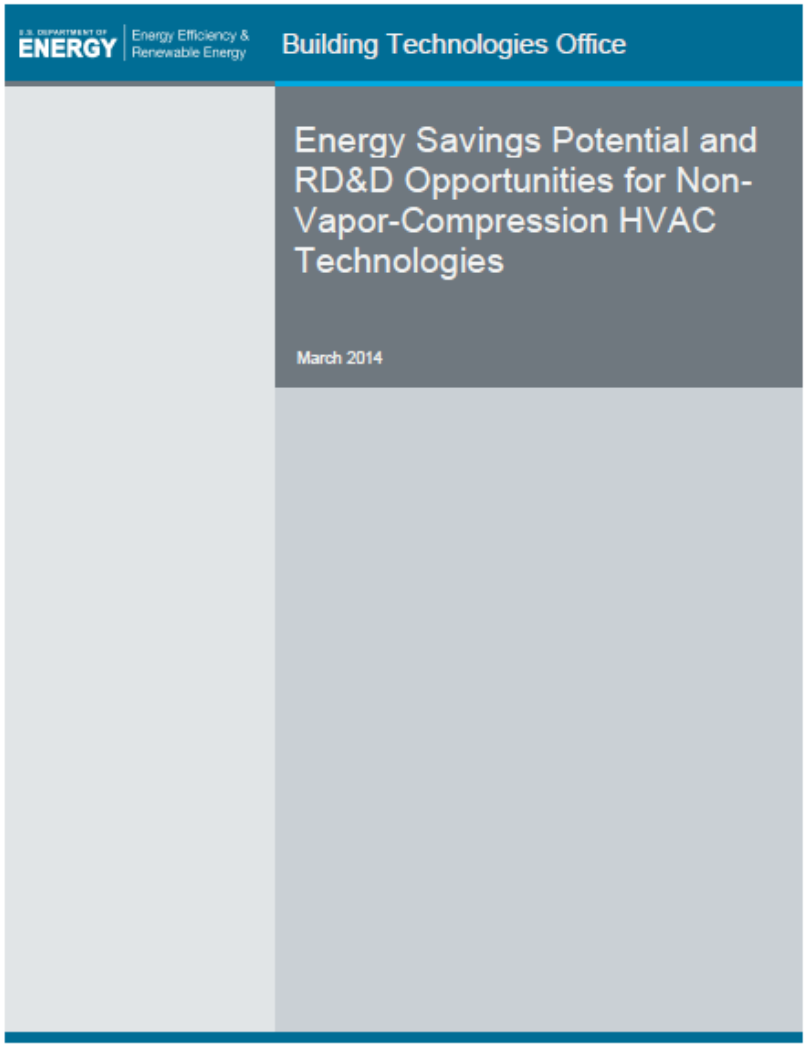
"Nearly all of the world's booming cities are in the tropics and will be home to an estimated one billion new consumers by 2025. As temperatures rise, they — and we — will use more air-conditioning.", *NYTimes.com*

Reports

Non-vapor-compression technology Report:

While vapor-compression technologies have served heating, ventilation, and air-conditioning (HVAC) needs very effectively, and have been the dominant HVAC technology for close to 100 years, the conventional refrigerants used in vapor-compression equipment contribute to global climate change when released to the atmosphere. This Building Technologies Office report:

- Identifies alternatives to vapor-compression technology in residential and commercial HVAC applications
- Characterizes these technologies based on their technical energy savings potential, development status, non-energy benefits, and other factors affecting end-user acceptance and their ability to compete with conventional vapor-compression systems
- http://energy.gov/eere/buildings/downloads/non-vapor-compression-hvac-technologies-report



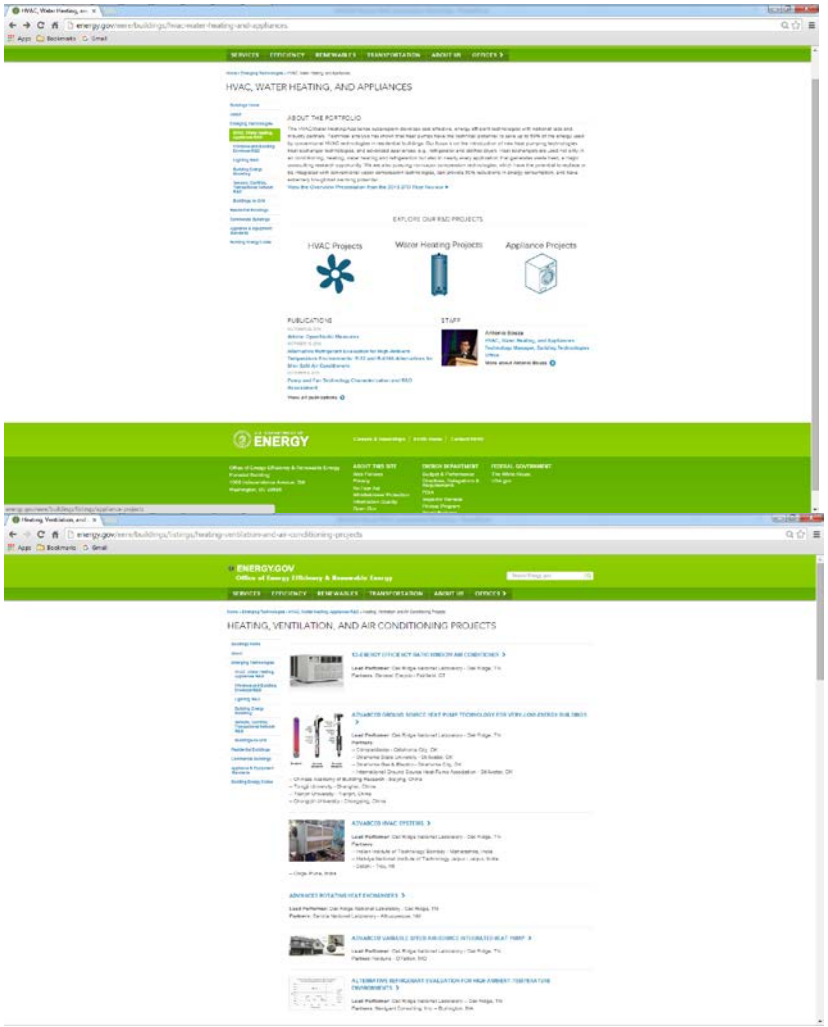
U.S. DOE's Air Conditioning R&D Projects

Projects:

- http://energy.gov/eere/buildings/hvac-water-heating-and-appliances
- http://energy.gov/eere/buildings/listings/heating-ventilation-and-air-conditioning-projects

Presentation:

- Just 9 projects, recent
- 2015
  - Centrifugal compressor (2)
  - Membrane HVAC
  - Thermoelastic
  - Magnetocaloric air conditioner (A/C)
  - Electrocaloric
  - Electrochemical compression (ECC) A/C
- 2014:
  - Rotary Vapor Compression Cycle Technology
  - Compact open absorption cycle



New Projects 2015: Advanced Vapor Compression

Mechanical Solutions, Inc. (MSI) (Whippany, New Jersey) and **Lennox Industries, Inc. (Lennox) (Richardson, Texas)** will receive $1 million to develop a low-Global Warming Potential (GWP) HVAC system featuring ultra-small centrifugal compression to meet DOE's requirement for more efficient HVAC systems. The developed system will be in the 2- to 20-ton range.

Design and develop an ultra-small, high-speed centrifugal compressor with improved efficiency over state-of-the-art scroll compressors:

- Achieve system-level integration of a low-GWP refrigerant and an ultra-small compressor, including heat exchanger, control methodology, "drop in" replace-ability, and more flexibility in product packaging
- Produce the compressor for a cost that is equal to or less than current heavier, bigger and less efficient solutions
- Ultra-small compressor will feature increased efficiency and oil-free operation
- All in a form factor less than 1/10th the size of a comparable scroll compressor
- Heat exchanger system will also be optimized for the oil-less, very low-GWP refrigerant

This project will initially focus on improving residential HVAC, which typically use 4-5 ton systems, and could eventually be scaled up to commercial systems as large as 20 tons.

http://energy.gov/eere/buildings/downloads/low-global-warming-potential-hvac-system-ultra-small-centrifugal

New Projects 2015: Advanced Vapor Compression

United Technologies Research Center (UTRC) (East Hartford, Connecticut) will receive $975,000 to demonstrate a high efficiency centrifugal compressor design.

- Enable high efficiency small commercial rooftop systems in the 1.5- to 10-ton range
- Compared to units operating in the 50-ton range
- Could provide 30% annual energy savings with less than two years payback by 2020
- If fully commercialized, could save 2.5 quads of energy by 2030 (USA only)

http://energy.gov/eere/buildings/downloads/high-efficiency-low-global-warming-potential-gwp-compressor

New Projects 2015: Non-Vapor Compression Technology

Dais Analytic (Odessa, Florida) will receive $1.2 million to advance membrane HVAC technology.

- Will use nanostructured polymer materials (membrane) to manipulate water molecules
- NanoAir HVAC technology transfers water molecules through a patented nanostructured polymer membrane to give the user independent control of humidity and temperature without using any conventional fluorocarbon refrigerants
- Membrane allows very rapid and selective permeation of water molecules through a solid plastic exposed to small vapor pressure differences, enabling isothermal dehumidification of air streams and evaporative cooling below local dew point temperatures
- Project team will construct a fully functional packaged rooftop unit (RTU) that will be thoroughly tested and evaluated at Oak Ridge National Laboratory (ORNL)
- Unit will demonstrate Technology Readiness Level 6 (TRL-6) by operating at scale in a controlled environment and provide a clear path to deploying TRL-7 pilot installations.
- Goal is to demonstrate improved comfort and control with a system that eliminates climate-sensitive refrigerants and demonstrates a 30 – 50% reduction in electrical consumption from today's RTUs
- Technology can be applied in many different configurations across the HVAC cooling market, which accounted for 5.68 Quads of primary energy in 2011 (14% of building energy consumption), with further uses in both heating and refrigeration.

http://energy.gov/eere/buildings/downloads/membrane-based-air-conditioning

New Projects 2015: Non-Vapor Compression Technology

Maryland Energy and Sensor Technologies, LLC (MEST) (College Park, Maryland) will receive roughly $600,000 to develop a compact thermoelastic cooling (TEC) system.

- Thermoelastic cooling (TEC) is recognized as one of the most promising non-vapor-compression HVAC technologies because of its high efficiency (COP~11 for TEC materials), large temperature lift (ΔT~21°C), and elimination of global warming refrigerants
  - TECs work by stretching and then relaxing metal rods, creating heat, but cooling rapidly when released
  - Alternation between the two states performs the same task as a heat pump compressor.
- Currently, the biggest hurdle preventing TEC from commercialization is difficulties in achieving an efficient way to apply large compression load (~ 900 MPa) with a small footprint with full recovery of the unloading energy
- Project will develop a novel loading mechanism that reduces the system size by a factor of 10
- Project aims to push the technology readiness level (TRL) of the TEC technology from 3 to 5 and to demonstrate that TEC is a commercially viable technology
- Assuming the TEC technology is commercially accepted by the market with 50% market penetration and 40% energy saving by 2025, the overall savings will be 1.48 quads of primary electricity and 74 million metric tons of CO2 emissions.

http://energy.gov/eere/buildings/downloads/compact-thermoelastic-cooling-system

New Projects 2015: Non-Vapor Compression Technology

Oak Ridge National Laboratory (Oak Ridge, Tennessee) will receive about $1.4 million to develop a novel magnetocaloric air conditioner. Vaccumschmelze GmbH & Co. KG., Hanau, Germany is a key partner in the project.

- Magnetocaloric air conditioning is an emerging technology with the potential for efficiency improvements of up to 25% over conventional vapor compression (VC) systems
- ORNL proposes to develop the first fully solid state magnetocaloric demonstration prototype air conditioner (AC) using a magnetocaloric refrigeration effect rather than a conventional VC cycle, thus eliminating the use of conventional high-global warming potential (GWP) refrigerants
- Project aims to develop a fully solid-state magnetocaloric AC that will result in significantly improved system efficiency and environmental friendliness (i.e., no use of GWP refrigerants)
  - Eliminate the need for many expensive system components such as rotating valves and hydraulic pumps
  - Such a system will significantly reduce the amount of required MCM mass and hence will achieve a higher magnetic flux than conventional AMR systems
- Proposed AC will be a small-scale demonstration prototype (500W nominal capacity) similar to a window air conditioning unit for residential applications using the MCMs
- The proposed technology can revolutionize the residential and commercial heating, ventilation, air-conditioning (HVAC) and refrigeration industry by creating unprecedented opportunities for non–VC systems.

http://energy.gov/eere/buildings/downloads/novel-solid-state-magnetocaloric-air-conditioner

New Projects 2015: Non-Vapor Compression Technology

United Technologies Research Center (UTRC) will also receive roughly $1 million to demonstrate an electrocaloric heat pump.

- Demonstrate a solid state (refrigerant-free), high efficiency, compact, zero direct global warming heat pump
- Has the potential to replace refrigerant-based vapor compression systems
- UTRC's extensive system analysis shows that the heat pump has potential to provide primary seasonal COP > 2.5 at a cost premium of <$67/(kBtu/hr)
- Proposed effort seeks to deliver a TRL 3 demonstration of the device
- DOE BTO funding will drastically improve the technology readiness level of this novel technology enabling commercial evaluation by HVAC manufacturers potentially disrupting the HVAC industry (including buildings and automotive) as a whole
- UTRC proposes to demonstrate an electrocaloric heat pump
  - Will be ~50% smaller than current models
  - Run more quietly and likely cost less to maintain because of its simple mechanical design
- If fully commercialized, the heat pump could result in annual energy savings of more than 1.5 quads and reduce greenhouse gas emissions by 60 million metric tons

http://energy.gov/eere/buildings/downloads/high-efficiency-solid-state-heat-pump-module

New Projects 2015: Non-Vapor Compression Technology

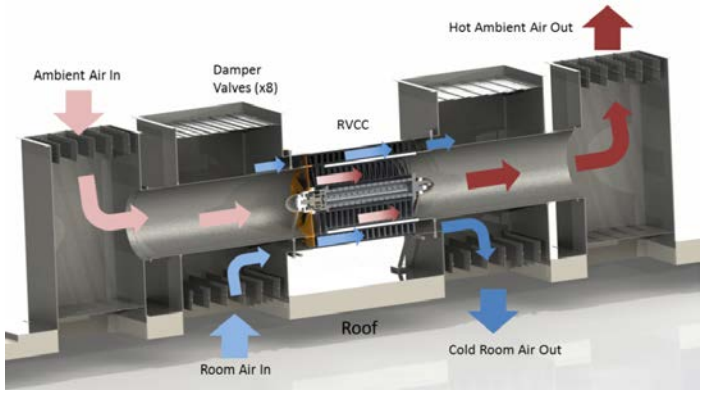
Xergy, Inc. (Seaford, Delaware) will receive $1.4 million to develop electrochemical compression (ECC) technology.

- Goal is to develop an electrochemical compressor (ECC) to replace mechanical compressors for use in building heating, ventilation and air-conditioning (HVAC) systems
- Xergy's ECC technology holds the promise of being able to compress gases isentropically with maximum exergetic efficiency – better than any alternative method of gas compression
- Overall objective of the proposed work is to develop and build a scalable 5,000 BTU/hr.
  - ECC-based air conditioning system operating with a rated Coefficient of Performance (COP) of 4.5 in cooling applications with a price premium of $70 installed per kBTU/hr
- Proposed ECC system will employ an environmentally benign refrigerant, water, as the working fluid
  - Water is environmentally benign and is an excellent refrigeration working fluid due to its high enthalpy of vaporization, but it is difficult to transport and compress with typical mechanical compressors
  - Electrochemical compression technology enables the use of water as a refrigerant for heat pump cycles by adapting technology originally created for hydrogen fuel cells
- ECC will be combined with an energy recovery module for improved management of latent and sensible heat loads to develop a novel AC system with unprecedented efficiency

http://energy.gov/eere/buildings/downloads/low-cost-electrochemical-compressor-utilizing-green-refrigerants-hvac

Projects started in 2014

Rotary Vapor Compression Cycle Technology: Sandia National Lab with Creative Thermal Solutions



- Purpose of this effort is to develop a vapor compression cycle architecture that can lead to an estimated 20% decrease in energy consumption in air conditioners (compared to SEER 14.6 units)
- Radically different device architecture is utilized exploits heat transfer enhancements in both air and refrigerant flows in a rotating reference frame
- To achieve this, two objectives must be met:
  - (1) proving that the proposed device architecture functions as designed, with the predicted heat transfer enhancements, and
  - (2) proving that the proposed device architecture can be fabricated cost effectively
- At the end of the project, a small scale (1 kW) prototype will be developed as a proof-of-concept.

http://energy.gov/eere/buildings/downloads/rotary-vapor-compression-cycle-technology-pathway-ultra-efficient-air

Projects started in 2014

Combined Water Heater, Dehumidifier and Cooler (WHDC), University of Florida with ORNL and Stony Brook University

- Goal is to develop a compact, low-cost combined water heating, dehumidification, and space cooling (WHDC)
- System dehumidifies the air and uses its energy for water heating
  - Condensed water can subsequently be given back to the dried air in an evaporative cooling process; or, when only dehumidification is desired, it can be simply drained from the system
  - Technology can utilize the A/C latent load for domestic hot water heating, resulting in significant energy savings for water heating and A/C
  - System can control humidity in residential buildings, resulting in comfort and significant health benefits.
- At the core of the system is an extremely compact open absorption cycle in which the water vapor releases its latent heat into the absorber
  - Released heat is subsequently transferred into the process water that cools the absorbent
  - Solution is regenerated in the desorber where it is heated by a heating fluid
  - Water vapor generated in the desorber is condensed and its heat of phase change is also transferred to the process water
- Technology utilizes non-corrosive and non-toxic ionic liquid (IL) that does not crystallize
  - Properties are critical to development of a robust cycle and its widespread adoption
- Demonstration unit will be fabricated and its performance will be evaluated for all suitable climates in an environmental testing chamber at Oak Ridge National Lab.

http://energy.gov/eere/buildings/downloads/combined-water-heater-dehumidifier-and-cooler-whdc