U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

BUILDING TECHNOLOGIES OFFICE

R&D to Market Success:

BTO-Supported Technologies Commercialized from 2010-2015

April 2017

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NOTICE

Preface

This report was developed based upon funding from UT-Battelle, LLC, Managing and Operating Contractor for the Pacific Northwest National Laboratory for the U.S. Department of Energy.

Prepared for:
U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
Building Technologies Office
energy.gov/eere/buildings

Prepared by:
Energetics Incorporated

List of Acronyms

AC	air conditioning
ADR	automated demand response
AIA	American Institute of Architects
ARRA	American Recovery and Reinvestment Act of 2009
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ATLAS	Automated Tri-Lite Assembly System
BAS	building automation system
BTO	Building Technologies Office
BEM	building energy modeling
CBECS	Commercial Buildings Energy Consumption Survey
COP	coefficient of performance
CPU	central processing units
CRADA	cooperative research and development agreements
CR	condensation resistance
CRF	condensation resistance factor
DIADR	distributed intelligent automated demand response
DOE	U.S. Department of Energy
DR	demand response
DRAS	demand response automation server
ECM	electronically commutated motor
EERE	Office of Energy Efficiency and Renewable Energy
EER	energy efficiency ratio
EIA	U.S. Energy Information Administration
ET	Emerging Technologies
EUI	energy use intensity
GHG	greenhouse gas
GHP	geothermal heat pump
GS-IHP	ground source integrated heat pump
GWP	global warming potential

HAM	heat, air, moisture
HFC	hydrofluorocarbon
HFO	hydrofluoroolefin
HP	heat pump
HPWH	heat pump water heater
HSPF	heating seasonal performance factor
HVAC	heating, ventilation, and air conditioning
IC	Integrated Concentrating
IGU	insulated glass units or insulating glass units
IHP	integrated heat pump
IR	infrared
ISO	Independent System Operator
kWh	kilowatt-hour
LBNL	Lawrence Berkeley National Laboratory
LED	light-emitting diode
Lm	lumens
Low-E	low-emissivity
NETL	National Energy Technology Laboratory
NFRC	National Fenestration Rating Council
NIR	near-infrared
NREL	National Renewable Energy Laboratory
NYSERDA	New York State Energy Research and Development Authority
NYSTAR	Empire State Development's Division of Science, Technology, and Innovation
MOCVD	metal-organic chemical vapor deposition
MYPP	Multi-Year Program Plan
OEM	original equipment manufacturer
OLED	organic light-emitting diode
ORNL	Oak Ridge National Laboratory
POEs	polyolesters
PET	polyethylene terephthalate

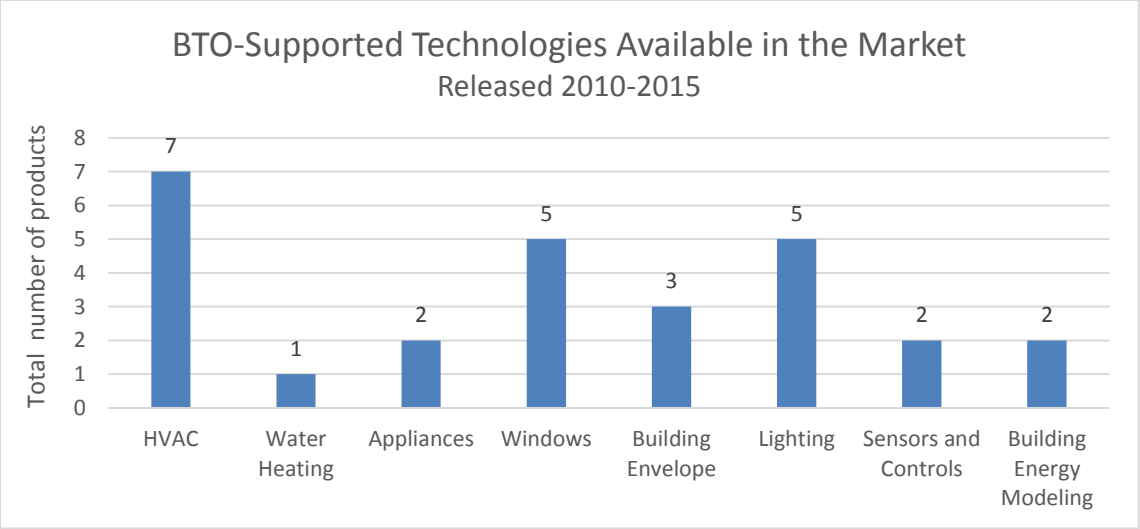
PGHP	packaged gas heat pump
PNNL	Pacific Northwest National Laboratory
PV	photovoltaic
R&D	research and development
RPI	Rensselaer Polytechnic Institute
RTO	Regional Transmission Organization
SBIR	Small Business Innovation Research
SBTT	Small Business Technology Transfer
SHGC	solar heat gain coefficient
SDK	software development kit
SRT	sunlight-responsive thermochromic
SSL	solid-state lighting
tBtu	trillion British thermal units
TES	thermal energy storage
UV	ultraviolet
WH	water heating

Executive Summary

For over three decades the U.S. Department of Energy's Building Technologies Office (BTO) has played a significant role in the improvement of American energy efficiency. It has supported technology development and deployment for a range of energy-related technologies in buildings, including energy-efficient water heaters, solid-state lighting, and energy-saving windows. Today, BTO continues to support development and market adoption of high-efficiency products to improve energy performance and design in the building sector and help meet national goals around improving energy and economic productivity and environmental quality.[1]

Technology commercialization plays an essential role in almost every facet of the U.S. economy. It spurs private sector funding that supports innovative breakthroughs, drives growth through increased productivity and product development, increases American competitiveness, and creates domestic jobs. The BTO Technology Commercialization report is an annual publication offering the latest information on successfully commercialized technologies resulting in part from BTO's research partnerships. This report defines a "commercialized technology" as a process, technique, design, machine, tool, material, or software that was developed with funds provided at least in part by BTO, and that has resulted in domestic sales or is in use in the U.S. This definition also applies to open source software products developed with support from BTO, all of which are currently distributed freely but are actively used for commercial purposes.

This report highlights the 27 BTO-supported, technology-oriented research and development (R&D) projects that resulted in the launch of a commercial product between 2010 and 2015, where the product remained on the market as of October 2016. The report also includes a listing of the 112 lighting components that benefited from BTO support and were commercialized and integrated into finished lighting products during the same timeframe.



[1] BTO also supports R&D and other activities to promote system-wide and whole buildings energy efficiency. More information about BTO's work can be found at https://energy.gov/eere/buildings/building-technologies-office.

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Overview

Residential and commercial buildings are the single largest energy-consuming sector in the U.S. economy. With about 130 million residential units and over 5 million commercial sites across the country, buildings account for more than 70% of all the nation's electricity use and about 40% of its total energy demand and carbon dioxide emissions.[2] As a result, Americans spend more than $420 billion every year to power their homes and offices.[3] Improving energy efficiency in the building sector through technology development and widespread deployment presents an enormous opportunity for energy savings.

The Building Technologies Office (BTO) within the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) leads a network of industry, small business, national laboratory, and university partners to drive the development of cost-effective energy-saving solutions for U.S. buildings. BTO's mission is to develop, demonstrate, and accelerate the adoption of affordable technologies, techniques, tools, and services that enable high-performing, energy-efficient buildings in new and existing building markets. Specifically, BTO's goal, which is expressed in its Multi-Year Program Plan (MYPP), is to reduce the energy use per square foot of U.S. buildings by 50% compared to 2010 levels.[4]

BTO's strategy to achieve its goal and mission includes research and development (R&D) that reduces cost and improves performance of high-impact, energy-saving technologies; activities to validate energy-efficient technologies and operational practices in new and existing buildings; and the provision of technical assistance around energy codes and promulgation of standards that set high performance benchmarks to incentivize further technological innovations and ultimately lock in lasting energy savings for all. By supporting public and private sector efforts to accelerate the pace of innovation in technologies for both existing buildings and new construction, BTO is working to make cost-effective products and solutions widely available to the American public and businesses that will greatly reduce energy use, save money, improve comfort, and enhance services provided to building occupants.

A key component of this success is enabling new technologies to move from the laboratory to the market; only when cleaner and more efficient technologies are available can they be used to reduce energy consumption. BTO's Emerging Technologies (ET) program supports applied R&D for technologies, systems, and models to help demonstrate feasibility and advance technologies to the market. *R&D to Market Success: BTO-Supported Technologies Commercialized from 2010 – 2015* highlights the commercial products that entered the market between 2010 and 2015 after receiving BTO support.[5] The products highlighted herein are

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[2] U.S. Energy Information Administration. *Annual Energy Outlook 2017 with projections to 2040*. DOE/EIA-0383(2017). Washington, DC: U.S. Department of Energy, January 2017. https://www.eia.gov/outlooks/aeo/pdf/0383(2017).pdf

[3] Ibid.

[4] U.S. Department of Energy, Building Technologies Office. *Multi-Year Program Plan: Fiscal Years 2016-2020.* Washington, D.C.http://energy.gov/sites/prod/files/2016/02/f29/BTO%20Multi-Year%20Program%20Plan%20-%20Final.pdf

[5] This report uses 2010 as the earliest year tracked as it is BTO's baseline year for its long-term goals. For information on technologies commercialized prior to 2010 please see – PNNL. *Buildings R&D Breakthroughs*.

limited to those available on the market as of October 2016, either for purchase or through an open source download or license.[6] This report is part of BTO's ongoing efforts to identify, track, and report on commercialized technologies it supported, which serve as one indicator of ongoing government investment in the sector. The report describes BTO's current approach to commercialization tracking, and also highlights commercialized components and the supported commercial technologies that are available on the market as of 2016, along with their applications and benefits.

Emerging Technologies Program

The commercialized products described in this report were originally supported through R&D under BTO's Emerging Technologies (ET) program. This program seeks to reduce the cost and improve the performance of high-impact energy saving building technologies and systems from early stage research and development through commercialization. Through this technology research and development, ET works to support the development of cost-effective technologies that can be taken up by the market to enable BTO's long-term energy savings goals. ET focuses on improving energy efficiency across six major technology areas: lighting; heating, ventilation, and air conditioning (HVAC), water heating, and appliances; building envelope and windows; sensors and controls; buildings-to-grid integration; and building energy modeling.

Heating, ventilation, and air conditioning (HVAC), water heating, and appliances: This sub-program seeks to reduce barriers to greater market adoption of premium-efficiency technologies in the near term by refining and reducing the cost of available technologies, such as heat pump technologies for space conditioning and water heating. Research areas of focus include energy efficiency and effective low-global warming potential refrigerants, novel heat pump technologies, non-vapor compression materials and technologies, and advanced compressors and heat exchangers. ET has developed research and development roadmaps for HVAC, next-generation refrigerants, next-generation appliances, and water heating technologies.

Windows and building envelope: Space heating and cooling accounts for approximately 30% of the primary energy consumed in buildings.[7] The building envelope, which includes the walls, windows, roof, and foundation, forms the primary thermal barrier between the interior and exterior environments, and plays a key role in determining levels of comfort, natural lighting, ventilation, and how much energy is required to heat and cool a building. This sub-program seeks to develop and accelerate next-generation, energy-efficient windows and building envelope technologies that reduce the amount of energy lost through the building envelope, contribute to improved occupant comfort, and have low product and installation costs to enable market adoption. The sub-program developed a windows and building envelope R&D roadmap to identify priority areas of

Washington, DC: U.S. Department of Energy April, 2012.
http://apps1.eere.energy.gov/buildings/publications/pdfs/corporate/rd_breakthroughs.pdf

[6] This report does not include technologies that were already commercialized and received BTO support for market demonstration and deployment efforts.

[7] U.S. Energy Information Administration. *Annual Energy Outlook 2014 with Projections to 2040*. DOE/EIA-0383(2014). Washington, DC: U.S. Energy Information Administration, 2014.
http://www.eia.gov/forecasts/archive/aeo14/pdf/0383(2014).pdf

interest. Research areas of interest include highly-insulating windows, low-cost materials and manufacturing processes for thermal insulation, and developing new high-performing air sealing systems, dynamic windows, window films, and daylighting technologies.

Lighting: Lighting is responsible for approximately 9% of electricity use in residential buildings and 11% in commercial buildings.[8] The Solid State Lighting (SSL) sub-program seeks to create a U.S.-led market for high-efficiency light sources that save energy, reduce costs, and have fewer environmental impacts than conventional light sources. SSL research areas of focus include accelerating development of LED and organic light-emitting diode (OLED) device technologies, improving product efficacy and performance, reducing SSL manufacturing costs, and overcoming technical barriers such as efficiency gaps that inhibit market acceptance. The research and development strategy for SSL is outlined in the Solid State Lighting 2016 R&D Plan, which provides analysis and direction for ongoing R&D activities to advance SSL technology, as well as an overview of BTO's current SSL R&D project portfolio.

Sensors and controls: This sub-program concentrates on developing sensors and controls solutions to improve data collection, monitoring, and optimization of building energy through sophisticated automation of building systems and energy-consuming equipment; better utilize building end uses to increase and enhance the penetration of energy efficiency and renewable generation at scale; and unlock new building market and financial opportunities for owners, operators, and end users. Research areas of interest include low-cost, self-powered, plug-and-play wireless sensor platforms with automated calibration, communication, and configuration, as well as low-cost, fault-tolerant, plug-and-play control systems with automated communication, configuration, and optimization.

Buildings-to-grid: This initiative's goal is to realize a connected world in which building equipment and systems can coordinate to efficiently meet the needs of both owners and occupants and even where buildings regularly transact with other buildings and the electricity grid, to benefit the entire energy system. Realizing this vision will require a holistic approach to integrating new technologies into the grid—one that ensures that buildings, building systems, and equipment are not just passive users of energy, but can actively, seamlessly and "intelligently" share information and coordinate their activities through value-driven transactions across the meter. Research areas of interest include across-the-meter control applications and deployment solutions that leverage open source controls platforms . Both research areas encourage transactive markets while also increasing and enhancing the hosting capacity of both energy efficiency and renewable energy at scale.

Building energy modeling: Whole-building energy modeling—or software calculations of building energy use given a description of the building's physical assets, operations, and weather conditions—is an enabling technology for increasing building energy

[8] U.S. Energy Information Administration. *Annual Energy Outlook 2017 with projections to 2040*. DOE/EIA-0383(2017). Washington, DC: U.S. Department of Energy, January 2017. https://www.eia.gov/outlooks/aeo/pdf/0383(2017).pdf

efficiency. Energy modeling supports system-level integrative design that simultaneously optimizes the building's envelope and systems to match its anticipated use profile and local conditions. This sub-program aims to increase the use of modeling tools in building design and operation. Research areas of interest include improving energy modeling engine accuracy, creating end-user applications with commercial partners, and testing and validating building energy models.

Between 2010 and 2015, BTO-supported projects have commercialized at least one product from every technology area within the Emerging Technology program. As more energy efficient products enter the market, BTO's technology deployment programs—the Residential Buildings Integration and Commercial Buildings Integration programs—or external deployment programs validate their use in new and existing buildings and help reduce the risk to builders, building owners and operators, and consumers who adopt the new technology, spurring additional investment from the private and public sectors in energy efficiency.[9] Once the market is mature, BTO's Codes and Standards programs help improve the energy performance baseline for all Americans and help drive further technology innovative.

Technology Tracking Approach

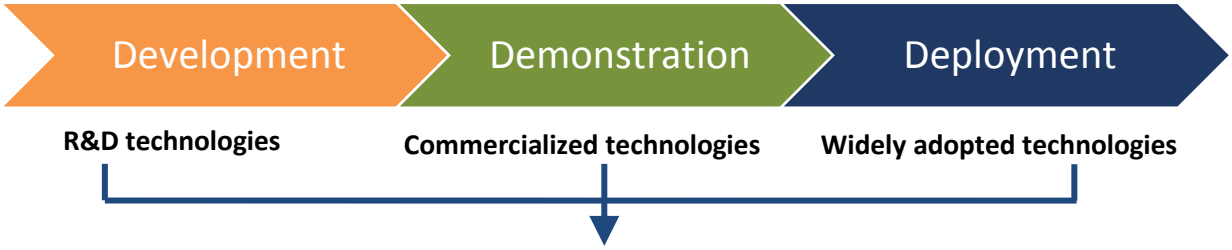
BTO regularly tracks and reports on the progress of its projects in order to evaluate progress towards its goals, specific accomplishments, and the overall impacts from its project portfolio. For this report's overview of commercialized technologies, the focus is on the R&D projects funded directly via the U.S national laboratories, the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (SBTT) programs, or under competitively solicited funding opportunities within the ET program for pre-commercial technologies. This report defines a "commercialized technology" as a process, technique, design, machine, tool, material, or software that was developed with funds provided at least in part by BTO, and that has resulted in domestic sales or deployment in the U.S.[10] This definition includes commercial grade open source software products that are freely downloaded or licensed in the U.S. A commercial grade software product is any software product that is publicly released for download, installation, or licensing and intended for commercial purposes.

Once a technology has been confirmed to be available on the market, BTO adds it to its list of actively-tracked commercialized technologies. The majority of technologies developed with BTO support are commercialized only after project closeout. BTO collects and attempts to verify technical and market data on each commercial technology's applications, capabilities, benefits, performance, and history. BTO retires a technology from tracking after it has been in the marketplace for 10 years, indicating market maturity, or after it is no longer available on the market, indicating no further product updates are forthcoming. The data for each commercial

[9] In addition to receiving Federal Government support, many BTO-supported R&D technologies receive significant external investments from third party programs. BTO technology R&D, demonstration, and deployment investments are often cost-shared and generate additional support from non-government sources to help get products to the market. In 2016, 95% of all BTO active projects were cost-shared, and 20% of the cost-shared projects exceeded federal funding by 100% or greater.

[10] The "commercialized technology" definition used in this report is used across all EERE technology offices. More specifically, BTO considers commercialized technology as a either a product or production method—these can be hardware or software or a service, a material, production method, or components.

technology is reviewed and confirmed by its Project Performer and BTO Technology Manager. A one-page profile is maintained for each technology and is updated for publication on an annual basis. Figure 1 below describes this process.



Project Performance Tracking Database	Collects technical and market data on all BTO-supported technologies
Active technology projects	Collect ongoing data from quarterly project reports
Closed technology projects	Verify the commercial status of a technology. Collect, track and annually update data associated with the commercial product
Products retired from tracking	No longer track when an active project is terminated, or when a commercial technology is mature and has been in operation for >10 years, or is no longer available on the market

Figure 1: Process for technology data tracking

Commercially Available Technologies

In 2016, BTO verified that 27 commercialized products were actively available on the market from 2010 to 2015 after benefiting from BTO support. Of these commercialized products, the plurality (10) are HVAC, water heating, or appliance technologies, closely followed by window and envelope technologies (8) and lighting products (5). Figure 2 below shows the full breakdown by specific technology type.

It should be noted that the figures for lighting products do not include the 112 component technologies commercialized from 2010 to 2015 that benefitted from BTO support; they were excluded from individual analysis as each component is installed across many individual products. Thus, the lighting products represented in the five technologies listed below are representative of the types of results enabled from BTO funding within the Solid-State Lighting sub-program. A full list of those component technologies can be found in Appendix A.

Technologies highlighted from the Building Energy Modeling sub-program are open source products developed with BTO support. Product developers are free to take these resources and incorporate them into private tools and derivative products without notifying the government. While several examples of their uptake by private actors have been noted in the one-page summaries, the list is not intended to be exhaustive. BTO's open source tools have been highlighted to show the impact of directly-supported technologies on the market, similar to the products from BTO's other technology areas.

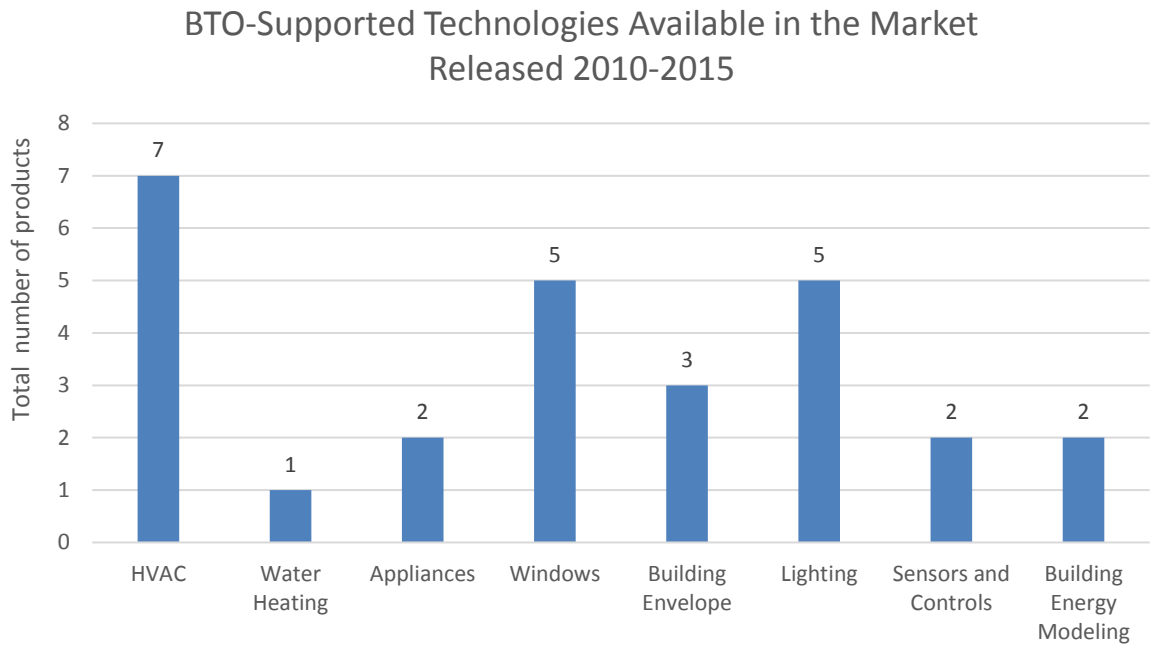


Figure 2: Total technologies (by type) commercialized from 2010 to 2015

Each of those 27 commercially available technologies is summarized below in Table 2. Further details about each technology, including its applications and benefits, can be found in a one-page profile in the subsequent sections.

Table 2. BTO-Supported Commercially Available Technologies (2010-2015)

Project	Organization	Year Commercialized*
HVAC		
NextAire™ Packaged Gas Heat Pump	IntelliChoice Energy	2010
Preserva® Advanced Sequential Dual Evaporator Cycle for Refrigerators	Whirlpool Corporation	2013
Everest® Polyolesters: Next-Generation Refrigerant Lubricants	Chemtura Corporation	2013
Trilogy® 45 Q-Mode® (QE) Ground-Source Integrated Heat Pump	ClimateMaster, Inc.	2013
Wireless Remote Monitoring System for Residential Air Conditioners and Heat Pumps	Mainstream Engineering Corporation	2014
QwikSEER+™ WattSaver: Energy Saving HVAC Control	Mainstream Engineering Corporation	2015
QwikSwap™: Energy Saving HVAC Control	Mainstream Engineering Corporation	2015
Water Heating		
Smart Energy Load Control Modules: CEA 2045 Compliant Wireless Controller for Water Heaters	Emerson Electric Company	2013
Appliances		
Advansor™: High-Efficiency, Low-Emission Refrigeration System	Hillphoenix Inc.	2014
Solstice® N40: A Low Global Warming Refrigerant	Honeywell	2014
Windows		
ATLAS™: An Energy-Efficient Triple IG Window Manufacturing System	GED Integrated Solutions, Inc.	2011
EnerLogic®: Low-Emissivity, Energy-Control Retrofit Window Film	Solutia Inc.	2011
OptiQ™: An Advanced Commercial Window Technology	Kawneer - An Alcoa Company	2011
Suntuitive™: Sunlight-Responsive Thermochromic Window Systems	Pleotint, LLC	2011
View® Dynamic Glass: Low-Cost, High-Energy-Savings, Solid-State Dynamic Glass	View, Inc.	2012
Building Envelope		
ThermaDeck®: An Insulated and Ventilated Roof System	Billy Ellis Roofing, LLC	2012
Integrated Concentrating (IC) Solar Array: Energy-Efficient Facades for Green Buildings	HeliOptix LLC	2015
LIQUIDARMOR™ CM: Advanced Energy-Saving Flashing and Sealant for Buildings	Dow® Chemical	2015

Lighting		
Cree, Inc. LEDs and Lighting Products	Cree, Inc.	2014
Veeco Instruments, Inc. LED Manufacturing Equipment	Veeco Instruments, Inc.	2012
WhiteOptics® Advanced Coatings: WhiteOptics Reflector Coating for LED Fixtures	WhiteOptics, LLC	2010
Lumileds' LUXEON® LEDs	Lumileds	2015
L Prize® LED Lighting Competition	Philips	2012
Sensor and Controls		
OpenADR Client: Distributed Intelligent Automated Demand Response (DIADR) Building Management System	Siemens Corporation	2011
Predictive Control Harnesses Building Thermal Mass as High Performance Energy Storage	Qcoefficient, Inc.	2012
Buildings Energy Modeling		
EnergyPlus Whole Building Energy Modeling Engine	National Renewable Energy Laboratory	2012*
OpenStudio®	National Renewable Energy Laboratory	2013*

* The year these open source technologies were commercialized refers to the year when the technology was released as a non-beta commercial grade product – whereby the product is no longer in the development stages and can be downloaded, installed, and/or modified to meet different user needs.

HVAC, Water Heating, and Appliances

HVAC systems, water heating equipment, and appliances consume approximately 22 quads of primary energy in United States every year, representing 55% of total energy use in buildings.[11] DOE has supported the research, development, and commercialization of more energy-efficient HVAC, water heating, and appliance technologies since the 1980s. BTO is working to enable development and commercialization of technologies by 2020 that could reduce the energy use intensity (EUI) of HVAC by 60%, water heating by 25%, and appliances by 15% from their 2010 levels. These EUI reductions correspond to approximate primary energy savings of 1.8 quads.[12]

Heating, Ventilation, and Air Conditioning (HVAC)

Currently, HVAC systems are the largest energy end use in buildings, accounting annually for almost 14 quads of primary energy use, or nearly 35% of all energy consumed in U.S. commercial and residential buildings each year.[13] The energy performance of HVAC systems has increased steadily over the past two and a half decades. For example, air conditioners manufactured today use about half as much energy as they did in 1990. However, the country's adoption and use of HVAC technologies has increased rapidly during this time, and further growth is expected. Globally, air conditioning (AC) equipment represents close to a $100 billion, 100 million-unit per year market. It accounts for 4.26 quadrillion Btus of site energy consumption per year and comprises just over 4% of global building site energy consumption.[14] The demand of AC technologies is projected to increase rapidly in developing countries with humid climates and growing populations. The IEA estimates that by 2050, AC energy consumption will increase 4.5 times over 2010 levels for non-Organization of Economic Coordination and Development (OECD) countries (compared to 1.3 times for OECD countries).[15]

In addition, although the associated electricity generation is the largest driver of emissions from HVAC, emissions of hydrofluorocarbon refrigerants (HFCs) have a large direct global warming impact. BTO is working with several partners to transition HVAC systems away from HFCs by developing a new generation of air conditioning and heating technologies that utilize low- to zero-global warming potential (GWP) innovations, while retaining performance and efficiency. In the short term, BTO's advanced vapor compression projects aim to reduce the cost and

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[11] U.S. Energy Information Administration. Annual Energy Outlook 2015 with projections to 2040. DOE/EIA-0383(2015). Washington, DC: U.S. Department of Energy, April 2015. Accessed August 16, 2016: http://www.eia.gov/forecasts/aeo/pdf/0383(2015).pdf.

[12] U.S. Department of Energy, Building Technologies Office. *Multi-Year Program Plan: Fiscal Years 2016-2020.* Washington, D.C.http://energy.gov/sites/prod/files/201F6/02/f29/BTO%20Multi-Year%20Program%20Plan%20-%20Final.pdf

[13] U.S. Energy Information Administration. Annual Energy Outlook 2015. DOE/EIA-0383(2015). Washington, DC: U.S. Energy Information Administration, 2015. Accessed August 11, 2016: http://www.eia.gov/forecasts/aeo/pdf/0383(2015).pdf

[14] U.S. Department of Energy, Building Technologies Office. *The Future of Air Conditioning for Buildings.* Washington, D.C: Accessed October 21, 2016: http://energy.gov/sites/prod/files/2016/07/f33/The%20Future%20of%20AC%20Report%20-%20Executive%20Summary_0.pdf

[15] Ibid

improve the energy performance of HVAC systems using refrigerants with reduced environmental impact. In the longer term, BTO is also working alongside its partners to develop highly efficient, non-vapor compression HVAC equipment that do not use refrigerants.

NextAire™ Packaged Gas Heat Pump

IntelliChoice Energy's 11-ton NextAire PGHP

U.S. commercial buildings are predominantly cooled and heated using packaged rooftop heating, ventilating, and air conditioning units, most of which rely on electric-motor compressors to drive the refrigeration cycle. Unfortunately, these units are expensive to operate when electricity prices are high, particularly in summer months when the demand for cooling services peak. Increased electricity demand for space cooling during peak hours puts stress on regional electric grids by requiring the development of excess generation capacity that is underutilized during off-peak hours.

In search of an alternative source of power to operate space conditioning equipment, IntelliChoice Energy, with assistance from the Building Technologies Office and the U.S. Department of Defense, developed the NextAire 11-ton packaged gas heat pump (PGHP). The PGHP uses a natural-gas-fired engine instead of an electric motor to drive its refrigerant compression cycle, providing numerous efficiency benefits. The unit's efficiency is enhanced in heating mode by its ability to capture and use waste heat from the engine for space heating. The engine can also operate at variable speeds, so it operates efficiently below its maximum cooling capacity. Because the PGHP occupies a similar footprint to traditional electric units currently in use, it is well-suited for new commercial construction and retrofit applications.

Widespread use of gas heat pump technology has the potential to produce large energy efficiency and resource conservation gains at the national level. According to the U.S. Energy Information Administration, more than 60% of primary energy consumed to generate the nation's electricity is lost in power plants during the conversion process. Shifting a significant fraction of commercial space conditioning to on-site natural gas would avoid these conversion losses, while simultaneously offsetting large amounts of water that would otherwise be consumed for traditional electricity generation purposes.

Technology History

NextAire was developed by IntelliChoice Energy with assistance from Southwest Gas Corporation and Oak Ridge National Laboratory. The product was commercialized in 2010. The technology has received numerous awards, including the 2010 New Product Award from the National Society of Professional Engineers and a 2011 R&D 100 award for innovation in technology. Efforts are ongoing to bring down initial installation costs.

Applications:

- Low-cost, energy-efficient space conditioning for commercial buildings**.**

Capabilities:

- Uses a natural-gas-fired engine instead of an electric motor to drive refrigerant compressors.
- Provides 11 tons of cooling/heating capacity with a cooling coefficient of performance (COP) of 1.1 and a heating COP of 1.4.

Benefits:

- Reduces operating costs by avoiding expensive demand and time-of-use electricity charges.
- Saves 0.5 gallons of water per kWh compared to similar–sized electric units consuming grid-generated energy.

Learn More:

- BTO Project Page - Derivative Residential Technology

Contact Information:

IntelliChoice Energy
6280 S. Valley View Drive
Suite 240
Las Vegas, NV 89118
www.iceghp.com

Preserva® Advanced Sequential Dual Evaporator for Refrigerators

Whirlpool's Advanced Dual Evaporator Refrigerator with Preserva®

Of all the appliances found in homes today, only water heaters consume more energy than refrigerators, which use roughly 6% of all U.S. residential building energy to preserve food. Since the 1930s, refrigerators have used a single vapor-compression cycle for both the fresh food and freezer compartments. Despite the cost and space advantages of using a single cycle, the overall coefficient of performance (COP) for refrigeration at freezer temperatures is below the COP for refrigeration required for fresh food temperatures. Single-cycle refrigeration exchanges air between the freezer and fresh food compartments. Energy could be saved if the majority of cooling was provided to meet the fresh food compartment's higher demands. For this reason, the potential energy savings of adopting separate cycles for the freezer and fresh food compartments has been investigated.

Whirlpool Corporation, with assistance from the Building Technologies Office, as part of the American Recovery and Reinvestment Act, developed a dual-cycle refrigerator that uses a sequential (or alternating) dual evaporator refrigeration cycle, a variable capacity compressor, heat exchanger technology, vacuum insulation panels, thermal storage material, and advanced controls to perform up to 50% better than single-cycle refrigeration units. Improvements were developed using an extensive, iterative modeling process to generate a final design.

The result of Whirlpool's development project is the Preserva® Food Care System that has been included in the Architect® Series II refrigerator. Preserva allows refrigerators to operate a separate system for fresh and frozen foods, resulting in longer-lasting foods and increased energy savings.

Technology History

The Preserva® Food Care System was developed by Whirlpool Corporation. The product was commercialized in 2013.

Applications:

- This efficient dual evaporator cycle can be used in residential refrigeration applications

Capabilities:

- Improves COP by operating the fresh food compartment evaporator at higher temperature
- Provides individual cooling needs of freezer and fresh food compartments
- Uses a single compressor and a three-way diverter valve to deliver refrigerant to dual evaporators

Benefits:

- Cost savings through reduced energy consumption with a cost premium less than $100, shortening payback period.
- Improves performance by minimizing temperature swings

Contact Information:

Whirlpool Corporation
200 N M 63
Benton Harbor, MI 49022
www.whirlpool.com

Everest® Polyolesters: Next-Generation Refrigeration Lubricants

Chemtura's Synthetic Refrigerant Lubricant

HVAC cooling and refrigeration in buildings account for about 21% of U.S. building energy consumption. Since the early 1990s, polyolesters (POEs) have been the primary lubricants for hydrofluorocarbon (HFC) refrigerant-based stationary refrigeration and air conditioning (AC) systems. Because HFCs inherently have high global warming potentials (GWPs), efforts are underway to commercialize alternative refrigerants with a considerably smaller influence on climate change. In almost all refrigeration compressor designs, lubricants act to create the final seal between the low- and high-pressure sides of the refrigeration loop. Optimized compatibility of the refrigerant with the lubricant is critical in order to reduce energy consumption, maximize the compressor's service life, and maintain high-efficiency heat transfers in the refrigeration system. In general, the molecular structure of POEs that contribute to the best efficiency in the refrigeration circuit are inversely related to those characteristics that improve lubricity and performance of the lubricant in the compressor.

Chemtura Corporation, with assistance from BTO as part of the American Recovery and Reinvestment Act , developed and patented POE technology for use as synthetic refrigeration lubricants that provide the necessary lubricity and refrigerant compatibility with improved energy efficiency versus today's commercial lubricants. Chemtura has optimized synthetic lubricants for several different refrigerants and applications, including low-GWP HFCs, hydrocarbons, and carbon dioxide (CO_2). One advantage of this synthetic ester technology is the structure of the molecules, which can be tailored and/or optimized for a specific refrigerant.

Technology History

Everest® Polyolesters was developed by Chemtura Corporation and was first commercialized in 2013. Development continues around large-scale manufacturing processes for next-generation synthetic lubricants and lubricant-refrigerant system testing and evaluation. By 2015, a total of 4 products were approved and sold in limited volumes for use in OEM compressors. Full commercialization is still pending.

Applications:

- Lubrication of appliances, residential AC, and commercial and industrial refrigeration and AC compressors and systems

Capabilities:

- Improves balance of frictional properties and refrigerant compatibility compared to existing commercial synthetic lubricants
- Provides synthetic ester lubricants for refrigeration applications using R-410A, hydrocarbon (R-290, R-600), and CO_2 (R-744) refrigerants
- Demonstrates technology development optimized for next-generation, ultra-low-GWP, R-410A equivalent refrigerants

Benefits:

- Maximizes energy efficiency of zero-ozone-depleting and low-GWP refrigerants in refrigeration and AC systems
- Optimizes balance between lubricity and refrigerant compatibility to achieve best lubrication performance and heat-exchanger efficiency

Contact Information:

Chemtura Inc.
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www.chemtura.com

Trilogy® 45 Q-Mode® (QE) Ground-Source Integrated Heat Pump

ClimateMaster's Trilogy® 45 Q-Mode® (QE)

Traditional heating, cooling, and water heating systems for commercial and residential buildings operate independently and require large energy inputs to keep spaces comfortable. Most cooling and heating systems today operate at fixed speeds, which causes large energy swings and decreases the building's energy efficiency. Increasing the energy efficiency of heating, cooling, and water heating systems will significantly lessen energy consumption, and decrease utility bills for homes and commercial buildings.

With assistance from the Building Technologies Office, the Oak Ridge National Laboratory (ORNL) developed a variable-capacity ground source integrated heat pump (GS-IHP) concept in 2007. The GS-IHP is able to use geothermal energy via a ground heat exchanger, horizontal or vertical loops dug into the ground, to provide heating, cooling, water heating, and dehumidifying services to a home in a single combined system, drastically decreases energy consumption and peak electrical demand. ClimateMaster, Inc. developed the Trilogy 45 Q-Mode based on the concept during the course of a collaborative project with ORNL to evaluate its performance. It recovers waste heat from its space cooling and dehumidification processes to heat water which reduces the overall purchased energy for the building. Repurposing the waste heat also serves to lessen the load on the ground heat exchanger. The Trilogy 45 incorporates three variable-speed technologies (compressor, indoor blower, and circulation pumps), all of which eliminate swings in temperature, to keep the building comfortable while using less energy.

Trilogy® 45 Q-Mode® (QE) has repeatedly demonstrated its energy efficiency. It received a 45 energy efficiency ratio (EER) rating, the highest ever achieved at the time of its market introduction in 2012. ENERGY STAR® designated it as one of the most efficient certified products in 2015 with a COP of 5.1. Based on ENERGY STAR projections, the unit will save users up to 69% above the federal minimum performance standard and provide the lowest operating costs on the market.

Technology History

The Trilogy® 45 Q-Mode® (QE) was developed by ClimateMaster, Inc. in collaboration with ORNL as part of a U.S.-China Clean Energy Research Center (CERC) project to accelerate ground source heat pump deployment. The technology was commercialized in 2012. ClimateMaster is a leading water-source heat pump manufacturer in North America. It has won numerous awards for the Trilogy® 45 Q-Mode® (QE) , including three in 2013 (the International R&D Award for Innovation, the Innovation Award at International Air-conditioning and Refrigerating Expo, and an R&D 100 Award), and the ACHR NEWS Dealer Design Gold Award in 2012.

Applications:

- A high-efficiency ground source integrated heat pump that can be used in new or retrofit residential and small commercial building applications

Capabilities:

- Provides the same space heating and cooling capacity as conventional heat pump systems, in addition to water heating and humidity control
- Coefficient of performance of 5.1
- Over 70% peak demand savings, location dependent

Benefits:

- Cost savings, 55% annual energy savings compared to minimum efficiency HVAC
- Reduces electricity consumption and peak demand by operating at less than full capacity and recovering waste heat

Contact Information:

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Wireless Remote Monitoring System for Residential Air Conditioners and Heat Pumps

Mainstream's Remote Monitoring System

In a typical home, an air conditioning (AC) or heat pump system is one of the largest consumers of energy. If an AC is operating at degraded efficiency, this typically results in wasted energy, reduced system life, and a tendency for units to fail on extremely hot days. A homeowner may be unaware of the equipment problem if the house is still cool. AC units that "break on the hottest day of the year" usually have been operating for some time at a reduced cooling capacity and for longer periods without cycling, but the reduced capacity only becomes apparent on the first hot day, when the unit cannot keep up any more.

Conventional systems capable of monitoring the "operational health" of AC units are typically expensive and only report raw sensor data that consumers cannot usually interpret. Therefore, new technologies are needed that are capable of analyzing AC performance and identifying problems and their likely causes. This will create a warning system for homeowners so they can take preventative actions to avert AC unit failures.

With assistance from a Department of Energy Small Business Innovation Research grant funded by the American Recovery and Reinvestment Act , Mainstream Engineering Corporation developed an innovative, low-cost device to detect AC problems and identify their causes. The remote monitoring system continuously monitors an AC unit to detect any maintenance needs (e.g., a clogged air filter or dirty condenser coils) and service issues (e.g., low refrigerant charge, faulty fans/blowers, or compressor short cycling) before they create system failures. Once a problem is detected, the system automatically sends a notification with problem-specific information to the homeowner and the AC service company that installed the AC unit. This information enables the service company to send a technician with the proper supplies, saving time and money by avoiding multiple trips. The homeowner or technician can log on to a secure website and investigate the unit's energy consumption, compare its current performance to previous data, and conduct "what if" calculations to determine the economic feasibility of replacing the current unit with a more efficient one.

Technology History

Mainstream Engineering Corporation commercialized the remote monitoring system technology in 2014. The technology's nationwide deployment is being pursued. It is currently being field tested with various regional partners in the HVAC&R service industry.

Applications:

- Automatically monitors and detects faults in residential air conditioning systems

Capabilities:

- Diagnoses common AC problems that waste energy and shorten equipment life
- Transmits information on system welfare to the homeowner and repair technician via a wireless internet signal
- Records equipment operating history to allow for energy consumption analysis and comparison

Benefits:

- Prevents costly replacement of failed AC units by alerting homeowners to simple maintenance issues that can be fixed with minimum time and expense
- Saves energy and money by rapidly detecting and resolving problems that degrade AC efficiency (e.g., low refrigerant charge)

Contact Information:

Mainstream Engineering Corporation
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Rockledge, FL 32955
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QwikSEER+™ and QwikSwap™: Energy Saving HVAC Control

Mainstream's QwikSEER+ WattSaver

Existing heating, ventilation, and air conditioning (HVAC) systems typically have inefficient oversized blower motors, which draw excess power and heat the air they are working to cool. Technicians often set these blowers at high speeds to ensure continued air movement in less-than-ideal ducts and minimize coil freeze-ups.

Mainstream Engineering, Inc. has developed a pair of electronic control systems that can be retrofitted into almost any residential or light commercial HVAC system to reduce the blower motor's inefficiencies. Both QwikSEER+™ and QwikSwap™ are easily installable electronic control boards that are directly wired to the blower motor. The electrical control system's sensors allow the evaporator airflow to be continuously and automatically adjusted, decreasing power use. An optional humidity sensor can be added so that the blower speed can also be optimized to reduce the structure's humidity. This technology works with new and existing AC units that are equipped with the low-cost permanent split capacitor motors, achieving efficiencies without investing in expensive electronically commutated motors.

QwikSEER+™ and QwikSwap™ provide cost-effective efficiency solutions for most traditional air conditioning systems. The control board, when installed, can boost an air conditioner's energy efficiency by 7%-13% and remove humidity 566% more quickly. The reduced energy use usually saves homeowners 10% or more on their annual operating costs.[1]

Technology History

The QwikSEER+™ and QiwkSwap™ technologies were developed by Mainstream Engineering Corporation with assistance from Building Technologies Office American Recovery and Reinvestment Act funding and Small Business Innovation Research grants. They were both commercialized in 2013. Both products are available worldwide from HVAC distributors. In 2015, QwikSEER +™ was awarded a U.S. patent, and three others are pending.

Applications:

- Residential and commercial HVAC systems to maximize system efficiency and improve summertime humidity conditions

Capabilities:

- Improves Energy Efficiency Ratio (EER) by 7.5 – 13.0 % (0.7 – 1.5 points)
- Allows automated, continuous adjustment of evaporator airflow to reduce power consumption
- Allows conversion of single speed to variable speed blower motor operation and control
- Provides energy savings up to 13% during periods of high demand, e.g. summertime
- Provides increased humidity removal (up to 2.5 times) which improves indoor comfort and air quality by inhibiting mold

Benefits:

- Affordable alternative for variable speed blower motor operation when compared to ECM blower motors.
- Universal retrofit for HVAC systems, no programming required.

Contact Information:

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Water Heating

Water heaters provide buildings with continual sources of hot water. Water heating accounts for 9% of primary energy use in buildings,[16] though 80% of this energy is consumed in the residential sector. Despite its inconspicuous role in the home, heating water for bathing, cleaning, and laundry can be the second largest household energy expense. In 2010, Americans spent $33.8 billion on residential water heating – anywhere from $200 to $600 per household.[17]

While more efficient tankless water heaters have made recent inroads in the marketplace, inefficient, storage-type water heaters still dominate the market, with nearly 90% market share.[18] BTO seeks to reduce the cost and complexity of water heaters while improving their efficiency in both residential and commercial applications. Current BTO water heating projects seek to achieve between 15% and 45% greater energy savings than the ENERGY STAR certified products available today.

One priority BTO research area is integrated heat pump technologies, where heat from one heat pump-driven process (e.g. space conditioning) can be used as the source of energy for another (e.g. water heating). However, BTO continues to pursue the development of individual end-use equipment like water heaters, as some consumers will not replace several pieces of equipment with a single unit.

[16] U.S. Energy Information Administration. Annual Energy Outlook 2015 with Projections to 2040. DOE/EIA-0383(2015). Washington, DC: U.S. Energy Information Administration, 2015. Accessed July 12, 2016: http://www.eia.gov/forecasts/aeo/pdf/0383(2015).pdf.

[17] *Hot Showers, Fresh Laundry, Clean Dishes.* U.S. Department of Energy. March 2013. Accessed August 16, 2016: http://energy.gov/eere/buildings/articles/hot-showers-fresh-laundry-clean-dishes.

[18] U.S. Energy Information Administration. Annual Energy Outlook 2015 with projections to 2040. DOE/EIA-0383(2015). Washington, DC: U.S. Department of Energy, April 2015. Accessed August 16, 2016: http://www.eia.gov/forecasts/aeo/pdf/0383(2015).pdf.

Smart Energy Load Control Module: CEA 2045 Compliant Wireless Controller for Water Heaters

Emerson's Smart Energy Load Control Module

Water heating is the second largest energy use in residential homes, accounting for roughly 13% of all residential building energy consumption according to EIA. Newer high-efficiency electric water heaters offer energy savings and the potential to lower peak electricity demand, when power utilities are forced to bring their oldest, costliest, and often dirtiest plants online.

Emerson Electric Co., with American Recovery and Reinvestment Act funding from the Building Technologies Office, developed a load control switch designed for electric water heaters. This new technology is a CEA-2045 compliant wireless controller for water heaters that integrates directly into a residential, smart-energy home network. It is one of the first products to comply with the CEA-2045 standard, which was developed to ensure the ease of utility-to appliance connectivity. Once the remote control switch is installed, the controlling utility can set it to turn on or off via schedules, price signals, or homeowner preferences.

Emerson's water heater technology combines smart grid and load switching technologies to smooth peak power demands and absorb sudden renewable energy power surges when the wind blows or the sun shines. Its "smart" operation enables communication between utility companies, the smart grid, and household appliances to improve energy efficiency and help consumers manage their home's energy consumption nearly in real-time. Smart grid-ready appliances can respond to external data and control signal inputs like power utility pricing information, and they can turn off all or part of the peak demand period with no inconvenience or impact on the home occupants.

Technology History

This technology was developed by Emerson Electric Co. It was commercialized in 2013. Currently, Emerson Electric is evaluating the market and working with utilities to offer the Smart Energy Load Control Module as part of demand response pilot programs.

Applications:

- This product can be used in residential and light commercial electric water heating applications

Capabilities:

- Achieves compliance with CEA-2045 communication standard
- Accepts various communications modules including ZigBee, Wi-Fi, FM, RDS, and cellular services
- Enables wireless temperature sensing
- Provides connectivity to the smart energy home area network
- Provides standard electric water heater control and enables "grid smart" capability

Benefits:

- Provides connectivity to the smart energy home area network
- Offers significant energy savings by automatically moving demand from the grid from peak hours to off peak hours

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Appliances

Residential appliances consume large amounts of energy within the United States. The daily use of refrigerator/freezers, dishwashers, laundry equipment, and cooking equipment accounts for approximately 15% of residential building primary energy consumption.[19] Appliances used for cooking and refrigeration in commercial buildings like grocery stores and hotels are another source of significant energy use.

Some advanced appliance technologies have been available in European and Asian markets for some time, but either are not manufactured in the U.S. or have not gained traction among U.S. consumers. For example, heat pump clothes dryers were developed in 1997 in Europe, and about 25 models were available on the European market by 2010.[20] In contrast, the first of these models became available in the U.S. only in late 2014. Heat pump clothes dryers can be as much as 50% more energy-efficient than conventional electric resistance clothes dryers, representing a clear opportunity for U.S. energy savings.[21] BTO's R&D efforts primarily focus on refrigerator/freezers and clothes washers and dryers, which offer the greatest opportunities for energy savings.

[19] U.S. Energy Information Administration. Annual Energy Outlook 2015 with Projections to 2040. DOE/EIA-0383(2015). Washington, DC: U.S. Energy Information Administration, 2015. Accessed July 12, 2016: http://www.eia.gov/forecasts/aeo/pdf/0383(2015).pdf

[20] Meyers, S.; Franco, V.; Lekov, A.; Thompson, L.; Sturges, A. Do Heat Pump Clothes Dryers Make Sense for the U.S. Market? Washington, DC: American Council for an Energy-Efficient Economy, 2010. Accessed July 9, 2016: http://www.aceee.org/files/proceedings/2010/data/papers/2224.pdf.

[21] Ibid.

Advansor™: High-Efficiency, Low-Emission Refrigeration System

Hillphoenix's Parallel Rack System with Advansor™

There are approximately 37,000 supermarkets in the U.S. that require substantial amounts of refrigerated floor space for displays and back-room storage. This refrigeration accounts for nearly half of all U.S. supermarket energy consumption, totaling 0.68 quads of primary energy each year. The structural requirements of supermarket refrigeration systems (i.e. long refrigerant piping to connect food display cases and store rooms) include large volumes of refrigerants to satisfy their extensive cooling needs, and the numerous piping interconnections introduce many opportunities for refrigerant leakage. On average, supermarkets leak 24% of their refrigerants, R-404A or R407A, which are HFCs with high global warming potentials (GWPs) that contribute to climate change. Leakages reduce refrigeration system efficiencies, thereby contributing to increases in indirect greenhouse gas emissions.

To address these issues, Oak Ridge National Laboratory (ORNL), with assistance from the Building Technologies Office and Hillphoenix, Inc., developed the Advansor™ transcritical CO_2 booster system, which uses carbon dioxide (CO_2) as its refrigerant. The Advansor™ system reduces GHG emissions from commercial refrigeration systems by over 75% by requiring 50% less refrigerant in the system, employing improved construction techniques to reduce leak rates, and utilizing a low-cost, low-GWP (i.e. 1) CO_2 refrigerant. As GHG emission regulations become more stringent, refrigerants with high GWPs will be replaced by lower GWP alternatives. Installing a CO_2 refrigeration system now would therefore eliminate the need for system retrofits to comply with future environmental regulations.

In addition to its environmental benefits, the Advansor™ system has been verified through testing by ORNL to use less energy than other refrigeration systems depending on the climate region. Regions with lower ambient temperatures will achieve greater energy savings than conventional HFC-based refrigeration systems. Natural refrigerant-based refrigeration systems (e.g. CO_2) have been successfully implemented in Canadian and European markets, giving U.S. manufacturers and consumers more confidence to explore these options.

Technology History

Developed and tested by Hillphoenix and ORNL with assistance from Danfoss, Luvata, and SWEP, the Advansor™ refrigeration system was first commercialized in 2014 and as of September 2016 has over 130 installations in the U.S. Efforts are ongoing to evaluate potential applications and develop marketing strategies. The Hillphoenix Advansor Transcritical Booster System was named an R&D 100 Award Finalist in 2015.

Applications:

- A low-GWP replacement for traditional commercial refrigeration systems

Capabilities:

- Offers lower installation costs than conventional supermarket refrigeration systems
- More efficient than conventional refrigeration systems in most climate zones in the U.S.
- Uses a natural refrigerant (CO_2) with zero ozone depletion potential and a GWP of 1

Benefits:

- Reduces energy consumption by 25%
- Reduces greenhouse gas emissions by 75%
- Achieves refrigerant leak rates of less than 25%

Learn More:

- BTO Project Page
- BTO Success Story

Contact Information:

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Conyers, GA 30013
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Solstice® N40: A Low Global Warming Refrigerant Solution

Solstice N40®(R-448A) Cylinder

Thousands of supermarkets across the country operate large-scale refrigeration systems, making it one of the most energy-intensive commercial sectors. These refrigeration systems require large amounts of electricity and refrigerants to chill and freeze perishable foods. The refrigerants used by these systems are hydrofluorocarbons (HFCs), strong greenhouse gases with very high global warming potentials (GWP). Today the most commonly used refrigerant is R-404A. Each year, a typical supermarket refrigeration system can leak up to 1000 pounds of R-404A, the equivalent emissions of 3.9 million pounds of carbon dioxide (CO_2). Improving efficiency and reducing the GWP refrigerants in commercial refrigeration systems will reduce harmful climate impacts to the global environment.

Solstice® N40 is a low-GWP refrigerant for commercial refrigeration systems. It provides an environmentally friendly solution to mitigate the high CO_2 equivalent emissions of conventional refrigerants. It is a non-toxic hydrofluoroolefin (HFO)-based refrigerant alternative. Lab studies conducted by ORNL and Honeywell concluded that N40 could replace R-404A without sacrificing performance in existing supermarkets. In addition, N40 can provide a significant reduction in GWP and lower energy consumption. N40 is non-flammable and compatible with typical system components used with R-404A commercial refrigeration systems, which makes it suitable for retrofit applications. Future work will focus on field evaluation of N40 in third party commercial refrigeration systems in order to validate the performance benefits in the field.

Technology History

Solstice® N40 was developed by Honeywell. The company received assistance from BTO to work with ORNL to test and evaluate the performance against the conventional R404A refrigerant. The technology was commercialized in 2014 and continues to undergo evaluation in supermarket refrigeration systems. It was named an R&D 100 Award Finalist in 2015.

Applications:

- A direct low GWP refrigerant replacement for existing R-404A systems

Capabilities:

- Achieves higher coefficient of performance (independent laboratory evaluations demonstrated 11% improved energy efficiency) compared to R-404A
- Compatible with R404A supermarket systems and maintains refrigeration capacity

Benefits:

- Non-flammable (ASHRAE A1)
- Lower GWP of 1273
- Maintains or improves refrigeration capacity using existing R404A equipment
- 5-15% higher energy efficiency and offers a 67% reduction in GWP over R404A

Learn More:

- BTO Success Story

Contact Information:

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Windows & Envelope

Space heating and cooling represents 30% of the primary energy consumed in residential and commercial buildings.[22] The building envelope, including windows, forms the main thermal barrier between interior and exterior spaces. When this barrier fails to provide a tight seal due to drafts, material inefficiencies, or solar heat gain, it can greatly impact how much energy is needed to heat or cool the interior to meet occupant comfort preferences. In 2010, the additional heating and cooling services needed to compensate for heat gained or lost through the windows and envelopes of buildings accounted for more than 15 quads of the country's total net primary energy consumption.[23] Improving the insulating capacity of window and envelope technologies—while simultaneously reducing costs to increase market share—could potentially lower the energy use intensity for heating and cooling buildings by roughly 60% in 2020, relative to a 2010 energy-efficient baseline.

Windows

Windows provide buildings with ventilation, natural daylighting, and architectural character, but they also impact a buildings energy performance. Among building envelope components, DOE studies show that the infiltration from heating and cooling and conduction through windows and walls appear to have the most impact on energy saving opportunities in buildings.[24] For instance, in cooling-dominated climates, solar heat gain from windows has a significant energy impact. The amount of air conditioning buildings must use to offset the added solar energy that windows allow through—particularly in summer months— creates peak electricity loads which strain the nation's generation capacity.

Window improvements alone could reduce the nation's building HVAC and refrigeration energy use by 1.1 quads.[25] Research efforts have sought to develop and produce cost-effective window products with improved coefficient of heat transfer values, or U-values, of <0.20 (R-5). Next-generation windows technologies have substantial potentials to reduce energy consumption in buildings. For example, the latest generation R-7 windows have the technical potential to save 600 tBtu of energy by 2030 in commercial buildings.[26]

DOE's window R&D efforts are focused on technologies and systems that dramatically reduce thermal losses and gains, actively modulate and control solar load to minimize summer cooling and offset winter heating, maximize effective use of daylight to offset electric lighting, and provide outside ventilation air displacing mechanical ventilation whenever possible. This includes R&D of low-cost advanced materials, improved manufacturing processes, and technologies with cost-effective installation techniques.

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[22] U.S. Energy Information Administration. Annual Energy Outlook 2014 with Projections to 2040. DOE/EIA- 0383 (2014). Washington, DC: U.S. Energy Information Administration, 2014.
[23] In some instances, windows and envelope components reduced heating and cooling-related energy consumption, such as through solar heat gain during the heating season. Source: Sawyer, K. Windows and Building Envelope Research and Development: Roadmap for Emerging Technologies. Washington, DC: U.S. Department of Energy, 2014. Accessed September 2, 2016: http://energy.gov/sites/prod/files/2014/02/f8/BTO_windows_and_envelope_report_3.pdf
[24] Ibid
[25] Ibid
[26] Ibid

ATLAS™: An Energy-Efficient Triple IG Window Manufacturing System

ATLAS™ Window Manufacturing System

A considerable portion of the energy consumed in commercial buildings is impacted by the insulation capacity and optical properties of windows. The Department of Energy (DOE) identified heat loss through windows as the largest single energy-related aspect of window performance. Low-emissivity glass coatings and the introduction of inert gases in the space between window panes are two technology areas that have reduced energy losses, but opportunities remain to increase energy savings by addressing glazing properties and the sash/frame combination. To provide customers with affordable and efficient commercial and residential windows that can reduce their energy bills, DOE has enabled the research, design, and development of high-volume, efficient manufacturing processes that can produce high-performance, energy-saving insulating glass units (IGUs).

With funding from the Building Technologies Office, GED Integrated Solutions, Inc. developed a high-volume, low-material, and low-labor-cost automated manufacturing system that produces high-performance IGUs. GED's revolutionary Automated Tri-Lite Assembly System (ATLAS™) for insulating glass fabrication is a culmination of developing manufacturing processes for improved efficiency and throughput and design for manufacturability consideration of the end product. The ATLAS™ produces a triple-pane IGU in 20 seconds, improving on conventional methods that can take two minutes or longer. GED's ATLAS™ can be installed in most existing window manufacturing facilities, and GED can produce a wide variety of IGU sizes for high thermal efficiency windows.

Technology History

This technology was developed by GED Integrated Solutions, Inc. and was commercialized in 2011. PPG Industries, Inc., a major U.S.-based glass manufacturer and developer of advanced window technologies, assisted GED with unit design support and analytical testing and commissioned the first ATLAS™ to validate performance in an actual production environment. It was awarded "Best in Show" in September 2011 at GlassBuild America, a major glass and window industry event.

Applications:

- Can be used for high-volume, low-cost manufacturing of triple-pane IGUs

Capabilities:

- Provides seamless integration into existing equipment and flexible, schedule-driven production
- Processes units from 16" x 14" up to 100" x 72" at a rate of up to six IG dual units per minute

Benefits:

- Minimizes glass breakage, contamination, and damage using touchless assembly and protects workers from injury and fatigue from handling glass
- Provides capability to handle small and large sized units, dual- and triple-glazed IGUs in any order or combination and still maintain optimum levels of production
- Uses vacuum lift mechanisms to lift and suspend the product without contact with the glass surfaces, ensuring contamination-free placement and alignment of triple IGUs

Contact Information:

GED Integrated Solutions, Inc.
9280 Dutton Dr.
Twinsburg, OH 44087
www.gedusa.com

EnerLogic®: Low-Emissivity, Energy-Control Retrofit Window Film

Eastman's EnerLogic® Window Film Before and After Installation

Research and development to improve energy conservation with new window technologies has investigated fenestration, glazing, and glazing treatments, including active and passive window tinting. For a technology to become successful in the consumer marketplace, the cost of ownership must have a perceived value and a short payback period. Also, technologies that can be retrofitted easily and cost-effectively are desirable. Currently, the best available retrofit window film technology has an emissivity of more than 0.35. Suspended films have been used in the air gap of dual pane window units, but these retrofits proved to be uneconomical and ineffective. Sealed, dual-pane windows can produce emissivity values as low as 0.02 in glass coatings within their air gaps, but low-emissivity coatings cannot be directly applied to aftermarket window films due to processing issues and substrate flexibility, corrosion, and abrasion resistance.

Solutia Performance Films, now Eastman Chemical Company, with assistance from the Building Technologies Office (as part of the American Recovery and Reinvestment Act), developed EnerLogic®, a retrofit window film technology with improved emissivity. The technology uses sputter coating processes from a flexible touch panel and display manufacturing, preventing damage and maintaining the film's flexibility. To improve abrasion resistance, acrylic coatings cannot be used because they increase a window's emissivity, which produces iridescence or even opaqueness in the far infrared (IR) spectrum that can significantly reduce a window's transparency.

Eastman's new abrasion resistant technology is flexible, IR-transmissive, and eco-lighting friendly. The product's low emissivity also decreases the energy payback period. Commercial users typically recoup their investment in 3-5 years, and homeowners save an average of $3,500 over the film's lifetime, which makes them suitable in a wider range of climates. Eastman currently produces four commercial and residential building window products with different light transmission and emissivity specifications to match various application requirements. Eastman distributes their products through a national dealer/installer network and has successfully demonstrated their products at numerous commercial and residential sites.

Technology History

This technology was developed by Solutia Performance Films, now Eastman Chemical Company, in 2011. Since then, over 1.5 million square feet of EnerLogic® Window Film has been installed.

Applications:

- Can be used in most existing window applications

Capabilities:

- Can be installed in a variety of existing low-e commercial or residential windows (single or dual pane and tinted or clear)
- Achieves a 3.5 times reduction of window emissivity to less than 0.1

Benefits:

- Reduces first cost by eliminating costly reinstallation or replacement of existing windows
- Improves product durability and flexibility using flexible display manufacturing techniques combined with precious metal sputter coating
- Improves window energy efficiency using reduced emissivity film coating and becomes energy neutral in less than 2 months of use

Contact Information:

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Fieldale, VA 24089
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OptiQ™: An Advanced Commercial Window Technology

OptiQ™'s Triple Pane Insulating Glass and Insulating Foam Strips

Aluminum window framing systems are used in more than 80% of commercial buildings because of their inherently good structural properties and long service lifetime. However, these traditional window frames are poor insulators, which helps to explain why windows are one of the least effective insulators in a building's envelope.

Kawneer has developed a cost-effective, commercial-grade aluminum window frame with greater insulating capabilities than those typically found on today's market. OptiQ™ Ultra Thermal Windows (AA4325) are 40% more effective at reducing energy losses than existing, commercially available, double-pane, low-emissivity (low-E) windows.

OptiQ™ windows have thermally optimized frames with high-performance glazing that are designed to accommodate double- or even triple-pane insulating glass. They are the first R-5 windows for the commercial buildings sector that have achieved an architectural structural rating.

OptiQ™ windows have coefficient of heat transfer values (U-value) of 0.17 and 0.22 for fixed and operable windows, respectively—a performance level only previously attainable with nonmetal framing materials that reduced window structural integrity. OptiQ™'s improved thermal performance and excellent moisture resistance are obtained by using an advanced framing design with a polyimide thermal break and a highly insulating glazing system.

Technology History

With American Recover and Reinvestment Act funding from the Department of Energy, Traco, a division of Kawneer, developed and commercialized OptiQ™ window frames in 2011. In 2014, Alcoa launched the second set of OptiQ™ Ultra Thermal Windows (Vertical Sliding Windows). In 2015, they launched the third set of OptiQ™ Ultra Thermal Windows (Horizontal Sliding Windows).

Applications:

- Energy-saving replacement or alternative to conventional aluminum windows in commercial buildings for new and retrofit applications

Capabilities:

- Provide coefficient of heat transfer values (U-value) of 0.17 and 0.22 for fixed and operable windows
- Improves the U-factor of commercial-grade aluminum windows by >40% compared with market leading commercial window systems
- Enables R-5 architectural grade windows in commercial buildings
- Improves thermal comfort
- Improves condensation resistance (CR>72, CRF>78) and reduces likelihood of mold

Benefits:

- Comfort: Increases both window insulating capability, which improves occupants' thermal comfort, and condensation resistance, which reduces formation of mold
- Cost Savings: Reduces heating and air conditioning costs by inhibiting heat transfer through aluminum window frames
- Emissions Reductions: Reduces greenhouse gas emissions by decreasing energy consumption for heating and cooling buildings

Learn More:

- Success Story

Contact Information:

Traco
71 Progress Avenue
Cranberry Township, PA 16066
www.kawneer.com

Suntuitive™: Sunlight-Responsive Thermochromic Window Systems

Pleotint's Suntuitive Thermochromic Interlayer Combined with PPG's Azuria Tinted Glass in the Dark and Light States

In 2010, space heating, cooling and lighting services consumed 56% of the energy used by commercial and residential buildings. The amount of energy consumed for heating and cooling depends on a building's insulative properties, which include the windows. For a number of years, there has been a potential market for variable tint, energy control windows with acceptable cost, performance, and durability characteristics.

Fixed tint windows are a compromise between how much light and solar heat gain is allowed to enter a building. Research has focused on developing window technologies with additional features that reduce or enhance the effects of solar heat gain, prevent sunlight glare, and are compatible with daylighting schemes.

Pleotint, LLC, has developed and commercialized a high-performance window with dynamic sunlight control, high insulation value, and low solar heat gain. This window, the Suntuitive™ sunlight-responsive thermochromic (SRT) window system, was tested and developed with support from DOE.

Through an alliance with PPG Industries, this product is currently being marketed in North America. Pleotint's SRT window is dynamic because it reversibly changes light transmission throughout the day based on the heat provided by the sun. This allows the windows to optimize the incoming brightness and heat load in buildings. Every day of the year, every time of the day, and on every orientation on a building, the windows tint according to the sun's intensity without using wires, power supplies, or controls. The interlayer is made of the most common safety glass lamination polymer, polyvinyl butyral, which can be produced in rolls and shipped to window fabricators throughout the world. This allows dynamic windows to be manufactured almost anywhere safety glass laminates are produced.

Technology History

Suntuitive™ was developed and commercialized in 2011 by Pleotint, LLC, through a marketing alliance with PPG Industries. Over 200,000 square feet have been installed.

Applications:

- Can be used to control daylighting and reduce energy consumption in residential and commercial buildings

Capabilities:

- Optimizes daylighting and provides visible light transmission between 50% and 10%
- Achieves solar heat gain coefficient as low as 0.11
- Provides dynamic window tinting without wires, power supplies, or controls

Benefits:

- Provides sound reduction and impact resistance, decreases glare, and minimizes fading from solar ultraviolet radiation without compromising visibility
- Achieves 20%-43% annual energy savings depending on climate, based in a LBNL study[27]
- Installation: Installs like any conventional glazing without special requirements
- Provides a thermochromic interlayer that can be supplied to laminators and window manufacturers worldwide

Learn More:

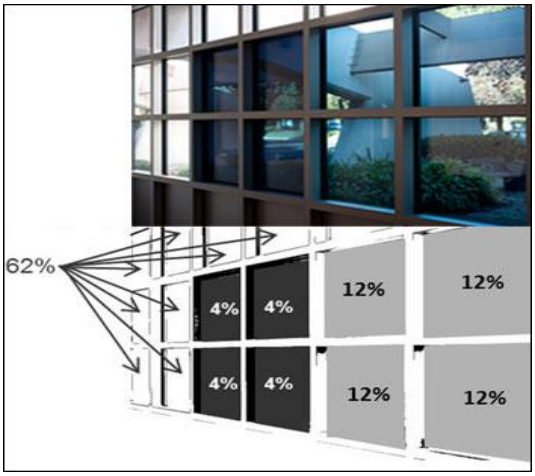
- BTO News Article

Contact Information:

Pleotinti, LLC
7705 west Olive Road
West Olive, MI 49460
www.suntuitive.com

[27] "An empirical study of a full-scale polymer thermochromic window and its implications on material science development objectives" Published in Solar Energy Materials & Solar Cells 116 (2013) pp. 14-26

View® Dynamic Glass: Low-Cost, High-Energy-Savings, Solid-State Dynamic Glass



View's Dynamic Glass Demonstration of 4%, 12%, and 62% Transmission

Heating, Ventilation, and Air Conditioning (HVAC) cooling during the summer months can be a result of solar loading, which ranges from 3 to 14 kWh/m2/day, depending on geographic location. A major contribution to energy conservation could be made by eliminating HVAC energy consumption from solar loading. Most current state-of-the-art windows use spectrally selective low-emissivity (low-e) glass, which blocks some ultraviolet (UV) and near infrared (NIR) light and allows visible light to pass through. High-performing, low-e insulated glass units (IGU) typically have a solar heat gain coefficient (SHGC) of 0.3 to 0.4 in residential settings (i.e., blocking 60-70% of the solar radiated heat), while transmitting 50-60% of the visible light. SHGCs in commercial settings, the main application for today's low-e glass, can be as low as 0.27 or even 0.20. Maximum insulated glass unit (IGU) dimensions are 6 feet by 10 feet.

View, Inc. (VI), with assistance from the Buildings Technologies Office (BTO) (as part of the American Recovery and Reinvestment Act), developed dynamic glass based on electrochromic technology—a multilayer coating stack applied to the inner surface of the outer pane of glass in a double-pane IGU. View® Dynamic Glass can be tinted by applying a DC voltage of less than 5 volts; reversing the applied voltage causes the glass to become clear. VI's dynamic, electrochromic glass technology provides an SHGC that can be tuned in real-time from 0.09 to 0.41, with visible light transmission from 1%-58%. In the tinted state, VI's dynamic glass eliminates glare and blocks over twice as much solar heat than state-of-the-art, low-e glass. In cold weather, dynamic glass can adapt to raise the SHGC, which allows the sun's rays to enter and passively heat the building, saving energy and money along the way. View® Dynamic Glass has the potential to reduce the commercial building energy consumption by as much as 25% and peak load by up to 30%, when compared to existing low-e glass. In residential buildings, the savings are 18% and 41% for energy and peak-load reduction, respectively. Today the product is cost competitive with traditional glass plus shading solutions and most often used in office, healthcare, and education settings. As of 2017, View® Dynamic Glass completed more than 300 commercial installations and have another 150 in progress.

Technology History

From 2010 to 2011, BTO invested in View, Inc. (formerly Soladigm, Inc.), an energy-efficient buildings materials company, to focus on advancing windows and envelope component technologies to enhance energy savings and performance. This technology was developed by View, Inc. and was commercialized in 2011. In 2017, View secured an additional 100 million in venture capital for the project.

Applications:

- Can be used for controlling the amount of light and heat entering building windows, reducing lighting and HVAC energy consumption

Capabilities:

- Controls radiant heat by blocking direct sunlight in summer and transmitting it in winter
- Reduces direct sunlight glare through windows
- Eliminates the need for blinds, shades, and related maintenance costs and provides unobstructed views and natural daylight to improve occupant comfort

Benefits:

- Has the potential to break-even initial cost based on HVAC downsizing, eliminating blinds or shades
- Reduces lighting and HVAC electricity consumption by 20%
- Reduces HVAC cooling peak load by 23%.
- Complies with industry standard performance and reliability testing per ASTM E2141-06

Learn More:

- BTO Success Story

Contact Information:

View, Inc.
195 S. Milpitas Blvd.
Milpitas, CA 95035
www.viewglass.com

Building Envelope

Every year, buildings leak about 4 quads of primary energy in United States every year, a loss roughly equivalent to 4% of total national energy use.[28] Priority areas to address this leakage for the BTO are improved building envelope material and air sealing technologies. Air leaks in the building envelope also contributes to moisture problems that can affect occupants' health and a structure's durability. Reducing the amount of air that leaks in and out of a home or business can lower energy consumption, cut heating and cooling costs, improve durability, increase comfort, and create a healthier indoor environment.

DOE's 2014 Windows and Building Envelope Roadmap lists air sealing technologies as a top priority research area that has the technical potential to save 1,600 tBtu by 2030.[29] These technologies help to control airflow across a building's thermal barrier and complements insulation. Today leaks or infiltration can typically be sealed with caulk, spray foam, weather stripping, or air sealing membranes that address basic moisture control. In the future, air sealing technologies will seek to reduce labor, installation error, and disruption during installation. Additional, value-added features beyond reduced air leakage will be crucial to scaling adoption in more efficient envelope technologies going forward.

Another key research area identified as a top priority in the 2014 Windows and Building Envelope Roadmap is insulating materials. These materials are used to provide resistance to heat flow, measured as R-value, to reduce the amount of energy necessary to maintain a building's internal temperature. Radiant barriers or reflective insulation systems instead work by reducing radiant heat gain. Numerous types of insulation materials exist, from fiber materials to rigid foam boards and from spray foam to reflective foils. Developing cost-effective insulating materials that meet durability requirements, minimize occupant disturbance, and have short payback periods are key targets for this technology.

DOE's building envelope R&D efforts are concentrated on cost-effective technologies such as insulating materials for retrofitting walls, commercial building roofing systems, and air sealing system technologies. Improving the cost-effectiveness of these technologies is required to improve wide spread adoption. Next-generation building envelope technologies must also maintain or improve building indoor air quality, acoustics, and enclosure durability, and protect against moisture and fire and meet structural requirements.

[28] Sawyer, K. Windows and Building Envelope Research and Development: Roadmap for Emerging Technologies. Washington, DC: U.S. Department of Energy, 2014. Accessed September 2, 2016: http://energy.gov/sites/prod/files/2014/02/f8/BTO_windows_and_envelope_report_3.pdf
[29] Ibid.

ThermaDeck®: An Insulated and Ventilated Roof System

ThermaDeck® Roofing System Controls Radiation, Convection, and has Insulation to Provide Conduction Resistance to Heat Transfer

Multiple problems exist with today's composition roofs found on most homes across America. Made from an asphalt petroleum-based material, they conduct the sun's heat extremely well and reach temperatures from 150º to 185º F. This heat crosses through the roof decks and into the attic space below, warming air conditioner (AC) ducting and making it difficult for the AC system to remove heat.

Billy Ellis Roofing, LLC designed the ThermaDeck® roofing system to address heat buildup caused by conduction, convection, and radiant heating, which increases cooling and heating, ventilation, and air conditioning (HVAC) costs. The technology uses a passive, convection-based ventilation system that pulls cool air through soffit vents into an airspace and exhausts warm air (heated by the sun) through a vented ridge at the roof. The system creates a constant airflow while the R5 rated foil-backed polystyrene both insulates the attic from conducting heat and reflects over 90% of the suns radiant heat. This, in turn, reduces cooling and HVAC costs.

Since 2008, the Oak Ridge National Laboratory (ORNL) has tested ThermaDeck®'s energy efficiency and benefits and found that it reduces radiant, convection, and conduction heat within an attic by more than 85% compared to conventional composition roofs. Shingle temperatures consistently stayed 10ºF cooler than conventional nailed shingle roofs, and the attic air temperature was never more than 5ºF warmer than the outdoor air temperature. Attic temperature reduction places less stress on AC systems, reducing HVAC energy expenditures.

Technology History:

The ThermaDeck® roofing system was developed and patented by Billy Ellis Roofing, LLC and tested by ORNL with support from the Building Technologies Office. Since it became commercially available in 2012, more than 200 roofing systems have been installed on homes across the U.S.

Applications:

- Can be used in residential applications to reduce heat gain in attics and subsequent heat transfer from an attic to conditioned spaces.

Capabilities:

- Reduces peak daytime heat transfer through roofs by 85% compared with conventional roofing.
- Maintains attic air temperatures at about the outdoor air temperature.

Benefits:

- Reduces cooling costs by minimizing heat transfer from the attic into air-conditioned spaces.
- Reduces operational costs by minimizing strain on AC units and ducting within attics.
- Lasts the lifetime of a home without any need for maintenance or replacement.

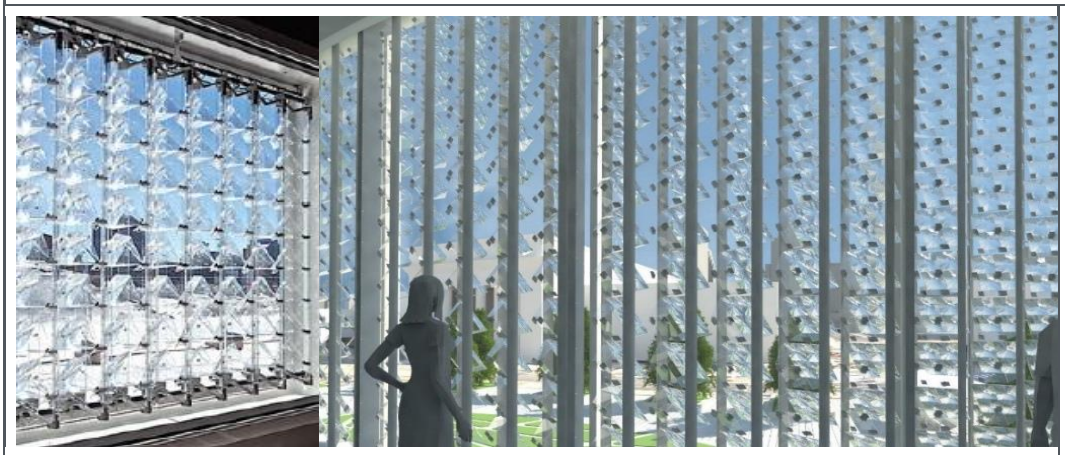
Learn More:

- ThermaDeck ORNL Test Results
- Technology Explanation Video

Contact Information:

Billy Ellis Roofing, LLC
2820 S.E. Loop 820
Fort Worth, TX 76140
www.billyellisroofing.com

Integrated Concentrating (IC) Solar Array: Energy-Efficient Facades for Green Buildings



HeliOptix's Integrated Concentrating (IC) Solar Array: Solar heat and power colle that improves daylight resources, generates power, and controls solar gains.

The Integrated Concentrating (IC) Solar Array has been developed to fulfill multiple criteria. The IC Solar provides views and diffuses daylight for occupants, while generating power as well as the associated benefits of solar gain reduction. The array is designed to integrate architecturally into the envelope of a building: its façades, clerestories, roofs, and atria. IC Solar's modular design complements a range of existing building structures, or, if implemented in new designs, suggests bold design opportunities.

The multiple benefits of IC Solar are accomplished by miniaturizing and distributing components of concentrating photovoltaic (PV) technology within a weather-sealed building envelope. To maintain optical alignment throughout the day, IC Solar actively tracks the sun with simplified mechanical linkages. Diffuse sunlight filters through the array's transparent components, providing daylighting. Glare and heat are reduced by intercepting and concentrating direct solar energy onto small ($1cm^2$) PV cells, which generate electricity at high efficiencies. A coolant in the small places between the PV cells captures and sequesters any unconverted solar gains. This heat can either be vented, applied to heating demands, or applied to domestic hot water and absorption or adsorption cooling cycles via hydronic circuits.

Technology History:

IC Solar was developed by the Center for Architecture Science and Ecology at Rensselaer Polytechnic Institute (RPI), with assistance from the Building Technologies Office, the New York State Energy Research and Development Authority (NYSERDA), and the Empire State Development's Division of Science, Technology and Innovation (NYSTAR). RPI has established multiple collaborations with architectural and building industry organizations, resulting in the first commercial installation of IC Solar slated for 2017, in the expansion of the Fashion Institute of Technology, New York City, as well as multiple new construction commercial building opportunities. ICSF was commercialized in 2015 and is licensed by HeliOptix, LLC.

Applications:

- Integrates into building envelope (façade, clerestories, roof, and atria) to enhance daylighting, reduce solar gains, generate electricity, and control heat transfer.

Capabilities:

- Provides diffuse daylighting, reduces glare.
- Generates electricity (185 Wp/m^2 at concentrating standard operating conditions) and hot water (235 Wp/m^2).
- Reduces solar transmittance through glazing by 70-90%.

Benefits:

- Reduces a building's cooling and lighting requirements and generates power at near-peak time to reduce electricity costs.
- Modular design easily integrates with a variety of existing or new designs.
- Reduces emissions by using renewable solar energy to meet building electrical and thermal loads.

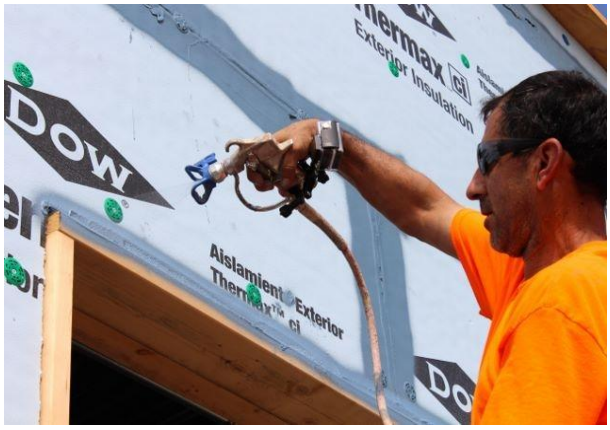
Learn More:

- Project Page

Contact Information:

HeliOptix LLC
233 Broadway 11th Floor
New York, NY 10279
www.helioptix.com

LIQUIDARMOR™ CM: Advanced Energy-Saving Flashing and Sealant for Buildings



LIQUIDARMOR™ CM Provides Advanced Moisture and Air Sealing Protection

Air leakage occurs when outside air enters and conditioned air leaves a building through cracks and joints in the skin of the building. Air leakage also contributes to moisture problems that can affect occupants' health and a structure's durability. Reducing the amount of air that leaks in and out of homes or businesses is one of the most cost-effective ways to lower energy consumption, cut heating and cooling costs, improve durability, increase comfort, and create a healthier indoor environment.

LIQUIDARMOR™ CM, developed by Dow Chemical, is an advanced sealing technology which has the potential to reduce energy losses related to air leakage by up to 50%. It is a one-step liquid flashing that can be brushed or sprayed on surfaces to seal gaps, cracks, and seams in the building envelope. Because it can be sprayed, LIQUIDARMOR™ CM can be installed as much as three to four times faster than tape, another common flashing method. The product's fluid nature also allows it to "fill" as well as "bridge" gaps, reliably achieving a high-quality seal even in areas with complex shapes and on rough openings where windows and doors are installed. Its elastomeric — or rubbery — liquid adheres well to most surfaces, even as buildings settle or adjust to wind pressures and changes in temperature.

LIQUIDARMOR™ CM was subjected to rigorous testing at Oak Ridge National Laboratory's (ORNL) Heat, Air, and Moisture (HAM) Penetration chamber to demonstrate its capabilities and validate its performance under challenging conditions. The HAM chamber, the only apparatus of its kind, can simulate indoor temperatures of 60°F to 90°F, outdoor temperatures of 0°F to 115°F, shifting pressures from wind and wind gusts up to ±30 PSF, and subject walls to 10% to 90% relative humidity.

Technology History:

LIQUIDARMOR™ CM was developed by Dow Chemical and evaluated at ORNL. The Building Technologies Office sponsored the ORNL-Dow collaboration through the US–China Clean Energy Research Center for Building Energy Efficiency, which supports the development of advanced technologies to reduce energy consumption and carbon dioxide emissions in the United States and China. In 2014, LIQUIDARMOR™ CM was commercialized in the U.S. It was recognized as an R&D 100 Award Finalist in 2015 and won the 2016 Gold Edison Award for Building Construction & Lighting Innovations.

Applications:

- Sealant and window flashing for commercial and residential wall systems.

Capabilities:

- Only one-step, sprayable liquid flashing on the market.
- 3 to 4 times faster to install than flashing tapes.
- Adheres to different substrates (i.e. concrete, steel, wood, aluminum, foam insulation, gypsum board).
- Easily conforms to complex geometries to form a tight, durable, seamless barrier along the rough openings of windows and doors.
- Penetrates and seals hard to reach gaps up to a ¼ inch wide without a supporting material.

Benefits:

- Reduced air leakage through the building envelope.
- Decreased energy use from heating and air conditioning systems.
- Reduced labor time and expenses for installation.

Learn More:

- BTO News Article
- BTO Success Story
- BTO Project Page

Contact Information:

The Dow Chemical Company
Dow Building Solutions
200 Larkin Center, 1605 Joseph Drive
Midland, MI 48674
www.building.dow.com

Lighting

Lighting consumes more than 2 quads of primary energy, which represented about 7% of the total energy use in the U.S. buildings sector in 2016.[30] This is equivalent to the total primary energy consumed by about 40 million homes.[31] Solid-state lighting (SSL) technologies offer one of the greatest opportunities for electricity savings in the building sector. By 2035, SSLs could cut electricity used for lighting in the U.S. by 75 percent, which would save some $50 billion worth of energy, or the equivalent of the total energy consumed by 45 million American homes today.[32]

BTO's SSL sub-program seeks to create a U.S.-led market for high-efficiency light sources that save energy, reduce costs, and have fewer environmental impacts than conventional light sources, all while creating jobs in the U.S. This sub-program focuses its efforts on accelerating innovation and product development, improving product efficacy and performance, reducing manufacturing costs, and overcoming technical challenges that inhibit market acceptance. These efforts result in energy saving SSL technologies, specifically inorganic light-emitting diode (LED) and organic light-emitting diode (OLED) technologies. Total LED installed penetration more than doubled between 2014 and 2015, representing 17.9% of the outdoor lighting market and 6.1% of the indoor lighting market.[33]

BTO accelerates the development and market acceptance of SSL by integrating three elements: competitive R&D, market-based technology advancement efforts, and market engagement. Through those activities, BTO seeks to commercialize products that achieve their 2020 goals: technologies with the collective potential to save approximately 2.8 quads of primary energy from a 2010 baseline.

DOE supported the development of individual components that have been incorporated into numerous commercial products. Consequently, the following technology summaries focus more broadly on DOE's partnerships with industry that have resulted in multiple commercialized products from 2010 to 2015. See Appendix A for a full list of commercialized SSL components.

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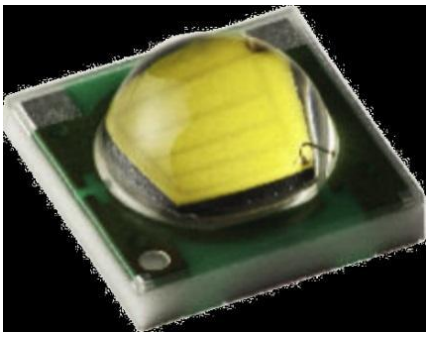
[30] U.S. Energy Information Administration. *Annual Energy Outlook 2016 with projections to 2040*. DOE/EIA-0383(2016). Washington, DC: U.S. Department of Energy, September 2016. https://www.eia.gov/outlooks/archive/aeo16/

[31] U.S. Energy Information Administration. 2009 Residential Energy Consumption Survey. Table CE1.1. Washington, DC: U.S. Department of Energy, 2012. Accessed August 7, 2016: http://www.eia.gov/consumption/residential/data/2009/index.cfm?view=consumption#summary.

[32] U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy. "DOE Solid-State Lighting Program: Modest Investments, Extraordinary Impacts." DOE/EE-1469, September 2016. Accessed October 21, 2016: http://energy.gov/sites/prod/files/2016/06/f32/ssloverviewbrochure_june2016.pdf.

[33] U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy. *Solid-State Lighting R&D Plan.* DOE/EE-1418, June 2016. Accessed October 21, 2016: http://energy.gov/sites/prod/files/2016/06/f32/ssl_rd-plan_%20jun2016_2.pdf.

Cree, Inc. LEDS and Lighting Products



CREE LEDs and lighting products deliver a wide portfolio of high-performance lighting solutions

Light-emitting diode (LED) lighting has the potential to be far more energy-efficient than conventional lighting technologies, and scientists, and engineers at Cree, Inc. are continually pushing the envelope of LED technology. These advances have found their way into millions of energy-saving products on the market in a wide range of applications like downlights, outdoor lighting, troffers, and replacement bulbs.

R&D projects supported by the Building Technologies Office (BTO) at Cree, Inc. have reduced the cost—and boosted and validated the performance—of LED chips, LED packaging, driver circuits, and entire lighting systems that, with further development, have proliferated into multiple Cree product lines at commercial production volumes. For example, Cree's first BTO-supported R&D project focused on then-novel designs that provided the foundation for a new generation of high-brightness LEDs: XBright® and XThin®. Another early R&D project contributed to the development of the highly successful EZBright® chip product line, which enabled nearly a doubling in efficiency and has become one of Cree's highest-volume product lines, proliferating into multiple technologies that can be found in numerous Cree, Inc. lighting products. More recently, a 2014 BTO-funded project took a comprehensive approach to lowering the cost of high-performance LED troffers by reducing the costs of various optical, thermal, and electrical subsystems without impacting performance.

The primary value of the Department of Energy funding has been to share the risk of exploring new areas of SSL R&D, which enables the company to be more aggressive than it might otherwise be in terms of leaving no stone unturned when looking for ways to move the technology forward. Over the past decade, Cree, Inc. more than tripled the efficiency of its blue EZBright chip, cut the cost of its driver by more than half, and lowered the cost of its lamps and luminaires by 90%.

Technology History:

Cree, Inc. was founded in 1987 to grow silicon carbide and use it in a variety of electronic devices to gain advantages in cost and performance. In 1989, the company commercialized its first LED, which was based on silicon carbide and used as an indicator light. Cree, Inc. entered the general-illumination LED market in 2004 and began making LED fixtures in 2007. Today, it makes a wide range of LED lighting products for multiple applications.

Applications:

- Cree LEDs are found in a wide range of lighting products, from replacement bulbs, to downlights, to troffers, to outdoor lighting

Capabilities:

- Highly energy-efficient
- Directional
- Dimmable
- Vibration-resistant
- Instant-on
- Color-tunable (in some cases)
- High-performing

Benefits:

- Reduces energy costs
- Cuts down on carbon emissions
- Reduces maintenance costs
- Reduces wasted light
- Provides excellent lighting quality
- Provides non-energy benefits such as improving health and productivity

Learn More:

- BTO Research Highlights Page
- BTO Research Highlights Page
- BTO R&D Impacts Success Story

Contact Information:

Cree, Inc.
4600 Silicon Drive
Durham, NC 27703
www.cree.com

Veeco MaxBright® MOCVD Multi-Reactor System for LED Manufacturing

Veeco LED manufacturing equipment drive down the cost of LEDs and accelerate adoption

A critical step in the manufacture of light-emitting diodes (LEDs) includes a process called metal organic chemical vapor deposition (MOCVD), which deposits light-emitting semiconductor layers onto a substrate wafer that is processed into LED chips. In order to lower the manufacturing cost and increase the quality of high-brightness LED chips, Veeco Instruments, Inc sought to make innovative improvements to its MaxBright® MOCVD Multi-Reactor System, used by LED manufacturers around the world.

With the help of Building Technologies Office (BTO) funding, Veeco Instruments, Inc. partnered with Sandia National Laboratories and Philips Lumileds on several enhancements to its MaxBright® system that improved temperature measurement and control methods to increase yield. For example, Veeco Instruments, Inc. developed an advanced wafer carrier design offering a 14x4" configuration (i.e., holding 14 4-inch wafers, compared with the standard 12x4" wafer carrier) to increase the capacity, and revised pocket shaping, in which the wafer holders are contoured to increase temperature uniformity. The introduction of optimized pocket shaping resulted in a wavelength uniformity improvement of 24%.

All told, Veeco Instruments, Inc.'s enhanced MaxBright® tool can reduce an LED manufacturer's MOCVD costs by more than 30% by improving throughput, growth uniformity, yield, and temperature stabilization. These innovations have helped Veeco Instruments, Inc. increase its global market share from ~25% in 2009 to more than 60% in the face of stiff foreign competition—an increase that actually brought overseas business to the U.S. and helped Veeco Instruments, Inc. remain a leading fabrication equipment supplier for the global LED market. Veeco Instruments, Inc. credits BTO funding with having accelerated the company's ability to commercialize cheaper MOCVD tools with significantly higher productivity and yield than previous generations, which enabled its global customers to make lower-cost LEDs and drive LED lighting adoption. The average price of an LED bulb was about $50 in 2010 but, aided by Veeco Instruments, Inc.'s MOCVD technological advancements, was near $10 in 2014 and is expected to drop as low as $5 by 2020.

Technology History:

Veeco Instruments, Inc. received one of DOE's first awards under the Solid-State Lighting Manufacturing Initiative, launched in 2009 with funds from the American Recovery and Reinvestment Act. The project concluded in 2012.

Applications:

- Manufacturing LEDs

Capabilities:

- Reduces MOCVD cost by more than 30%
- Improves LED wavelength uniformity by 24%
- Increases LED wafer yield to about 90%
- Reduces epitaxial process cost twofold

Benefits:

- Lowers the cost of manufacturing high-brightness LEDs by improving throughout, growth uniformity, yield, and temperature.

Learn More:

- BTO Research Highlights Page
- BTO R&D Impacts Success Story

Contact Information:

Veeco Instruments, Inc.
1 Terminal Drive
Plainview, NY 11803
www.veeco.com

WhiteOptics® Advanced Coatings: WhiteOptics Reflector Coating for LED Fixtures

LED luminaire parts coated with WhiteOptics' high-reflectance composite

Light management elements are critical to any light fixture. Reflector coatings boost the efficiency of light-emitting diode (LED) fixtures by directing light to where it's needed and away from where its services are wasted; fewer LEDs are needed for illumination, which reduces lighting costs. *WhiteOptics*® manufactures low-cost, high-reflectance white coatings and applies them to film and metal for use in luminaires, to improve efficiency and light distribution. The company's customers are primarily indoor fixture manufacturers.

Thanks to research partially funded by the Building Technologies Office, *WhiteOptics*® was able to increase the overall reflectance of its composite coating, scale up its low-cost production methods, and complete long-term accelerated durability testing. The result was a highly successful commercial product that can be applied to many different types of surfaces, which is now used in hundreds of fixtures by many designers and manufacturers.

WhiteOptics® Advanced Coatings are typically used in new, cutting-edge fixtures that today are primarily LEDs. By maximizing light reflection, this coating can increase fixture output by 10%–30% over standard reflector materials. These coatings are especially well-suited to LED lighting because they're not only highly reflective, but also highly diffuse, so they scatter the light efficiently, softening it and reducing "hot-spot" imaging and glare without exaggerating the LED's actual brightness. Because of the coating's high (97%) reflectance, which improves overall optical efficiency by 15%, the same light output can be achieved with 15% fewer LEDs. This increases energy efficiency, reduces cost, and extends luminaire lifetime by reducing system temperatures. These coatings are applicable to many luminaire designs, offering an overall system cost-improving solution for LED optics.

Technology History:

WhiteOptics® got its start in 2009 and commercialized its first product in 2010. That same year, the company received a Department of Energy research grant enabling it to develop and perfect its new coating technology.

Applications:

- Used to improve the efficiency and reduce the cost of LED lighting fixtures

Capabilities:

- 97% reflective
- Improves overall optical efficiency of fixtures by 15%
- Can increase fixture light output by 10%-30%

Benefits:

- Boosts LED fixture efficiency while reducing costs

Learn More:

- BTO Research Highlights Page
- BTO R&D Impacts Success Story

Contact Information:

WhiteOptics LLC
243-G Quigley Blvd.
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www.whiteoptics.com

Lumileds' LUXEON® LEDs

Lumiled LED products enable the next generation of lighting solutions

Light-emitting diodes (LEDs) have come a long way in the past decade, but industry experts agree there is still significant room for further improvements. Scientists and engineers at Lumileds are working at the cutting-edge of LED technology to improve its efficacy and performance.

Building on Lumileds' innovative approach, R&D projects supported by the Building Technologies Office (BTO) have boosted many aspects of LED performance and lowered their cost. These improvements often map into multiple Lumileds product lines, which to date have been incorporated into millions of LED lighting products on the market. LUXEON® M LED, for instance, has been successfully commercialized in a wide range of products, including the first LED bulb with the same luminosity of a 100-watt incandescent lightbulb to qualify for an ENERGY STAR® rating. This project's concept was also carried over to Lumileds' LUXEON® T and LUXEON® TX families of LEDs.

Another BTO-funded Lumileds project led to the development of a high-power "warm-white" LED package for high-efficacy, high-color-rendering products, which leveraged the experience gained from making the L Prize®-winning bulb. Yet another project evaluated various LED substrate technologies that could reduce manufacturing costs, which ultimately identified patterned sapphire as the most effective approach. This finding led to the development of a whole family of LUXEON® "FlipChip" LEDs. Building on that approach, a subsequent 2015 BTO-funded project industrialized the fabrication of patterned-sapphire-substrate LEDs, and by optimizing part of the manufacturing process, reducing costs by up to 30% and cutting down on the need for labor-intensive operations.

The primary value of the BTO funding has been to enable disruptive innovations in product development and manufacturing, which have helped make Lumileds a leader in LED technology and the worldwide LED market and spur the adoption of energy-saving LED lighting. In the past six years alone, the performance of Lumileds' warm-white high-power LEDs has more than tripled, while the price has dropped by a factor of six.

Technology History:

More than 200 Lumileds product stock keeping units have been impacted by BTO funding. The result of a partnership between Agilent Technologies and Philips, Lumileds became Philips Lumileds in 2005 and in 2014 was spun off to become Lumileds.

Applications:

- Lumileds LEDs are found in the full spectrum of lighting applications

Capabilities:

- Highly energy-efficient
- Directional, Dimmable, and Vibration-resistant
- Instant-on
- Color-tunable (in some cases)
- High-performing

Benefits:

- Reduces energy costs
- Cuts down on carbon emissions
- Reduces maintenance costs
- Reduces wasted light
- Provides excellent lighting quality
- Provides non-energy benefits such as improving health and productivity

Learn More:

- BTO Research Highlights
- BTO Research Highlights
- BTO Research Highlights
- BTO Research Highlights
- BTO Research Highlights
- BTO R&D Impacts Success

Contact Information:

Lumileds
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L Prize® LED Lighting Competition

The L Prize® spurs technology innovation and quality performance

Lighting accounts for one-fifth of the electricity consumed in the United States, and most lighting products are far from energy-efficient. That's why, at the behest of Congress, the Building Technologies Office launched the L Prize® competition in 2008. The goal was to challenge the lighting industry to develop high-quality, high-efficiency light-emitting diode (LED) lighting products and stimulate market adoption. At that time, most LED replacement bulbs were of poor quality and wouldn't satisfy consumers who were looking to replace an incandescent bulb.

In August 2011, Philips Lighting North America was declared the L Prize® winner in the category of an LED replacement for the 60-watt incandescent bulb. The color quality, light distribution, and light output of Philips' product was comparable to a 60-watt incandescent bulb, but it consumed less than 10 watts (an energy savings of 83%) and was still going strong after 25,000 hours of testing, whereas incandescent bulbs burn out after 1,000-2,000 hours.

Philips' entry helped catalyze market competition and pushed the industry toward a clear target for consumer satisfaction and success. As a result, prices dropped and performance improved to the point where there are now many competitive LED 60-watt replacement bulbs on the market. Advances developed by Philips for the L Prize® have had a lasting impact on the company's LED offerings. Philips estimates that this family of products accounted for more than $51.3 million in energy savings in the first two years alone and that the L Prize competition accelerated its efforts three to five years ahead of where they would otherwise have been. The competition has also increased knowledge about LED lighting technology's capabilities, through long-term testing conducted on the Philips product.

Technology History:

In late 2009, the L Prize® competition received Philips' entry, which then went through a rigorous 18-month evaluation that included field assessments by 31 utilities and energy efficiency organizations that had signed on as L Prize® partners. In August 2011, the Philips entry was declared the L Prize® winner in the 60-watt replacement category, and the product hit retail shelves on Earth Day, 2012.

Applications:

- LED replacement for the 60-watt incandescent bulb
- Technology developed for L Prize bulb utilized in other Philips LED lighting products

Capabilities:

- Emits 940 lumens
- Omnidirectional
- Durable
- Energy-efficient (97 lumens/Watt)
- Long life (> 25,000 hours)
- Dimmable
- Instant-on

Benefits:

- Reduces energy costs
- Cuts down on carbon emissions
- Could reduce maintenance costs
- Underlying technology improved a whole family of Philips LED lighting products

Learn More:

- L Prize Website
- BTO R&D Impacts Success Story

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Sensors and Controls

Improving building operations through sensors and controls could reduce energy consumption in buildings by up to a 30%, even without upgrading existing appliances, devices, and equipment.[34] BTO's Sensors and Controls sub-program concentrates on developing sensors and controls solutions to improve data collection, monitoring, and optimization of building systems and energy-consuming equipment; to better utilize building end uses to increase and enhance the penetration of energy efficiency and renewable generation at scale, and to unlock new building market and financial opportunities for owners, operators, and end uses. Sensors and controls that can automatically respond to, and even anticipate, changing conditions enable buildings to use energy optimally and help commercial building owners and managers better manage energy use with minimal input. Sensors can measure pre-defined variables and communicate with a building's control system to make predetermined decisions about a building's energy use. The controls then respond to those inputs to make real-time changes to the building's energy consumption.

Sensors and controls technologies can extend the life cycle of major building appliances and systems by allowing them to run consistently at optimal efficiency levels or detect and respond to faults. Low-cost sensors and controls present new opportunities to reduce energy costs and manage energy loads more effectively by keeping energy systems at their peak performances. Building energy systems can be managed to incorporate weather forecasts (e.g., to aid in balancing distributed generation), or respond to pricing signals from the larger energy system and contribute to its needs.

BTO's research areas of interest in this sub-program include low-cost, self-powered plug-and-play wireless sensor platforms with automated calibration, communication, and configuration as well as low-cost, fault-tolerant plug-and-play control systems with automated communication, configuration, and optimization.

[34] Roth, K.W., Detlef Westphanlen, Michael Y. Feng, Patricia Llana, and Louis Quatararo. *Energy Impact of Commercial Building Controls and Performance Diagnostics: Market Characterization, Energy Impact of Building Faults and Energy Savings Potential*. No. D0180, TIAX LLC, Cambridge, MA. November 2005. Accessed October 21, 2016, http://s3.amazonaws.com/zanran_storage/www.tiaxllc.com/ContentPages/42428345.pdf.

OpenADR Client: Distributed Intelligent Automated Demand Response (DIADR) Building Management System

Siemens OpenADR Client

Demand-side management strategies present an opportunity to improve energy efficiency in buildings across the nation. Demand response (DR), especially automated demand response (ADR), is a method to improve the efficiency of the whole electrical power grid, which could offer significant economic and environmental benefits. DR is a set of actions taken to reduce load when the electric grid's supply-demand balance is at risk of disparity or when market conditions raise electricity costs. ADR automatically signals from a utility or Independent System Operator (ISO)/ Regional Transmission Organization (RTO) to connect, in real-time, with its customers' end-use control systems and strategies. ADR technology is key to realizing sufficient DR adoption rates.[35] The Department of Energy estimates that if 20% of peak load can be reduced by 2019, it would result in an 188GW load reduction, which is equivalent to 367 medium sized power plants.[36]

Essentially, the OpenADR Client communicates with a demand response automation server (DRAS), per standard protocol, to send information and signals to switch electrical power-using devices off in periods of high demand. This highly flexible infrastructure facilitates the automation of customer and third party responses to various DR programs and dynamic pricing, so that utilities, ISOs, energy and facility managers, aggregators, and hardware and software manufacturers can optimize the energy system's performance.

With support from the Building Technologies Office (BTO), the University of California Berkeley, the Lawrence Berkeley National Lab (LBNL), and Siemens Corporation collaboratively demonstrated a distributed intelligent automated demand response server (DIADR) that reduced peak loads by 30% at a building on Berkeley's campus run by Siemens Apogee Insight building automation system. Utilizing the OpenADR protocol developed by LBNL, the team integrated an ADR system with a Siemens Smart Energy Box, which provided supervisory control and comprehensive demand-side energy management for lighting, plug load, and heating, ventilation, and air conditioning systems.

Technology History:

Siemens' OpenADR Client was developed and validated by Siemens Corporation, Corporate Technology, UC Berkeley, and LBNL with support from BTO. It was commercialized in 2011 by Siemens Building Technologies.

Applications:

- Facilitates automated demand response to reduce peak load on the power grid

Capabilities:

- Enables automated building demand response management
- Provides information exchange between building automation systems and utilities or ISO
- Agent based control network for central and distributed load controls

Benefits:

- Achieves up to 30% peak load shavings in commercial buildings
- Improves power grid efficiency through automated demand response
- Enables utility rebate qualification for commercial buildings, and provides a 5 year payback

Learn More:

- To date, several OpenADR certified products from Siemens and other vendors are available on the market (see list)

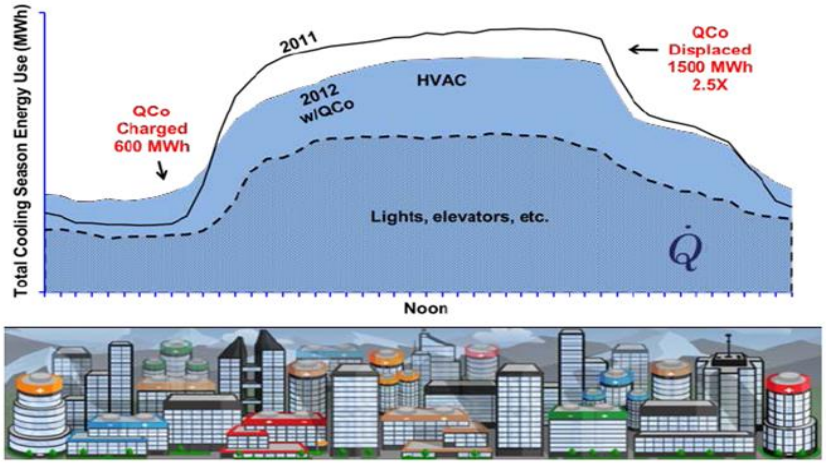
Contact Information:

Siemens Corporation
755 College Road East
Princeton, NJ 08540
www.usa.siemens.com/entry/en

[35] A. McKane, et. al, "ADR: The Missing Link in the Electricity Value Chain." 2008 ACEEE Summer Study on Energy Efficiency in Buildings.

[36] "A National Assessment of Demand Response Potential." 2009: https://www.smartgrid.gov/document/national_assessment_demand_response_potential_0#

Predictive Control Harnesses Building Thermal Mass as High Performance Energy Storage



QCoefficient's Energy Displacement Data for Willis Tower

In the U.S., heating, ventilation, and air conditioning (HVAC) systems use 48% of the total energy used in buildings, primarily during the summer.* HVAC system efficiencies have improved over the last several decades, but methods to manage energy demand have not been realized until recently. Thermal energy storage (TES) shifts all or a portion of a building's structural and equipment cooling needs to off-peak, night time hours when electricity prices are lower by employing passive and/or active strategies.

QCoefficient, Inc. (QCo) and the University of Colorado, with assistance from the Building Technologies Office, developed a system that utilizes large commercial building mass as a TES medium to optimize building load profiles. The system is a multi-objective optimization and predictive control algorithm. It analyzes the building's composition and the building's cooling demand profile, then re-schedules the peak uses for non-peak demand times for utility rate negotiation. The algorithm uses information about the building's existing HVAC efficiency characteristics under load, as well as short-term weather forecasts, electricity price data, and the building's energy profile (its size, structural materials, envelope characteristics, and occupancy) to devise an optimal TES/HVAC control strategy. The algorithm provides an operating strategy in advance without comprising occupant comfort and taking advantage of the energy storage embedded in the physical structure of the building—from its foundation to its furniture—to dynamically reshape the building cooling load profile.

Technology History:

QCo and the University of Colorado at Boulder developed this technology utilizing a building's mass as a TES medium to optimize the building load profile. The technology was commercialized in 2012 by QCo. It has been demonstrated in several large commercial buildings in downtown Chicago, Washington D.C., and Houston, including through the U.S. General Services Administration's Green Proving Ground Program. QCo is commercially deploying the technology through sales channel partners in several other large U.S. cities.

**2011 Buildings Energy Data Book (Table 1.1.4), U.S. DOE, March 2012.*

Applications:

- Offers portfolio optimization at grid scale to electric supplier, utilities, grid operators and building managers in commercial, campus. Shopping mall, mixed use, and airport building applications.

Capabilities:

- Optimizes large commercial building cooling operations via an automated, cloud-based control platform.
- Optimizes and coordinates a portfolio of such buildings, creating an energy asset in a grid-congested urban market.
- Targeted operation improves and accommodates occupant comfort.
- Achieves rapid deployment, within 4 weeks.

Benefits:

- Reduces site energy expense by 20–40%.
- 1-3 month payback by reducing energy cost with low installation and operating expenses.
- Reduces greenhouse gas emissions by reducing and shifting daytime energy use to the night.
- Improves grid efficiency and operation by reducing congestion and shifting demand to more efficient baseload plants.

Learn More:

- BTO Success Story

Contact Information:

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Building Energy Modeling

Building energy modeling (BEM) is the physics-based calculation of building energy consumption and is a multi-use tool for addressing building energy efficiency. It allows for a whole building examination of a building's design in order to optimize its systems to match its anticipated use and local conditions. BEM is primarily used by engineers and architects in the design of new buildings and deep retrofits. This includes the development of whole-building energy efficiency codes and standards (e.g. ASHRAE 90.1) and performance-path compliance with those codes (e.g. ASHRAE 90.1 "Appendix G" Performance Rating Method); beyond-code asset rating and labeling (e.g. the U.S. Green Building Council's LEED energy credit); and the development of prescriptive design guides (e.g. ASHRAE's 50% Beyond 90.1 Advanced Design and Retrofit Guides). Emerging use cases include the design of building control algorithms, continuous commissioning of building HVAC systems, and dynamic building control for energy reduction or for demand response.

BTO aims to accelerate the use of energy modeling in current and emerging use cases by continuing to develop open source tools such as EnergyPlus and OpenStudio®; test and validate energy modeling programs; advance capabilities through research and development; partner with leading organizations to support the energy modeling community; and provide technical support for BEM across BTO's portfolio. BTO estimates[37] that using energy modeling in the design phase of buildings could yield annual energy savings of 442 tBtu for newly constructed buildings and 230 tBtu for deep retrofits to existing buildings. By using EnergyPlus or other advanced engines, the potential savings jump to 590 tBtu for new construction and 306 tBtu for deep retrofits.[38]

Because EnergyPlus and OpenStudio® are both open-source products, they are not "commercialized" in the same way as other BTO-supported technologies. BTO continually updates and refines both products based on user feedback. BTO seeks to increase industry acceptance and uptake of these programs and of building energy models more broadly. The following section outlines the capabilities of each product, the major industry partnerships, and the depth of each project's market uptake.

[37] Farese, P.; Gelman, R.; Hendron, R. A Tool to Prioritize Energy Efficiency Investments. NREL/TP-6A20-54799. Golden, CO: National Renewable Energy Laboratory. Accessed August 22, 2014: http://www.nrel.gov/docs/fy12osti/54799.pdf

[38] U.S. Department of Energy. Building Technologies Office *Multi-Year Program Plan: 2016-2020.* Accessed September 14, 2016: http://energy.gov/eere/buildings/downloads/multi-year-program-plan

EnergyPlus Whole Building Energy Modeling Engine

EnergyPlus is the Department of Energy's (DOE's) open source building energy modeling engine, designed to embody the state-of-the-art in building energy modeling (BEM) knowledge and techniques in a comprehensive and robust tool. EnergyPlus implements detailed building physics to enable evaluation of low-energy designs and systems, including the ability to model sub-hourly time steps, combined solution of heat, air, and moisture transfer, component-level heating, ventilation, and air condition, and a programmable interface for modeling control sequences.

DOE's market strategy is for BEM is to provide EnergyPlus along with OpenStudio®—a software development kit for EnergyPlus —facilitating third-party development of BEM applications that target different use cases and constituencies. EnergyPlus has been adopted by software and service vendors and embedded in commercial products. Recent EnergyPlus based products include Sefaira Architecture and Systems, Autodesk's Insight360, NORESCO's CBECC-Com, and DOE's own Commercial Asset Score.

DOE releases EnergyPlus updates twice a year to include bug fixes and new features, as well as example files and full documentation. Since 2015, DOE has been using a web service to gather, prioritize, and refine feature requests from end users and software vendors. Recent feature sets include support for modeling homes—EnergyPlus has historically been used to model only commercial buildings—as well as data centers and computer rooms.

An analysis of 1,112 completed projects submitted to the AIA 2030 Commitment program demonstrates that, relative to a CBECS 2003 baseline, buildings designed using EnergyPlus consume 20% less energy than buildings designed using no modeling. Extrapolated to new commercial construction, use of EnergyPlus for design has the potential to save 896 tBtu per year by 2030.

Technology History:

DOE has funded the development BEM engines since the 1970s, before its ascension to a cabinet level department. EnergyPlus follows previous engines CAL-ERDA, DOE-1, and DOE-2. EnergyPlus has been in continuous development since 1997. The development team is led by the National Renewable Energy Laboratory and Lawrence Berkeley National Laboratory and includes other national labs (currently the Oak Ridge National Laboratory), competitively solicited development contractors at universities, and private firms.

EnergyPlus was relicensed as open source software in 2012. With the help of Autodesk Inc., it was also translated from a legacy FORTRAN implementation to a more modern C++ codebase. With significant help from OpenStudio®, EnergyPlus downloads have grown from just over 5,000 per version update in 2010 to over 35,000 in 2016.

Applications:

- Design of new buildings and retrofits
- Development of energy efficiency codes and standards
- Code compliance demonstration
- Beyond code energy savings calculations for ratings, certificates, and financial incentives
- Development of prescriptive energy-efficiency guidelines
- Design of building control algorithms
- Continuous commissioning and fault detection in HVAC systems
- Dynamic, model-predictive control

Capabilities:

- Models building energy consumption for heating, cooling, ventilation, lighting and plug and process loads

Benefits:

- For the design use case, yields 20% improvement in energy savings compared with buildings designed without energy modeling, projecting to 896 tBtus in potential energy savings per year by 2030
- Benefits of other use cases have not been quantified

Learn More:

- BTO Project Page
- BTO Peer Review

Contact

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OpenStudio® Energy Modeling Software Development Kit (SDK)

Whole-building energy modeling (BEM) is a multi-use tool for building energy efficiency. Use cases include design of new buildings and retrofits, development of and compliance with energy-efficiency codes and standards, asset rating and labeling, and development of prescriptive design guides, design of building control algorithms, continuous commissioning, and dynamic control. EnergyPlus is the Department of Energy's (DOE's) BEM engine. Designed to support these use cases, EnergyPlus has advanced capabilities, but also a detailed text-based interface that is cumbersome for both end users and third-party vendors who wish to embed EnergyPlus into applications.

To address this gap and spur EnergyPlus adoption among both end-users and developers, DOE's Building Technologies Office (BTO) and the National Renewable Energy Laboratory (NREL) developed OpenStudio, an open source cross-platform collection of software modules that can be combined in different ways to create different applications. The fundamental module is the OpenStudio Software Development Kit (SDK) which allows developers to access EnergyPlus inputs and outputs programmatically—by calling methods on objects—rather than by reading and writing files, improving productivity. OpenStudio includes a graphical application for model editing and result navigation that is usable by energy modelers and acts as a template for developers. Other applications that have been developed using the OpenStudio SDK include DOE's Energy Asset Score and Scout, NORESCO's CBECC-Com, NEEA's Spark, Concept3D's Simuwatt, and Xcel Energy's EDAPT.

One of OpenStudio's most unique and powerful features is Measures. OpenStudio Measures are small programs that can operate on OpenStudio models. Measures were first used to model transformation that correspond to ECMs, hence the name. But with full access to the model, simulation results, the local system and internet resource, Measures have been used to create custom reports and visualizations, to perform quality assurance checks, and to automate analysis workflows by connecting EnergyPlus to other tools. Recently, Measures have been released that automate the "code-baseline" transformation used in code-compliance and LEED. Over 200 Measures are now available on the Building Component Library.

A final module is OpenStudio Server, which allows OpenStudio users to leverage the cloud for cost-effective high-throughput simulation by using Measures to define a large simulation space quickly and systematically. OpenStudio Server supports parametric analysis, uncertainty analysis, optimization, and calibration.

Technology History:

OpenStudio began in 2008 as an EnergyPlus geometry creation plug-in for the 3D drawing tool SketchUp. It assumed its current form and strategic mission in 2011.

Applications:

- BEM application development with OpenStudio SDK
- Graphical editing, results navigation and small-scale parametric analysis with OpenStudio Application
- Large-scale analysis on the cloud with OpenStudio Server

Capabilities:

- Open source cross-platform collection of modules for BEM application development
- Support for EnergyPlus, Radiance, CONTAM, ESP-r, and CEN/ISO 13790 simulation engines.
- Flexible scripting facility "Measures" for task and workflow automation
- Cloud access for high-throughput simulation

Benefits:

- Rapid, low cost development of new BEM applications and analyses.
- Dynamic, shareable content and Measures on BCL
- Documentation, training materials, user and developer support

Learn More:

- BTO Project Page
- 2016 Peer Review

Contact

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Appendix A: Summary of Commercialized Solid-State Lighting Technologies as a Result of SSL Program Funding[39]

Manufacturer	Technology name	Product type (i.e., component, material)	Number of product offerings[40]	Description	Initial commercialization
Cree	LED package	LED component	12	Development of QX-B, QX-D chips	2014
Philips Lumileds	LED chip	LED component	5	Development of 100 lm/W 800 lumen warm white LED	2010
Philips Lumileds	LED chip	LED component	39	Development of 130 lm/W, 1000 lumen warm white LED	2012
Philips Lumileds	LED chip	LED component	8	Development of low cost, illumination grade LEDs	2013
Philips Lumileds	LED chip	LED component	2	Development of high power warm white hybrid LED package	2013
Philips Lumileds	LED chip	LED component	5	Development and industrialization of InGaN/GaN LEDs on patterned sapphire substrates	2015
Philips Lighting	L Prize LED replacement for 60W lamp	LED product	1	Development of L Prize-winning product with 90 lm/W, 900 lumens, CRI of 90, CCT at 2700-3000 K, less than 10 watts	2012
Philips Lighting	LED power supplies	LED power supplies	3	Development of high efficiency driving electronics for LED luminaires	2012
GE Lighting	Phosphor manufacturing method	LED product	15	Development of advanced red phosphor material and manufacturing method, used in multiple energy-efficient GE lighting products	2012
Lightscape Materials	Phosphor product	Materials	2	Development of 2 phosphor products that are used as downconverters in LED packages	2011
WhiteOptics	Coating product	Materials	15	Development of low-cost, stable, highly reflective coating material used in thousands of LED products	2013

[39] As of September 1, 2016, for more information, see http://energy.gov/eere/ssl/downloads/solid-state-lighting-commercial-product-development-resulting-doe-funded-projects

[40] Numbers reflect products directly developed or enabled by DOE SSL Program funding, and do not reflect millions of derivative, influenced, or next-generation products.

Veeco Instruments, Inc.	Metal organic chemical vapor deposition (MOCVD) tool	Manufacturing tool	3	Development of 3 product features used to improve Veeco Instruments, Inc.'s state-of-the-art MOCVD tool to produce LED wafers	2012
Ultratech	Lithography tool	Manufacturing tool	1	Development of low-cost lithography tool for manufacturing high-brightness LEDs	2012
KLA Tencor	Inspection tool	Manufacturing tool	1	Development of inspection tool for monitoring incoming sapphire substrates, to reduce defective parts and increase yield	2012
Total			**112**		

Appendix B: BTO-Supported Technologies that were previously commercialized but not individually profiled

Technology Type	Manufacturer	Product	Initial commercialization	Reason for No Profile
HVAC	Hi-Z Technology, Inc.	Thermoelectric Materials for Waste Heat Recovery	2015	Company product no longer on the market
Windows	Southwall Insulating Glass LLC	Low-Cost R10/High SHGC Heat Mirror® Window Development	2013	Company product no longer on the market
SSL	Philips	XQ series of LEDs; Philips Lumiled's LUXEON TX LED package	2014	Represented in Lumiled technology profile
SSL	Philips	Efficient LED System-in-Module for General Lighting	2011	Represented in Philips profile
SSL	Philips	LUXEON A and LUXEON S: Warm White Illumination-Grade LED	2011	Represented in Philips profile
SSL	Redwood Systems Inc.	Lighting Power and Control Network for SSL Systems	2010	Not enough data
HVAC & R	Sunlight Direct LLC	Hybrid Solar Lighting	2009	Out of scope for this report
HVAC & R	EchoFirst, Inc., a SunEdison Company	Echo: A Hybrid Solar Electric/Thermal System	2009	Out of scope for this report
SSL	Philips	Integrated, Solid-State LED Luminaire for General Lighting	2009	Out of scope for this report
SSL	Energy Focus, Inc.	Ballast/Drive Technology for Metal Halide or Solid-State Lighting Systems	2009	Out of scope for this report
Water Heating	GE Company	GeoSpring Hybrid Water Heater	2009	Out of scope for this report
Heat Pump	Bard Manufacturing Company, Inc.	Quiet Climate 2: Efficient Heat Pump for Classrooms	2008	Out of scope for this report
Envelope	ORNL	Next-Generation Envelope Materials	2007	Out of scope for this report
SSL	ELB Electronics	Adapting Wireless Technology for Lighting Control	2007	Out of scope for this report
Windows	SAGE Electrochromics, Inc.	SageGlass Electrochromic Windows	2007	Out of scope for this report
Controls	NorthWrite, Inc.	Wireless Infrastructure for Performance Monitoring, Diagnostics, and Control in Small Commercial Buildings	2006	Out of scope for this report
SSL	Cree	High-Efficiency LED Lamp for Solid-State Lighting	2006	Out of scope for this report
Water Heating	A. O. Smith Corporation	Vertex Residential Gas Condensing Gas Water Heater	2006	Out of scope for this report

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