# Appendix C – GPRA06 Building Technologies (BT) Program Documentation

# Introduction

**Table 1** outlines the activities characterized for the GPRA06 Building Technologies Program. Characterizations and inputs for these activities were provided to the Department of Energy's (DOE's) Office of Energy Efficiency and Renewable Energy (EERE) as inputs to EERE's integrated modeling effort.

Often such analysis requires the development and use of enabling or simplifying assumptions. In many cases, no citable sources exist for substantiating assumptions. Therefore, assumptions are developed through an iterative process with project managers, project contractors, and GPRA analysts. Often, we base these assumptions on project knowledge and experience, as there are varying degrees of corroborative studies available on which project information can be substantiated, depending on the maturity of the project. Enabling assumptions are sometimes relatively crude and should be revisited annually as new and better data are developed.

**Table 1. Building Technologies Subprograms, Projects, and Activities**

| Subprogram | Project | Activity |
|---|---|---|
| Residential Buildings Integration | Research & Development: Building America | Research & Development: Building America |
| | Residential Building Energy Codes | Residential Building Energy Codes |
| Commercial Buildings Integration | Research & Development | Research & Development |
| | Commercial Building Energy Codes | Commercial Building Energy Codes |
| Emerging Technologies | Lighting R&D | Lighting R&D: Controls |
| | | Solid State Lighting |
| | Space Conditioning & Refrigeration R&D | Refrigeration R&D: Unitary DX System |
| | | Refrigeration R&D: Ventilation Load Reduction |
| | | Refrigeration R&D: Commercial Refrigeration |
| | | Refrigeration R&D: Remote Fault Detection and Diagnostics |
| | Appliances & Emerging Technologies R&D | Appliances & Emerging Tech R&D: Roof Top AC |
| | | Appliances & Emerging Tech R&D: Recessed Can Lights |
| | | Appliances & Emerging Tech R&D: R-Lamp |
| | Building Envelope R&D: Window Technologies | Window Technologies: Electrochromic Windows |
| | | Window Technologies: Superwindows |
| | | Window Technologies: Low-E Market Acceptance |
| | Analysis Tools and Design Strategies | Analysis Tools and Design Strategies |
| Equipment Standards and Analysis | Equipment Standards and Analysis | Standards: Commercial Unitary AC/HP |
| | | Standards: Distribution Transformers |

# 1.0 Residential Buildings Integration

The long-term goal of Residential Buildings Integration is to develop cost-effective designs for net Zero Energy Buildings (ZEB)—houses that produce as much energy as they consume on an annual basis—by 2020.

## 1.1 Residential Building Energy Codes

### 1.1.1 Target Market

**Project Description.** The Residential Building Energy Codes project improves the minimum or baseline energy efficiency of new residential buildings requiring code permits. The project promulgates upgraded energy-efficiency requirements for residential buildings. Similarly, the project works with model energy code groups to upgrade the energy-efficiency requirements of their codes. Federal, state, and local jurisdictions then adopt and implement these upgraded federal and model energy codes. The long-term goal is to improve the minimum energy efficiency by 20% to 25% in new low-rise residential building construction.

**Market Description.** The market includes new residential low-rise buildings three stories or less in height and all additions and renovations to buildings requiring code permits.

**Size of Market.** Each year, nearly 1.6 million residential building permits are issued, approximately 80% of which are single-family dwellings. Although not all jurisdictions currently have energy efficiency building codes in place, the Pacific Northwest National Laboratory (PNNL) estimates that about half of all new residential construction comes under building energy code requirements. Also, consumers spend several billion dollars a year on remodeling and renovating projects in private residences, about half of which could be covered by an energy code. One market not covered by codes is manufactured homes, which fall under Housing and Urban Development (HUD) jurisdiction and regulations.

**Baseline Technology Improvements.** Initial compliance with new codes was assumed to be lower in the base case, i.e., without the Building Energy Codes project, than with the project. For FY06, the percentage of potential savings, in the first year of the single future code, was assumed to be approximately 35% for heating and cooling measures without the project.

**Baseline Market Acceptance.** Under the baseline scenario, 23 states were assumed to have adopted the IECC 2000 or IECC 2003 standard by the end of 2005. The GPRA estimates were partly based on states' accelerated schedule of adoption of the IECC 2000 and IECC 2003 codes. Through the efforts of the Building Energy Codes project, 31 states were assumed to have adopted the 2000 or 2003 standard by the end of 2005. The project was assumed to accelerate the adoption of the standard by an average of three years nationwide.

### 1.1.2 Key Factors in Shaping Market Adoption of EERE Technologies

**Price.** PNNL assumed a five-year payback period on investment to develop incremental investment costs (i.e., an annual energy cost savings of $1 implies an initial investment of $5).

This corresponds to a total incremental cost of approximately $120 million in 2010, $285 million in 2020, and $300 million in 2030.

**Key Consumer Preferences/Values.** The following nonenergy characteristics were not considered.

- Improved environment and more comfortable buildings.
- Lower home maintenance and repair activities
- Reduced pollution due to the reduced burning of fossil fuels and electricity generation, which improves air quality and mitigates the negative impacts of global warming.

### 1.1.3 Methodology and Calculations

**Inputs to Base Case.** With respect to codes, it is indeterminate as to whether potential future code improvements are incorporated into the National Energy Modeling System (NEMS) base case. The NEMS-GPRA06 base case does include some improvements to the building shell efficiency; however, the basis for these improvements (e.g., general building practice improvements, changes in codes requirements, improvements in materials) is not specified by the Energy Information Administration (EIA). Codes that have been issued (but that have not gone into effect) may be included in the NEMS-GPRA06 base case, but would not be included in the GPRA forecast of savings for the code development activity, because it no longer would be funded. Only an estimate of potential future codes is included in the GPRA estimates. Therefore, PNNL did not provide inputs to change the base case assumptions for the program markets.

**Technical Characteristics.** The FY 2006 GPRA estimates are based on increased compliance with existing codes, accelerated adoption of the 2000 edition of the International Energy Conservation Code (IECC) code (to comply with Section 304 of the Energy Conservation and Production Act), and the future development of more stringent building codes. The energy-savings methodology was applied at a state level to better link changes in the national codes (e.g., IECC 2000) with variations in climate by states (and differences among states) in their adoption and enforcement of building codes. This discussion uses national averages of some of the key assumptions related to adoption and compliance to help summarize the methodology.

The principal difference between the 1995 Model Energy Code and the IECC 2000 involves the solar heat gain requirements for windows and increased thermal resistance requirements for ducts in unconditioned spaces. Based on a series of simulations for various U.S. locations, the percentage reduction in cooling load was estimated to be about 15%. This requirement increases the heating load by a small amount, about 2% nationally. The requirement itself is restricted to the southern tier of states. The GPRA estimates were partly based on states' accelerated schedule of adoption of the IECC 2000 and 2003 codes. Through the efforts of the Building Energy Codes project, 31 states were assumed to have adopted the standard by the end of 2005. The project was assumed to accelerate the adoption of the standard by an average of three years nationwide.

The IECC's ongoing activities were assumed to lead to more stringent residential standards in the future. The Department of Energy (DOE) was assumed to play a major role in developing the analytical and economic basis for such standards. For the GPRA process, these activities were subsumed in a single upgrade of the IECC standard assumed to become available in the latter part of the current decade. Based on discussions with EERE-Building Technologies (BT) staff, PNNL assumed that the results of these upgrades were to reduce heating and cooling loads in new residential structures by 10%. Without these activities, PNNL assumed that the same standard would be adopted, on average, three years later.

> *Relationship to WIP*. EERE's efforts to support building codes covers two aspects: 1) the development of new codes with greater stringency or ease of enforcement and 2) activities to improve the compliance with codes and to accelerate adoption of the most recent codes by states and localities. The development of new codes is supported by the Building Technologies Program, and efforts to improve compliance and accelerate adoption are supported in the Weatherization and Intergovernmental Program (WIP). The methodology to develop the total effect from these two EERE programs is integrated. The documentation below discusses both aspects of EERE activities with regard to energy codes.
>
> More explicitly for modeling purposes, the GPRA energy savings estimates for BT (in regard to codes) is restricted to the development of a single new national residential code, expected to be published in the latter part of the current decade. However, with the ongoing efforts to promote adoption and compliance, the impact of the published code would be modest. However, without development of a new code, activities to promote adoption and compliance would be meaningless. Thus, the issue becomes assignment of savings from future code between the BT and WIP programs. In the GPRA estimates for 2006, 50% of the savings attributable to accelerated adoption and increased compliance of the new code were allocated to the BT program.

**Expected Market Uptake.** The project's activities also were assumed to improve compliance rates for codes currently adopted by states and localities, as well as future building codes. Compliance increases through better familiarity with the codes, simplifications to the code while maintaining stringency, and the availability and increased use of compliance tools by builders and enforcement officials. Compliance rates, with and without the project, were estimated for various standards as discussed above. Compliance with the several key provisions in the IECC 2001 and 2003 (compared with the 1995 Model Energy Code) was expected to be higher from the outset. On average, compliance was estimated to be 68% in the year of the adoption. By 2010, compliance rates were assumed to increase to 69% without the project and 74% with the project. For homes that do not comply with the standard, only half of the incremental energy savings were assumed to be achieved by adopting IECC 2001 or 2003.

The analysis assumed that when states first adopt the new standard (assumed to become available in the 2006-2007 time frame), the potential energy savings from moving to the new standard would be 85% at the time of adoption, increasing to 90% with the effect of the project after the first 10 years.

## 1.2 Research and Development: Building America

### 1.2.1 Target Market

**Project Description[1,2].** The project's long-term goal is to develop integrated cost-effective whole-building strategies to enable residential buildings to use up to 70 percent less total energy than current code-compliant buildings by 2020 and provide up to 30% in additional energy savings through the use of integrated onsite power systems.[a] BT also will develop techniques to integrate new home energy efficiency and onsite power technology into existing homes to improve the energy efficiency of existing homes by up to 30 percent. In addition, user-friendly residential control packages are expected to be designed that interconnect and drive all components and reduce summer peak energy consumption by 100 percent when needed and annual energy consumption by 10-20 percent, by 2025.

**Market Description [1]:** The target market primarily includes all new residential homes. The new home energy conservation approaches will also be tested and demonstrated in existing homes beginning FY 2006, however the impacts on existing homes were not modeled for the FY 2006 effort.

**Size of Market[4]:** Each year about 1.2 million new housing units are built. In 2002, 976,000 new single-family homes were built. These units are primarily owner occupied.

**Market Introduction:** Initial penetration of zero-net energy designs began in the southwest in 2003 and the design approach is anticipated to expand into the northern climate zones beginning in 2008[5]. The renewable technologies supported by this project currently exist; however, penetration into the general market is expected to continue to be extremely low without DOE funding because the technology is currently unaffordable for production home builders. PNNL assumed that Building America activities would not occur without DOE funding; therefore, no acceleration of market acceptance was modeled.

**Baseline Technology Improvements.** For this analysis, PNNL did not suggest any changes in technology improvements, apart from the EIA baseline.

### 1.2.2 Key Factors in Shaping Market Adoption of EERE Technologies

**Key Consumer Preference/Values – Nonenergy Benefits**. The cost and performance characteristics were used to model this project in NEMS-GPRA06/MARKAL-GPRA06. The following nonenergy characteristics were not considered in the model:

- Improved comfort, durability, and occupant health from better indoor air quality
- Reduced on-site generated waste
- Better sustainability
- Reduced maintenance.

### 1.2.3 Methodology and Calculations

For any one year, the Building America project's energy savings are calculated by multiplying the number of homes built with Building America techniques that year multiplied by the percent

a Whole house energy savings are measured relative to the BA Research Benchmark Definition (Building America, Building America Research Benchmark Definition, Version 3.1, November 11, 2003, National Renewable Energy Laboratory) which consists of the 2000 IECC requirements plus lighting, appliances and plug load energy levels (www.buildingamerica.gov) savings per home. Added to this are the energy savings, accrued in that year, for Building America homes built in previous years, beginning in 2006.

Incremental costs for whole-building energy savings were developed with Navigant Consulting's Residential Optimization Model (Version 5.7). Cost increments were developed for three levels of percentage savings from the baseline: -40%, -60%, and -70%. PNNL assumed that half of the costs and corresponding savings for the first level (equivalent to 20% savings from the baseline) would occur as a result of other related programs in EERE, namely appliance standards, building codes, and Energy Star homes. Thus, the savings percentages with Building America are translated to 20%, 40%, and 50% of the baseline unit.

The ROM simulations were conducted for four cities: Minnesota, Boston, Atlanta, and Phoenix (see **Table 2**). Population weights to develop a national average were assigned in rough fashion (see **Table 3**). Because the NEMS shell module only treats heating and cooling, the energy savings from the inputs shown in **Table 2** will underestimate the potential savings from BT's Residential R&D program. NEMS does produce the number of new homes that are deemed to use one of the five shell packages available in the model. Assuming the same cost and performance of the technologies not modeled specifically in the shell module, the total savings would be roughly three times that shown in the model (i.e., 1.00/0.30 = 3.33). These other savings would occur in lighting, water heating, and other appliances in homes building to Building America criteria. The challenge for the integrated modeling effort is to try to incorporate these additional savings, with a link to the number of homes using shell package four or five (as shown in **Table 4**).

The Building America program is assumed to result in cost reductions in various residential technologies. The impact of this aspect of the program is shown in Shell package #5. Starting in 2010, the overall cost of the package is assumed to be 10%, falling by an additional 10% every five years.

**Table 2. ROM Simulation Results for Representative Cities**

| | | Minneapolis | | Boston | | Atlanta | | Phoenix | |
|---|---|---|---|---|---|---|---|---|---|
| Cost Impact | | | | | | | | | |
| All Technologies | Building America | Total Cost | Delta Cost | Total Cost | Delta Cost | Total Cost | Delta Cost | Total Cost | Delta Cost |
| Base | | $46,499 | | $25,164 | | $22,884 | | $28,384 | |
| 20% | | | | | | | | | |
| 40% | 20% | $48,297 | $899 | $27,373 | $1,105 | $24,818 | $967 | $29,646 | $631 |
| 60% | 40% | $51,543 | $5,044 | $30,793 | $5,629 | $28,376 | $5,492 | $32,671 | $4,287 |
| 70% | 50% | $62,467 | $15,968 | $39,880 | $14,716 | $39,784 | $16,900 | $40,112 | $11,728 |
| | | | | | | | | | |
| Energy Use | | MMBtu/HH | | MMBtu/HH | | MMBtu/HH | | MMBtu/HH | |
| Base | | 214.9 | | 191.7 | | 164.2 | | 176.0 | |
| 20% | | 172.0 | | 153.4 | | 131.3 | | 140.8 | |
| 40% | | 129.0 | | 115.0 | | 98.5 | | 105.6 | |
| 60% | | 107.5 | | 95.9 | | 82.1 | | 88.0 | |
| 70% | | 64.5 | | 57.5 | | 49.3 | | 52.8 | |

**Table 3. Population Weights and Incremental Costs for Representative Cities**

| City | Weight | Incremental Costs, Building America 20% | 40% | 50% |
|---|---|---|---|---|
| Minneapolis | 0.2 | $899 | $5,044 | $15,968 |
| Boston | 0.3 | $1,105 | $5,629 | $14,716 |
| Atlanta | 0.3 | $967 | $5,492 | $16,900 |
| Phoenix | 0.2 | $631 | $4,287 | $11,728 |
| Average * | | $927 | $5,203 | $15,024 |
| HVAC share ** | 0.3 | $278 | $1,561 | $4,507 |

*Costs for percentage reduction in whole-building energy use
**Costs for percentage reduction in heating and cooling consumption

**Table 4. Suggested Adjustments to NEMS Shell Factors**

| *Heating Shell Efficiency Adjustments (multiplicative factors)* | | | | | | |
|---|---|---|---|---|---|---|
| Package | 2003 | 2005 | 2010 | 2015 | 2020 | 2025 |
| 4* | 1.00 | 0.80 | 0.80 | 0.60 | 0.50 | 0.50 |
| 5* | 1.00 | 1.00 | 0.80 | 0.60 | 0.50 | 0.50 |
| *Cooling Shell Efficiency Adjustments (multiplicative factors)* | | | | | | |
| Package | 2003 | 2005 | 2010 | 2015 | 2020 | 2025 |
| 4 | 1.00 | 0.80 | 0.80 | 0.60 | 0.50 | 0.50 |
| 5 | 1.00 | 1.00 | 0.80 | 0.60 | 0.50 | 0.50 |
| *Shell Cost Adjustment Factors (Amount Subtracted)* | | | | | | |
| Package | 2003 | 2005 | 2010 | 2015 | 2020 | 2025 |
| 4 | 0 | -$278 | -$278 | -$1,561 | -$4,507 | -$4,507 |
| 5 | | | -$223 | -$1,093 | -$2,704 | -$2,254 |

* Packages 4 and 5 represent Building America
** Costs are incremental, above the baseline

PNNL refined the target market to reflect new home sale prices because homes built with renewable energy technologies will be targeting the higher-end housing market. Based on U.S. Census[6,7] data, PNNL assumed that high-end homes would be represented by those new homes that sold for at least $200,000 in the South and West regions (about 45% of new homes sold in those regions) and Northeast and Midwest regions (about 48% of new homes sold in those regions).

The fundamental premise leading to wide adoption is that existing technologies and projects will eventually reduce energy use by about 70% and reduce summer peak loads to zero. This, in turn, will result in significantly less solar electric and solar thermal technology needed to supply the home's load, while shaving summer peak loads and thereby alleviating some of the need to expand the grid to accommodate system summer peaks. With much improved load characteristics, DOE expects zero-net energy houses through 2007 to receive slightly lower electric rates or utilize time of use (TOU) rates, and by 2020 will have a zero electric bill in return for zero summer peak loads[5].

Estimates do not include potential applications to manufactured homes or in existing buildings – both project goals – as cost estimates for these targeted areas are not yet available. Developers are assumed to be more likely to negotiate for favorable electrical service with local utilities –

based on the zero-net energy home concept. Energy savings resulting from adoption by smaller spec builders and one-off builders are not captured but could be significant if utilities offer a renewable energy rate to all homeowners.

### 1.2.4 Sources


(1) "Building Technology Program: Research, Development and Demonstration Plan, Planned Program Activities for 2004-2010." Final Draft. U.S. DOE, January 9, 2004.
(2) Final Draft: Zero Energy Homes' Opportunities for Energy Savings: Defining the Technology Pathways Through Optimization Analysis, U.S. Department of Energy Building Technologies Program, October 2003.
(3) U.S. Department of Energy, Building America Research Benchmark Definition. Version 3.1, November 11, 2003. Accessed online March 2004, at http://www.eere.energy.gov/buildings/building_america/benchmark_def.html.
(4) Annual Energy Outlook (AEO) 2003, Department of Energy, Energy Information Administration.
(5) Information obtained in discussions with the project manager, Lew Pratsch, August/September 2003.
(6) New Houses Sold, by Region, by Sales Price: Annual Data. U.S. Census Bureau, Manufacturing and Construction Division. www.census.gov/const/regsoldbypricea.pdf, accessed August 8, 2003.
(7) Buildings Energy Databook (July 26, 2003), Table 5.1.1., "2001 Five Largest Residential Homebuilders."


# 2.0 Commercial Buildings Integration

The long-term goal of this subprogram is to develop cost-effective designs for commercial buildings that produce as much energy as they use on an annual basis. Research will focus on reducing total energy use in a commercial building by 60% to 70%.

## 2.1 Commercial Building Energy Codes

### 2.1.1 Target Market

**Project Description.** The Commercial Building Energy Codes project improves the minimum energy efficiency of new commercial and multifamily high-rise buildings and additions and alterations to existing buildings requiring code permits. The project promulgates upgraded energy-efficiency requirements for federal commercial and high-rise residential building types. Similarly, the project works with model energy code groups to upgrade the energy-efficiency requirements of their codes. These upgraded national energy standards are then adopted by federal, state, and local jurisdictions as part of their building codes. The project's long-term goal is to improve minimum energy efficiency by 30% to 35% in new commercial building construction. Energy use will be reduced by states and local jurisdictions widely adopting the national standards as building energy codes.

**Market Description.** The market includes new commercial and multifamily high-rise (above three stories) buildings and all additions and renovations to commercial buildings requiring code permits.

**Size of Market.** The commercial market size is about 2 billion square feet of new commercial floor space each year. The Federal sector represents nearly 2.3% overall of new commercial building construction.

**Baseline Technology Improvements.** Initial compliance with new codes was assumed to be lower in the base case, i.e., without the Building Energy Codes project. For FY06, the percentage of potential savings, in the first year of the single future code, was assumed to be approximately 20% for envelope measures and 30% for lighting measures without the project.

**Baseline Market Acceptance.** The FY 2006 GPRA estimates are based on increased compliance with existing codes, accelerated adoption of the 1999 and 2001 editions of ASHRAE 90.1-1999[4] standard (to comply with Section 304 of the Energy Conservation and Production Act), and the future development of more stringent building energy codes. Through the efforts of the Building Energy Codes project, 21 states were assumed to have adopted the standard by the end of 2005. The project was assumed to accelerate the adoption of the standard by an average of four years nationwide.

### 2.1.2 Key Factors in Shaping Market Adoption of EERE Technologies

**Price.** PNNL developed incremental investment costs by assuming a five-year payback period on investment (i.e., an annual energy cost savings of $1 implies an initial investment of $5).

**Key Consumer Preferences/Values.** The following nonenergy characteristics were not considered.

- Improved environment and more comfortable buildings.
- Lower utility bills
- Lower home maintenance and repair activities
- Reduced pollution due to the reduced burning of fossil fuels and electricity generation, which improves air quality and mitigates the negative impacts of global warming.

### 2.1.3 Methodology and Calculations

**Inputs to Base Case.** With respect to building codes, it is indeterminate the extent to which potential future code improvements are incorporated into the NEMS-GPRA06 base case. The NEMS-GPRA06 base case does include some improvements to the building shell efficiency; however, the basis for these improvements (e.g., general building practice improvements, changes in code requirements, and improvements in materials) is not specified by EIA. The impact of accelerated adoption and improved compliance by states of recently issued national building standards (e.g., IECC 2003) is included in the GPRA forecast of savings. The GPRA savings estimates for WIP also include a portion of the impact of changes in building codes that are anticipated within approximately the next 10 years. (A portion of the savings from increased stringency of future codes is also allocated to the Building Technologies Program). Therefore, PNNL did not provide inputs to change the base case assumptions for the program markets.

**Technical Characteristics.** Energy savings from this project result from some basic improvements to the overall energy efficiency of commercial buildings in their space-heating, space-cooling, and lighting loads. This project funds research analysis of cost-effective levels of energy codes for new commercial and multifamily high-rise buildings. This BT program works with the Training and Assistance for Codes project within the Office of Weatherization and Intergovernmental Programs, which funds the development of core materials (such as compliance tools and training materials) and provision of training and financial and technical assistance for states to update and implement their building energy codes. Benefits cannot be clearly allocated to either project, thus the benefits estimated are a function of both training and deployment as well as development of the commercial building energy codes and standards.

Savings estimates for commercial codes are based on increased stringency from the combined impact of the forthcoming ASHRAE 90.1-2004 code and the "next" code assumed to be published in 2007. For FY06, future codes (up through 2010) are assumed to achieve a total reduction of 18% in electricity and a 10% reduction in natural gas as compared to 90.1-1999, based on a series of simulations for various U.S. locations. Benefits for FY 2006 were assumed to be allocated according to the ratio of actual funding levels.

The project impacts energy consumption through two primary avenues: 1) developing and supporting code changes to improve the minimum energy-efficiency requirements for commercial and multifamily high-rise buildings and 2) providing technical and financial assistance to states to update and implement their building energy codes. The latter includes developing tools that can ease the adoption of new codes and through their use, can support improvements in compliance and enforcement of code provisions. Tools take the form of code compliance software, computer-based training tools for building energy codes, and tools for implementing noncomputer-based codes.

Improvements to building codes are primarily supported by research efforts to review existing codes and specific targeted areas of building energy use, as well as the adoption of code modifications that promote cost-effective reductions in these energy-use areas. Support for the research work has typically taken place in three areas:

- Upgrading ASHRAE/IES Standard 90.1-1989, "Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings"[(1)]
- Upgrading the Federal commercial and multifamily high-rise building energy code, 10 CFR 434, "Energy Code for New Federal Commercial and Multi-Family High Rise Residential Buildings"[(2)]
- Upgrading the International Energy Conservation Code (IECC).[(3)]

The FY 2006 GPRA estimates are based on increased compliance with existing codes, accelerated adoption of the 1999 and 2001 editions of ASHRAE 90.1[(4)] standard (to comply with Section 304 of the Energy Conservation and Production Act), and the future development of more stringent building energy codes. The energy-savings methodology was applied at a state level to better link changes in the codes with variations in climates by states and differences among states in their adoption and enforcement of building codes. The discussion below uses national averages of some of the key assumptions related to adoption and compliance to help summarize the methodology, but appropriate state averages were used in the analysis.

The principal differences between the ASHRAE 90.1-1989, 90.1-1999, and 90.1-2001(5) standards relate to requirements for better windows, reduced installed wattage for lighting, and more efficient heating and cooling equipment. The savings from improved equipment are not included in the project's savings estimates, because they are reflected in the Equipment Standards and Analysis decision unit in this appendix. Based on a series of simulations that include various U.S. locations and that were developed specifically to evaluate the two ASHRAE standards (often referred to as the "determination" study[6]), the average reduction in site energy use was estimated to be about 3.5% or 2 MMBtu/sq ft. The GPRA estimates were partly based on states' accelerated adoption schedule of the ASHRAE 90.1-1999 and 90.1-2001 standards. Through the efforts of the Building Energy Codes project, 21 states were assumed to have adopted the standard by the end of 2005. The project was assumed to accelerate the adoption of the standard by an average of four years nationwide.

The ongoing activities of the ASHRAE 90.1 committee were assumed to lead to more stringent commercial-building standards in the future. DOE was assumed to play a major role in developing the analytical and economic basis for such standards. For the GPRA process, these activities were subsumed in a single upgrade of the ASHRAE standard, assumed to become available in the latter part of the current decade. The GPRA analysis assumed that the overall result of these upgrades is to reduce electricity consumption by 10% and natural gas consumption by 10% in new commercial buildings. Many states adopting this standard by 2010 also depends on the project's continuing activities to assist states in the adoption (and compliance) process. Without these activities, the analysis assumed that the same standard would be adopted, on average, six years later.

The project activities also were assumed to improve compliance rates for codes currently adopted by states and localities, as well as future building codes. Compliance is increased through increased familiarity with the codes, simplifications to the code while maintaining stringency, and the availability and increased use of compliance tools by builders and enforcement officials. Compliance is effectively measured as the percentage of potential savings moving from one code to the next. Compliance rates estimated between the existing code (assumed to be 90.1-1989) and a code based on ASHRAE 90.1-1999; and between 90.1-1999 and a new code discussed above.

Without the program, the percentage of potential savings is assumed to be modest, as the program is directed toward software tools and training that facilitate adherence to the code. In this case, on average, PNNL estimated the percentage of potential energy savings for envelope measures to be about 20% in the year of adoption. Ten years later, the percentage of potential energy savings is assumed to increase to approximately 50%. For lighting, these percentages were 30% and 55%, respectively. With the program, the percentage of potential energy savings is expected to be higher at the outset and increase more rapidly. For envelope measures, the initial potential savings is about 70%, increasing to about 95% 10 years later. For lighting measures, the initial percentage of savings is 80%, again increasing to about 95% years later.

**Expected Market Uptake.** As part of work for an unpublished analysis of the historical impacts of Building Energy Codes in August 2003, the assumptions regarding the acceleration effect of the program were modified (e.g., program activities leading to states adopting codes more rapidly than they would have otherwise). In general, the states were classified into groups that: 1) immediately adopted the ASHRAE 90.1-1989 code, 2) would have adopted within five years without the building codes project, or 3) would have adopted within 10 years without the building codes project. These time periods were then reduced by one year for each successive major code cycle after the 1989 code. (For example, a five-year lag for 90.1-1989 is assumed to fall to three years for the forthcoming ASHRAE 90.1-2004 code). The overall impact of this change was to decrease the average lag between the publication of a new standard and when it is adopted – without the project. This modified set of assumptions increases the overall estimate of the future energy savings impact from the program.

### 2.1.4 Sources


(1) ASHRAE/IES Standard 90.1-1989, "Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings," American Society of Heating, Refrigeration, and Air-Conditioning Engineers and Illuminating Engineering Society.

(2) 10 CFR 434, "Energy Code for New Federal Commercial and Multi-Family High Rise Residential Buildings," *Code of Federal Regulations*, as amended.

(3) International Energy Conservation Code. 2003. International Code Council, Falls Church, Virginia.

(4) ASHRAE/IES Standard 90.1-1999, "Energy Standard for Buildings Except Low-Rise Residential Buildings," American Society of Heating, Refrigeration, and Air-Conditioning Engineers.

(5) ASHRAE/IES Standard 90.1-2001, "Energy Standard for Buildings Except Low-Rise Residential Buildings," American Society of Heating, Refrigeration, and Air-Conditioning Engineers.

(6) U.S. Department of Energy. March 2002. "Commercial Buildings Determinations, Explanation of the Analysis and Spreadsheet (90_1savingsanalysis.xls)." http://www.energycodes.gov/implement/determinations_com.stm


## 2.2 Technology Research and Development

### 2.2.1 Target Market

**Project Description.** [1] In order to reach net zero conventional energy buildings (ZEB) by 2025, DOE will employ integrated whole-building strategies to enable commercial buildings to be designed and constructed to use 70% less energy. By 2010, the BT goal is to integrate design approaches, highly efficient component technologies and controls, improved construction and maintenance practices, and operating procedures that will make new and existing commercial buildings durable, healthy and safe for occupants, and will reduce energy use for new buildings by 50% and by 30% for existing buildings, relative to conventional practice. [b]

**Market Description[1]:** Although this project does not explicitly exclude any particular building type, the types of commercial buildings that will most likely be impacted by the technologies developed by this project primarily include small commercial buildings with

[b] Energy savings are measured relative to the 2001 International Energy Conservation Code (IECC).

relatively higher energy use intensities such as assembly, education, food service, food sales, lodging, mercantile and service, and office buildings.

**Baseline Technology Improvements.** For this analysis, PNNL did not suggest any changes in technology improvements, apart from the EIA baseline.

**Baseline Market Acceptance.** In 1998, PNNL conducted a study examining the historical market penetration for 10 energy-efficient products related to the buildings sector. The results of this study are documented in the PNNL report, *Methodological Framework for Analysis of Buildings-Related Programs: The GPRA Metrics Effort* (2004)[(6)]. The study suggested several generic penetration curves based on the type of equipment of interest. PNNL used the curve related to design products to model this project.

### 2.2.2 Key Factors in Shaping Market Adoption of EERE Technologies

**Price.**
**Cost of Conventional Technology**[(4)]: Average of $101/ft$^2$ for the targeted new commercial and multifamily; $0 for existing buildings.
**Cost of BT Technology**[(5)]: $103.00/ft$^2$ for new commercial and multifamily; $3/ ft$^2$ (2001 to 2009), increasing to $4/ ft$^2$ (2010 to 2030) for existing buildings.
**Incremental Cost**[(5)]: 2% above base for new buildings; $3/ ft$^2$ (2005 to 2009), increasing to $4/ ft$^2$ (2010 to 2030) for existing buildings.

**Key Consumer Preference/Values – Nonenergy Benefits**. The following nonenergy characteristics were not considered in developing energy output estimates:

- Reduced operation and maintenance expenses
- Improved indoor environmental quality
- Increased property asset value
- Higher tenant satisfaction and retention rates
- Increased technology sales.

### 2.2.3 Methodology and Calculations

**Inputs to Base Case.** The base case was developed based on an assortment of sources including AEO 2003, CBECS 95, RECS 97, and several other sources, all of which are documented in the 2004 PNNL report, *Methodological Framework for Analysis of Buildings-Related Programs: The GPRA Metrics Effort* (Elliott et al 2004).

**Technical Characteristics.** In concert with the Analysis, Tools, and Design Strategies project, the performance goals are to reduce heating and cooling loads by 50% in new small commercial construction and by 30% in existing buildings.[c]

[c] The percentage of the load reduction attributed between Commercial R&D and Analysis Tools and Design Strategies is in proportion with their respective budget requests.

**Expected Market Uptake.** The market penetration goal[3] is to accelerate the penetration of high-performance building designs, such that 60% of new commercial and multifamily construction (**Figure 1**) and 20% of existing construction incorporates the products supported by this project by 2020 (**Figure 2**). Penetration curves were developed based on market diffusion curves developed by PNNL[6]. PNNL assumed that this project accelerates the adoption of relevant energy-savings products, technologies and designs by 10 years.

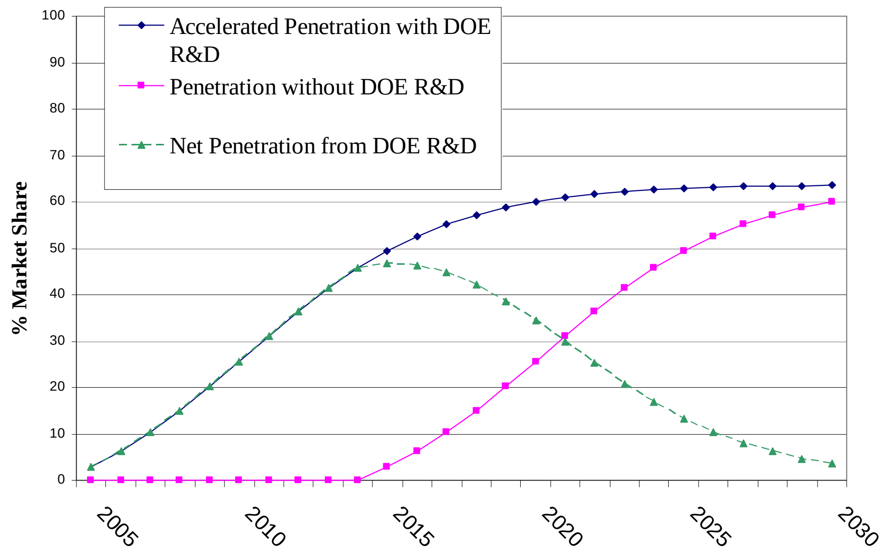


**Figure 1. Market-Penetration Curve for Commercial R&D Project Targeting New Buildings**

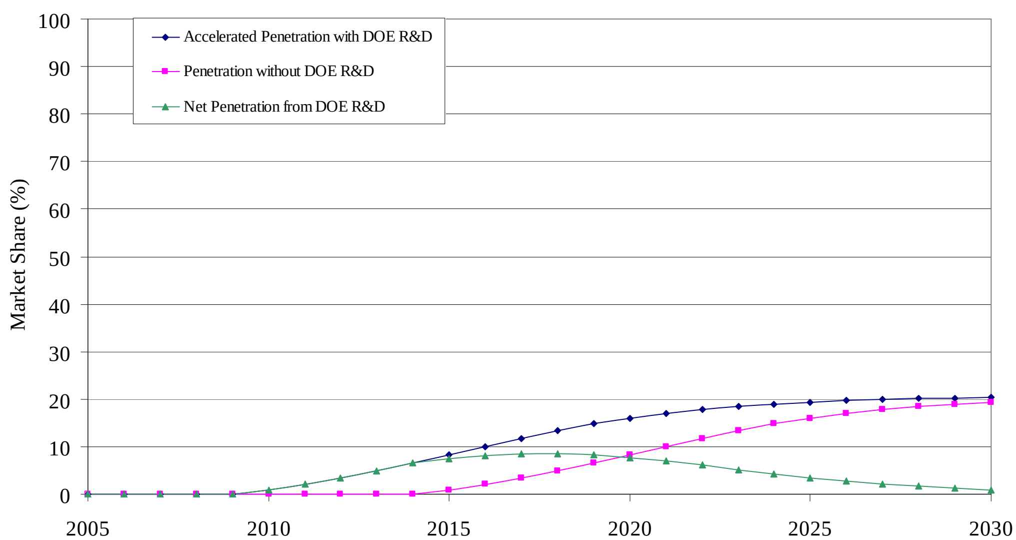


**Figure 2. Market-Penetration Curve for Commercial R&D Project Targeting Existing Buildings**

### 2.2.4 Sources

(1) "Building Technology Program: Research, Development and Demonstration Plan, Planned Program Activities for 2004-2010." Final Draft. U.S. DOE, January 9, 2004.
(2) Torcellini, Paul, et. al. Lessons Learned from Field Evaluation of Six High-Performance Buildings, NREL/CP-550-36290, National Renewable Energy Laboratory, June 2004.
(3) E-mail correspondence with project manager, Dru Crawley, June 2003.
(4) RS Means Company, Inc. 2002. "RS MEANS Square Foot Costs." 23rd Edition, Kingston, MA.
(5) Kats, Greg (Capital E), et. al. "The Costs and Financial Benefits of Green Buildings," A Report to California's Sustainable Building Task Force. October 2003.
(6) Elliott, D.B., D.M. Anderson, D.B. Belzer, K.A. Cort, J.A. Dirks, D.J. Hostick. 2004. *Methodological Framework for Analysis of Buildings-Related Programs: The GPRA Metrics Effort*. PNNL-14697. Pacific Northwest National Laboratory, Richland, Washington.

# 3.0 Equipment Standards and Analysis

As legislatively mandated, BT will pursue energy efficiency standards for appliances and building equipment, setting higher standards where technologically feasible and economically justified.

## 3.1 Commercial Unitary AC/HP Standards

### 3.1.1 Target Market

**Project Description.** DOE is required by the Energy Policy and Conservation Act and its amendments to consider national energy conservation standards for certain commercial unitary air conditioners and heat pumps.

**Market Description:** The market includes all residential and commercial equipment covered by the appropriate legislation.[1,2]

**Size of Market:** The market size includes all applicable residential and commercial equipment in the market to which legislation applies (ovens/ranges and medical equipment, for example, are not covered).

**Baseline Technology Improvements.** For this analysis, PNNL did not suggest any changes in technology improvements, apart from the EIA baseline.

### 3.1.2 Key Factors in Shaping Market Adoption of EERE Technologies

**Price.** Incremental investment costs were developed assuming a nine-year payback period on investment (i.e., an annual energy cost savings of $1 implies an initial investment of $9)[d]. This

[d] Screening Analysis for EPACT-Covered Commercial HVAC and Water Heating Equipment (PNNL-1223). P. D-12. Payback period for Upgrade Group relative to EPCA 1992 for Central Air Source AC Units, >= 65K, < 135 kBtu/h

corresponds with a total incremental investment cost of approximately $200 million in 2005, $1 billion in 2010, $1.4 billion 2020, and $600 million in 2030.

**Key Consumer Preferences/Values.** The following nonenergy characteristics were not considered in developing energy output estimates:

- Reduced $CO_2$ and $SO_X$ emissions
- Reduced water consumption from plumbing equipment
- Increased life of equipment operating at cooler temperatures
- Reduced first costs that transform new technologies into commodities.

### 3.1.3 Methodology and Calculations

**Technical Characteristics.** For FY 2006, the energy savings from commercial equipment standards activities were based primarily on a PNNL screening analysis conducted in late 1999 and early 2000(3) to provide preliminary estimates of the potential energy savings from updated commercial equipment standards. PNNL used the spreadsheet developed for this study to estimate the energy savings from various levels of standards for nearly 40 types of equipment covered by the Energy Policy Act (EPAct). The spreadsheet results were used to identify technologies that could achieve significant energy savings beyond the efficiency levels set in the recent ASHRAE 90.1-1999 publication.(4)

Based on the spreadsheet EPACT_SA.XLS (essentially identical to the spreadsheet installed on the BT Web site for public comment subsequent to the EPAct screening analysis), the tables below summarize the efficiency assumptions and energy savings results for technologies that EERE-BT will further analyze. The key assumptions and results were summarized for 12 cooling technologies the **Table 5** and for boilers and a high-capacity instantaneous water heater in the **Table 6.** Cumulative savings, shown in the last column in both tables, were based on the savings from the effective date of the standards through 2030.

**Table 5. Key Assumptions and Results for Cooling Products**

| | Efficiency (SEER and EER)* | | | Energy Savings by Year (TBtu) | | | |
|---|---|---|---|---|---|---|---|
| **Equipment Category** | **EPAct** | **New Std** | **Eff. Date** | **2010** | **2020** | **2030** | **Cum.** |
| 3-Phase Single Package, Air Source Air Conditioning, <65 kBtu/h | 9.7 | 12.0 | 2005 | 4.6 | 21.0 | 26.5 | 396.0 |
| 3-Phase Single Package, Air Source Heat Pump, <65 kBtu/h | 9.7 | 12.0 | 2005 | 1.2 | 3.1 | 3.4 | 60.2 |
| 3-Phase Split, Air Source Air Conditioning, <65 kBtu/h | 9.7 | 11.0 | 2005 | 0.9 | 4.1 | 5.2 | 78.1 |
| 3-Phase Split, Air Source Heat Pump, <65 kBtu/h | 9.7 | 12.0 | 2005 | 9.1 | 24.0 | 26.5 | 463.0 |
| Central, Water Source Heat Pump, >17 and <65 kBtu/h | 9.3 | 12.5 | 2008 | 1.5 | 7.1 | 11.1 | 146.9 |
| Central, Air Source Air Conditioning, >=65 and <135 kBtu/h | 8.9 | 11.0 | 2008 | 5.5 | 25.0 | 31.6 | 471.6 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Central, Air Source Air Conditioning, >=135 and <240 kBtu/h | 8.5 | 11.0 | 2008 | 5.4 | 24.6 | 31.0 | 463.1 |
| Packaged Terminal Air Conditioning, 7-10 kBtu/h | 8.6 | 10.8 | 2008 | 0.4 | 1.8 | 2.2 | 33.3 |
| Packaged Terminal Air Conditioning, 10-13 kBtu/h | 8.1 | 10.2 | 2008 | 0.6 | 2.6 | 3.3 | 49.5 |
| * SEER = seasonal energy efficiency ratio; EER = energy efficiency ratio. | | | | | | | |

**Table 6. Key Assumptions and Results for Boilers and a High-Capacity Instantaneous Water Heater**

| Equipment Category | Efficiency (SEER and EER) | | | Energy Savings by Year (TBtu) | | | |
|---|---|---|---|---|---|---|---|
| | EPAct | New Std | Eff. Date | 2010 | 2020 | 2030 | Cum. |
| Pkg'd Boilers, Gas, 400 kBtu/h, Hot Water | 75% | 78% | 2008 | 0.2 | 0.9 | 1.7 | 19.7 |
| Pkg'd Boilers, Gas, 800 kBtu/h, Hot Water | 75% | 78% | 2008 | 0.4 | 2.0 | 3.7 | 43.0 |
| Pkg'd Boilers, Gas, 1500 kBtu/h, Hot Water | 75% | 78% | 2008 | 0.1 | 0.7 | 1.2 | 14.2 |
| Pkg'd Boilers, Gas, 3000 kBtu/h, HW | 75% | 80% | 2008 | 0.2 | 0.7 | 1.3 | 15.2 |
| Pkg'd Boilers, Gas, 400 kBtu/h, Steam | 72% | 76% | 2008 | 0.1 | 0.6 | 1.1 | 12.6 |
| Pkg'd Boilers, Gas, 800 kBtu/h, Steam | 72% | 76% | 2008 | 0.4 | 1.6 | 3.0 | 34.5 |
| Pkg'd Boilers, Gas, 1500 kBtu/h, Steam | 72% | 79% | 2008 | 0.3 | 1.2 | 2.3 | 26.7 |
| Pkg'd Boilers, Gas, 3000 kBtu/h, Steam | 72% | 80% | 2008 | 0.2 | 0.9 | 1.7 | 19.2 |
| Instantaneous Water Heaters, 1000 kBtu/h | 80% | 83% | 2008 | 1.0 | 4.4 | 5.6 | 83.3 |

## 3.2 Distribution Transformers

### 3.2.1 Target Market

**Project Description.** Distribution transformers convert high-voltage electricity from distribution centers to lower-voltage electricity for use at the household level. During this conversion process, a small fraction of heat is lost. The Energy Policy and Conservation Act (EPCA) of 1975 established an energy conservation program for major household appliances. The National Energy Conservation Policy Act of 1978 amended EPCA to add Part C of Title III, which established an energy conservation program for certain industrial equipment. The Energy Policy Act of 1992 amended EPCA to add certain commercial equipment, including distribution transformers.

BT conducts the program that develops equipment energy conservation standards and has overall responsibility for rulemaking activities for distribution transformers in fulfillment of the law.

The first step in developing energy-conservation standards was the secretarial determination in 1997 that, "Based on its analysis of the information now available, the department has determined that energy conservation standards for transformers appear to be technologically feasible and economically justified, and are likely to result in significant savings" 62 FR 54809 (October 22, 1997).

The department is currently conducting two rulemakings for Distribution Transformers: an energy conservation standard and a test procedure.

**Baseline Technology Improvements.** For this analysis, PNNL did not suggest any changes in technology improvements, apart from the EIA baseline.

### 3.2.2 Key Factors in Shaping Market Adoption of EERE Technologies

**Price.** PNNL assumed a 10-year payback period on investment to develop incremental investment costs (i.e., an annual energy cost savings of $1 implies an initial investment of $10). This corresponds to a total incremental investment of approximately $580 million in 2010, $780 million in 2020, and $230 million in 2030.

**Key Consumer Preferences/Values.** The following nonenergy characteristics were not considered in developing energy output estimates:

- Reduced $CO_2$ and $SO_X$ emissions

### 3.2.3 Methodology and Calculations

**Inputs to Base Case.** The base case was developed based on an assortment of sources, including AEO 2003, CBECS 95, RECS 97, and several other sources, all of which are documented by PNNL[(7)].

**Technical Characteristics**

**Performance Target:** Savings estimates for a distribution transformer standard were based on the DOE Draft ANOPR Analysis for Distribution Transformers Rulemaking (January 6, 2004).[(5)] The analysis assumed the following:

- Average savings of 140 watts per unit
- A transformer sales forecast (see **Table 5**).
- 0% sales complying with the new level without the standard (this was taken into account in calculating the 140 watts average savings)
- 8,760 annual operating hours per unit
- 30-year life of equipment.

PNNL assumed that the distribution transformer standard would not go into effect until 2008, based on an internal schedule indicating that the final rule would be issued May 2005, with the standard going into effect three years later.[6] The savings estimate of 140 watts per unit installed was multiplied by the estimated hours of operation and then by the forecasted number of units installed.

### Expected Market Uptake

**Table 7. Distribution Transformer Market Penetration**

| Year | Transformer Sales Forecast |
|---|---|
| 2005 | 1,422,000 |
| 2006 | 1,452,000 |
| 2007 | 1,485,000 |
| 2008 | 1,521,000 |
| 2009 | 1,549,000 |
| 2010 | 1,582,000 |
| 2011 | 1,614,000 |
| 2012 | 1,646,000 |
| 2013 | 1,673,000 |
| 2014 | 1,701,000 |
| 2015 | 1,729,000 |
| 2016 | 1,756,000 |
| 2017 | 1,782,000 |
| 2018 | 1,810,000 |
| 2019 | 1,840,000 |
| 2020 | 1,870,000 |
| 2021 | 1,898,000 |
| 2022 | 1,929,000 |
| 2023 | 1,960,000 |
| 2024 | 1,994,000 |
| 2025 | 2,025,000 |
| 2026 | 2,058,000 |
| 2027 | 2,090,000 |
| 2028 | 2,124,000 |
| 2029 | 2,158,000 |
| 2030 | 2,192,000 |

## 3.3 Sources


(1) National Appliance Energy Conservation Act of 1987, Public Law 100-12.
(2) Energy Policy Act of 1992, Public Law 102-486.
(3) Somasundaran, S. et al. 2000. *Screening Analysis of EPAct-Covered Commercial HVAC and Water Heating Equipment*. PNNL-13232, Pacific Northwest National Laboratory, Richland, Washington.
(4) ASHRAE 90.1-1999, "Energy Standard for Buildings Except Low-Rise Residential Buildings," American Society of Heating, Refrigeration, and Air-Conditioning Engineers.
(5) DOE Draft ANOPR Analysis for Distribution Transformers Rulemaking, January 6, 2004.
(6) Internal DOE schedule tracking document for David Garman, Aug. 29, 2003
(7) Elliott, D.B., D.M. Anderson, D.B. Belzer, K.A. Cort, J.A. Dirks, D.J. Hostick. 2004. *Methodological Framework for Analysis of Buildings-Related Programs: The GPRA Metrics Effort*. PNNL-14697. Pacific Northwest National Laboratory, Richland, Washington.


# 4.0 Emerging Technologies

The Emerging Technologies subprogram seeks to develop cost effective technologies, e.g., lighting, windows, and space heating and cooling, for residential and commercial buildings that can reduce the total energy use in buildings by 60% to 70%. The improvement in component and system energy efficiency when coupled with research to integrate onsite renewable energy supply systems into the commercial building can result in marketable net zero energy designs.

## 4.1 Analysis Tools and Design Strategies

### 4.1.1 Target Market

**Project Description.** [1] The Analysis Tools and Design Strategies project researches the interrelationship of energy systems and building energy performance, develops various building analysis tools to more accurately model energy use in new and existing buildings, and provides recommendations and strategies to cost effectively lower energy use and improve building performance. The project focuses on whole-building software tools for evaluating energy efficiency and renewable energy. The project also focuses on nonsoftware solutions such as improved standards, guidelines, and performance measurements, all of which bring about excellence in designing new buildings. The project's long-term goal is to improve energy designs for all building types through a number of widely used analytical tools and guidance documents.

**Market Description:** Although this project does not explicitly exclude any particular building type, the types of commercial buildings that most likely will be impacted by the technologies developed by this project include those with relatively higher energy use intensities such as assembly, education, health care, lodging, and office buildings.

**Market Introduction[1,3]:** PNNL assumed that this project accelerates the introduction and market penetration of the advanced building energy tools and design strategies by 10 years. Historically, there have been a number of building energy tools that have been developed privately; however, most of these tools use algorithms, code, and modules developed by DOE. PNNL assumed that a proportion of these activities (50%) would not occur without DOE funding. These assumptions are necessary in the absence of citable sources documenting DOE's influence on building energy tool adoption and algorithm attribution.

**Baseline Technology Improvements.** For this analysis, PNNL did not suggest any changes in technology improvements, apart from the EIA baseline.

**Baseline Market Acceptance.** In 1998, PNNL conducted a study examining the historical market penetration for 10 energy-efficient products related to the buildings sector. The results of this study are documented by PNNL[5]. The study suggested several generic penetration curves based on the type of equipment of interest. PNNL used the curve related to design products to model this project.

### 4.1.2 Key Factors in Shaping Market Adoption of EERE Technologies

**Price[3,4].** Although the tools supported by this project are distributed free of charge, users must invest a certain amount of time to learn the tools. Without a user-friendly interface, approximately one person-month is required to be come proficient with the tools. Analysis Tools and Design Strategies is currently developing energy-simulation tools without a user-friendly interface, with the idea that the private sector can use these algorithms, codes, and modules and design a suitable user-friendly interface.

**Key Consumer Preference/Values – Nonenergy Benefits**. The following nonenergy characteristics were not considered in developing energy output estimates:

- Improved indoor environmental quality, such as thermal comfort and ventilation adequacy
- Improved indoor air quality
- Fire safety
- Overall environmental sustainability (i.e., Green Buildings).

### 4.1.3 Methodology and Calculations

**Inputs to Base Case.** The base case was developed based on an assortment of sources, including AEO 2003, CBECS 95, RECS 97, and several other sources, all of which are documented by PNNL[5].

**Technical Characteristics[2].** In concert with Commercial Buildings R&D project, the performance goals are to reduce heating and cooling loads by 50% in new small commercial construction and by 30% in existing buildings.[e]

**Expected Market Uptake[3].** The market penetration goal is to accelerate the penetration of high-performance building design, such that 50% of new commercial and multifamily construction and 30% of existing construction incorporates the products supported by this

[e] The percentage of the load reduction attributed between Commercial R&D and Analysis Tools and Design Strategies is in proportion with their respective budget requests.

project by 2020. PNNL assumes that this project accelerates the adoption of relevant energy-savings products, technologies and designs by 10 years. The market penetration is shown in **Figure 3**.

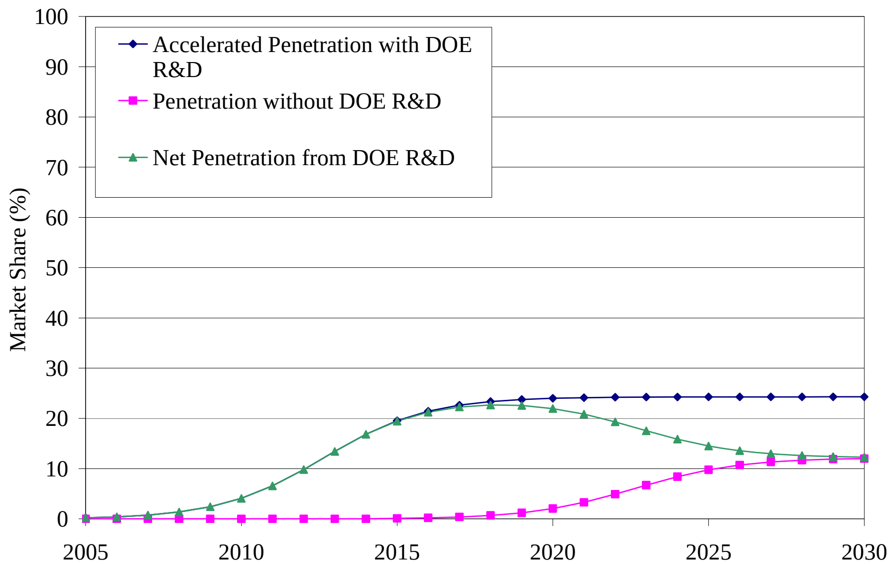


**Figure 3. Market-Penetration Curve for Analysis Tools and Design Strategies**

### 4.1.4 Sources


(1) "Building Technology Program: Research, Development and Demonstration Plan, Planned Program Activities for 2004-2010." Final Draft. U.S. DOE, January 9, 2004.

(2) Torcellini, Paul, et. al. *Lessons Learned from Field Evaluation of Six High-Performance Buildings*, NREL/CP-550-36290, National Renewable Energy Laboratory, June 2004.

(3) E-mail correspondence with project manager, Dru Crawley, June 2003 and June 2004.

(4) Kats, Greg (Capital E), et. al. "The Costs and Financial Benefits of Green Buildings," A Report to California's Sustainable Building Task Force. October 2003.

(5) Elliott, D.B., D.M. Anderson, D.B. Belzer, K.A. Cort, J.A. Dirks, D.J. Hostick. 2004. *Methodological Framework for Analysis of Buildings-Related Programs: The GPRA Metrics Effort*. PNNL-14697. Pacific Northwest National Laboratory, Richland, Washington.


## 4.2 Appliances and Emerging Technologies R&D

### 4.2.1 Target Market

**Project Description.** This project helps manufacturers and utilities commercialize highly efficient appliances and equipment by providing the following assistance:

- Technology procurement to bring new technologies to market (late developmental work).

- Independent third-party evaluation and verification of highly efficient technologies using field studies and demonstrations increase market share of emerging technologies and Energy Star technologies with very low market penetration.
- R&D on appliances not covered by other projects but offering significant energy-savings potential.

**Market Description:** The market includes residential and commercial building technologies, with emphasis on appliances, water heating, lighting, and building equipment.

**Size of Market:** The market size depends on the selected equipment:

- **Rooftop Air Conditioners:** One of the most widely used technologies with greatest commercial space conditioning energy use; more than a million tons sold in 1998.
- **Residential Can Lights:** An estimated 22 million incandescent can fixtures sold in 2001.
- **Reflector CFLs (R-lamps):** Nearly 125 million parabolic/reflector lamps sold to the residential market.

**Baseline Technology Improvements.** For this analysis, PNNL did not suggest any changes in technology improvements, apart from the EIA baseline.

### 4.2.2 Key Factors in Shaping Market Adoption of EERE Technologies

**Key Consumer Preferences/Values.** The following nonenergy characteristics were not considered in developing energy output estimates:

- Reduced carbon emissions
- Dehumidification provided by heat-pump water heater.
- Reduced lamp replacement frequency with R-CFLs and CFL cans.

### 4.2.3 Methodology and Calculations

**Rooftop Air Conditioning**

The intent of the rooftop air conditioner project is to use competitive procurements of large numbers of units to stimulate the production of high-efficiency equipment. The immediate goal is to get high-efficiency equipment installed in buildings owned by the federal government and other state and local agencies.

With this long-term goal in mind, PNNL provided costs of high efficiency roof top air conditioners to be used in the NEMS-GPRA06 commercial model to reflect the principal influence of this project. In NEMS-GPRA06, three air conditioners are specified in the rooftop category—a baseline unit (energy efficiency ratio of 8.9), a moderate efficiency unit (energy efficiency ratio of 10.2) and a high-efficiency unit (energy efficiency ratio of 14.7). No subgroups are distinguished by capacity (e.g., 65 to 135 kBtu/hr vs. 135 to 240 kBtu/hr).

For this analysis, the incremental cost was reduced by 40%, based on project goals. Given the proportion of the market assumed in the NEMS-GPRA06 to display high discount rates in the selection of equipment, this cost reduction yielded a 4 to 12% penetration of the higher efficiency units through the projection period. By 2025, the proportion of the total rooftop air conditioning stock using the higher efficiency units is about 11%.

**Market Introduction:** No acceleration of market acceptance was modeled because the impact was determined to be negligible. Because the technology has only modest penetration (10%) by 2020 and only a few percent by 2010, assuming that this project accelerated market acceptance would not have a significant impact over the analysis period.

**Performance Target:** An efficiency increase from 10.3 to 11.0 energy efficiency ratio for 65 to 135 kBtu/hr and from 9.7 to 10.8 for 135 to 240 kBtu/hr.

**Lifetime:** 15 years.

## Residential Can Lights

The intent of this project is to develop a recessed can light fixture that uses compact fluorescent lamps rather than incandescent.

**Market Introduction:** These projects were assumed to accelerate the introduction of these technologies into the marketplace by seven years.

**Performance Target:** Assumed efficacy of 37.5 lumens/watt[f]. Actual project requirements should be similar to other programs; here, efficacy is expected to improve by a factor of 2.5, while R-lamps are expecting an improvement factor of 3.33 and Energy Star CFLs are looking to an improvement factor of 3.42.

**Installed Cost**: Incremental cost above incandescent cans is $24/can in 2006 declining to $20/can by 2011.

**Lifetime:** 30 years.

## R-Lamps

The intent of this project is to develop a floodlight or spotlight (lamps using reflector surfaces) that can utilize a screw-base compact fluorescent lamp rather than an incandescent lamp.

**Market Introduction:** These projects were assumed to accelerate the introduction of these technologies into the marketplace by five years.

**Performance Target:** Assumed efficacy of 36 lumen/watt[g]. Actual project requirements should be similar to Energy Star (within WIP), as **Table 8** shows.

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[f] Actual efficacy is lower than this value. The value of 37.5 assumes an existing technology value of 15 lumens/watt; actual incandescent can lights have efficacies significantly lower than this. However, BESET currently assume all incandescent lighting to have an efficacy of 15 lumens/watt. The proposed technology, which has the same lumen output as the current technology, is rated at 26W, while the existing incandescent technology is rated at 65W. Hence 15 * 65 / 26 = 37.5.

[g] Weighting the Energy Star targets 58% for less than 20W and 42% for 20W or more (58% of incandescent lamps in homes have Wattages less than 75W and 42% of incandescent lamps in homes have Wattages 75W and greater[(1)]) yields an average lumens/watt of 36. The comparison incandescent lamp, EPACT 65W R-lamp, has approximately 700 lumens or 10.8 lumens/watt.

**Table 8. Performance Targets for R-Lamps**

| Lamp Power (watts) and Configuration | Minimum Efficacy: Lumens/watt* |
|---|---|
| **Reflector Lamp:** | |
| Lamp power <20 | 33 |
| Lamp power >=20 | 40 |
| * Based on initial lumen date. | |

**Installed Cost:** Initial cost is about $7/compact fluorescent lamp reflector lamp; which represent an initial incremental cost of about $5/unit in 2006 which declines to $1.50/unit by 2020.

**Lifetime:** 8,000 hours

### 4.2.4 Sources


(1) Estimated from http://enduse.lbl.gov/Info/LBNL-39102.pdf, p.19.
(2) Gordon, K.L., and M.R. Ledbetter. 2001. *Technology Procurement Screening Study*. Pacific Northwest National Laboratory, Richland, Washington.
(3) The Freedonia Group, Inc. 1999. *Lamps in the United States to 2003*. Cleveland, Ohio. (See the following sections: "Introduction," "Executive Summary," "Market Environment," "Supply and Demand," "Incandescent Lamps," "Electrical Discharge," and "Lamp Markets.")


## 4.3 Envelope Research and Development

### 4.3.1 Target Market

**Project Description**[(1)]**.** Windows typically contribute about 30 percent of overall building heating and cooling loads with an annual impact of about 3.7 quads, with an additional potential savings of 1 quad from daylight use. The BT approach is to first convert windows from their current role as significant thermal losses to the point where they are energy neutral, and then move to a higher level of performance, where they contribute to a net energy surplus in a ZEB, thus offsetting other energy costs.

About 60 percent of window sales are to the residential sector and 40 percent to commercial, so that this program targets both sectors. Sales are evenly distributed between new construction and existing buildings, so both markets are included in the R&D program. Because the energy needs of residential differ from commercial, and new construction and renovation/retrofit are different, and because all performance is strongly influenced by climate and orientation, developing a single "silver bullet R&D solution" that solves all problems is not possible. Furthermore, window impacts on building energy use are linked to other building systems. Therefore the technical approach of the Windows activity is built around three themes:

1. The need for a broad portfolio of cost-effective advanced technologies to address the disparate heating, cooling and daylighting needs of these different conditions;

2. Recognition that these advanced glazing and façade technologies will perform best when they are optimized as part of fully integrated building systems to address competing performance needs as a function of time, climate, building type and orientation; and
3. The need for decision-support infrastructure to rate and label products, and the tools to select and optimize selection and design solutions. For existing energy efficient products, rating and labeling an entire suite of products with a strong focus on commercial building applications will remove barriers for product specification and promotion by industry and non-profit organizations.

**Market Description:** The market includes new and existing commercial and residential buildings in all climate zones.

**Size of Market:** 500 million square feet of windows for commercial buildings and approximately 55 million manufactured units sold each year for residential and light commercial.

**Baseline Technology Improvements.** For this analysis, PNNL did not suggest any changes in technology improvements, apart from the EIA baseline.

### 4.3.2 Key Factors in Shaping Market Adoption of EERE Technologies

**Key Consumer Preferences/Values.** The following nonenergy characteristics were not considered in developing energy output estimates:

- Reduced utility and building peak loads
- Reduced HVAC Requirements and first costs
- Improved indoor comfort and aesthetics.

### 4.3.3 Methodology and Calculations

**Inputs to Base Case.** The base case was developed based on an assortment of sources including AEO 2003, CBECS 95, RECS 97, and several other sources, all of which are documented by PNNL[2].

**Electrochromic Windows[1]**

Windows are capable of providing solar heat when it is needed, rejecting solar gain to reduce cooling loads, and offsetting most of a building's lighting needs during daylight hours. To fully accomplish these functions, windows and skylights must continuously and dynamically control their transmittance of sunlight and daylight. In commercial buildings the dynamic tradeoffs between cooling load reductions and daylight utilization are particularly complex. Glazings whose solar optical properties can be varied rapidly over a wide dynamic range are needed to address these performance needs. Research activities include development of durable chromogenic coatings, emphasizing electrochromic technology for the first generation of products and exploring other switchable coating mechanisms with lower cost, faster switching and wider dynamic range over time. Work includes fundamental coating technology, characterization, durability testing, prototype testing, and controls integration and optimization including field-testing.

**Market Introduction:** 2010; This project was assumed to accelerate the introduction of this technology into the marketplace by 10 years.

**Performance Parameters:** Performance parameters for Electrochromic Windows are presented in **Table 9**.

**Table 9. Performance Parameters for Electrochromic Windows**

| End Use | Shading Coefficient | U-Value |
|---|---|---|
| Heating | 0.6 | 0.25 Btu/ft2·°F |
| Cooling | 0.1 | 0.25 Btu/ft2·°F |

**Performance Target:** Performance characteristics vary by building type and climate zone. The estimated savings per building were determined by simulating residential and commercial buildings in all climate zones (see **Table 10**). Commercial lighting savings are estimated to be 5% in all regions.

**Table 10. Performance Targets for Electrochromic Windows**

| Region | Sector | End Use | New Building Savings | Existing Building Savings | Units |
|---|---|---|---|---|---|
| Northern | Commercial | Heating | 1.83 | 1.61 | MMBtu/ksf |
| | | Cooling | 4.62 | 4.58 | MMBtu/ksf |
| North Central | Commercial | Heating | 1.88 | 1.66 | MMBtu/ksf |
| | | Cooling | 5.80 | 5.52 | MMBtu/ksf |
| South Central | Residential | Heating | 3.91 | 4.38 | MMBtu/HH |
| | | Cooling | 11.16 | 11.30 | MMBtu/HH |
| | Commercial | Heating | 0.94 | 0.88 | MMBtu/ksf |
| | | Cooling | 5.75 | 5.51 | MMBtu/ksf |
| Southern | Residential | Heating | 3.00 | 3.61 | MMBtu/HH |
| | | Cooling | 7.51 | 7.76 | MMBtu/HH |
| | Commercial | Heating | 0.56 | 0.53 | MMBtu/ksf |
| | | Cooling | 3.05 | 2.92 | MMBtu/ksf |
| Weighted National Average (Southern and South Central for Residential) | Residential | Heating | 3.65 | 4.16 | MMBtu/HH |
| | | Cooling | 10.13 | 10.28 | MMBtu/HH |
| | Commercial | Heating | 1.43 | 1.28 | MMBtu/ksf |
| | | Cooling | 4.96 | 4.81 | MMBtu/ksf |

**Installed Cost:**—Incremental Cost Over competing technology (Low-e Double-Pane Windows)

2010 \$54.42/ $ft^2$
2011 \$44.42/ $ft^2$
2012 \$34.42/ $ft^2$
2013 \$24.42/ $ft^2$
2014 \$19.42/ $ft^2$
2015 \$14.42/ $ft^2$
2016 \$9.42/ $ft^2$
2017 \$7.42/ $ft^2$
2018 \$5.42/ $ft^2$
2019 \$3.42/ $ft^2$
2020 \$1.42/ $ft^2$

**Lifetime:** 20 years.

**Expected Market Uptake.** The goal is to obtain 50% of window sales by 2020 in the commercial sector, and 20% of window sales by 2020 in the residential sector. Penetration curves were developed and documented based on market diffusion curves developed by PNNL[(2)]. The "Accelerated" penetration curve represents the percent of electrochromic window sales with the DOE project; the "Net" penetration curve represents the percent of sales attributable to DOE, as PNNL assumed that the DOE project would accelerate market acceptance by 10 years. See penetration curves in **Figures 4 through 7**.

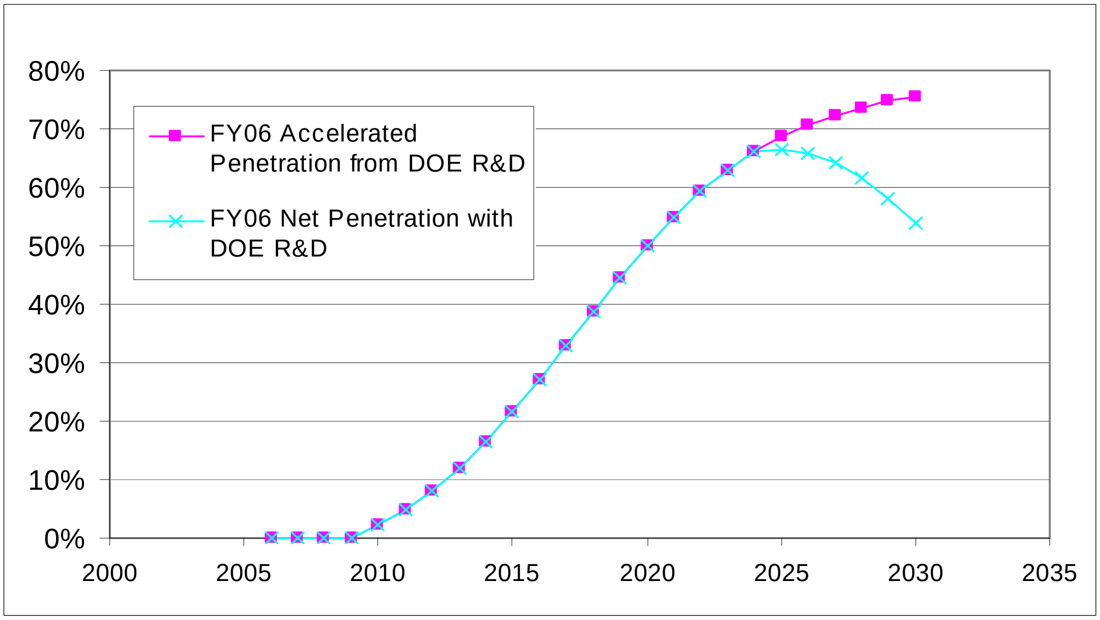


**Figure 4. Electrochromic Windows – New Commercial Buildings Percent of Sales**

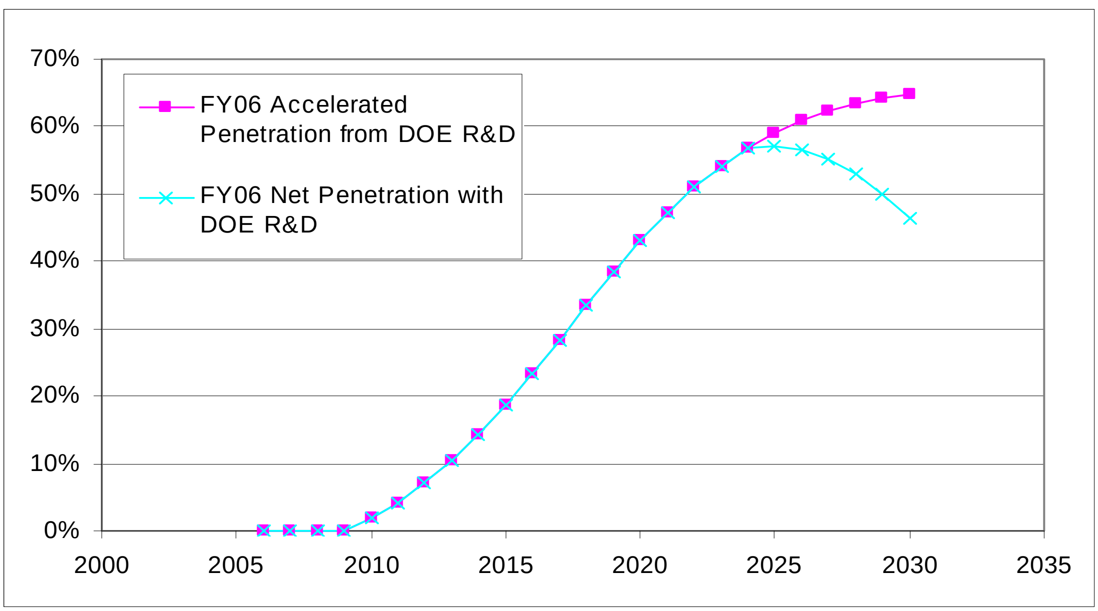


**Figure 5. Electrochromic Windows – Existing Commercial Buildings Percent of Sales**

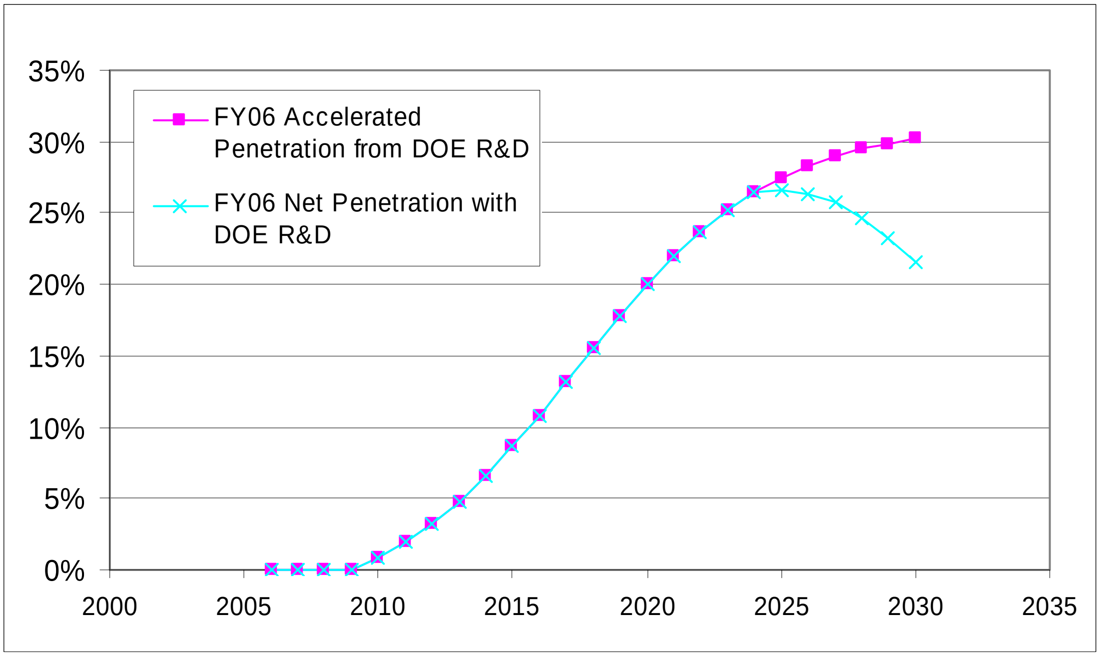


**Figure 6. Electrochromic Windows – New Residential Buildings Percent of Sales**

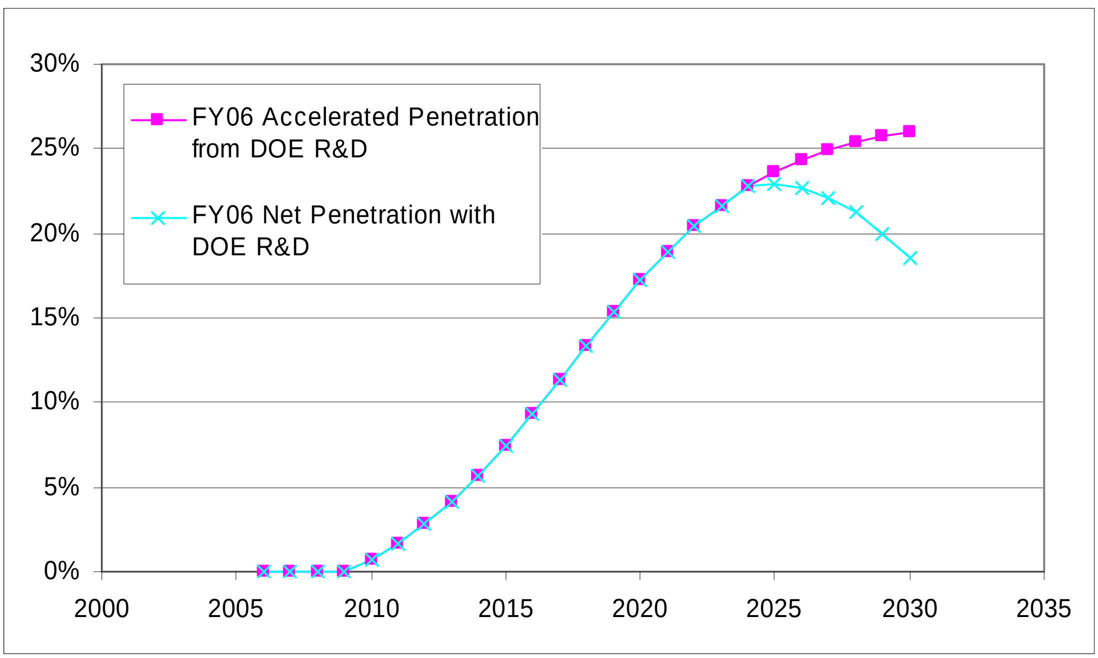


**Figure 7. Electrochromic Windows – New Commercial Buildings Percent of Sales**

**Superwindows[(1)]**

With heating loads being the largest end-use impact, improving winter performance has the potential for large energy savings. Low-E gas-filled windows introduced in the 1980s have now captured more than 40% of the residential market. But, heat loss rates for whole windows must be reduced by at least a factor of 2 to approach levels needed for zero-energy buildings. Highly leveraged competitive R&D will be conducted towards achieving these impacts. Research activities will include basic and exploratory research on advanced optical coatings, gas filled and evacuated cavities, microporous transparent insulating materials, improved edge and frame materials; and applied research to support rating, design tools, and implementation of efficient window technologies.

**Technical Characteristics**

**Market Introduction:** 2007; PNNL assumed that this project would accelerate the introduction of this technology into the marketplace by 10 years.

**Performance Parameters:** Superwindows have maximum U-value and SHGC for four climate zones. These climate zones do not directly correspond to the traditional climate zones used in CBECS or RECS; they also do not correspond to the census divisions used in NEMS. These new climate zones are based on the eight climate zones that were developed as part of the IECC 2003 code change cycle or Residential IECC Code Change (RICC). In general, the Superwindow zones map from the RICC zones is as follows in **Table 11**.

**Table 11. Mapping of RICC Zones to Superwindow Zones**

| RICC Zone | Superwindow Zone |
|---|---|
| 1 | Southern |
| 2 | Southern |
| 3 | South/Central |
| 4 | North/Central |
| 5 | Northern |
| 6 | Northern |
| 7 | Northern |
| 8 | Northern |

To construct the four Superwindow zones there was a fair amount of smoothing required due to geo-political boundaries, existing codes, and commercial regions. For example, a strict adherence of the eight RICC zones to four Superwindow zones shown above would have portions of California in all four Superwindow zones and would result in discontinuities in the zones across the country. The final result is that California is wholly within the South/Central zone and all four Superwindow zones are continuous across the country. Performance parameters are listed in **Table 12**.

**Table 12. Performance Parameter Maximums for Superwindows**

| Region | End Use | Shading Coefficient | U-Value |
|---|---|---|---|
| Northern | Heating | 0.6087 | 0.10 Btu/ft2·°F |
| | Cooling | 0.2609 | 0.10 Btu/ft2·°F |
| North Central | Heating | 0.6807 | 0.10 Btu/ft2·°F |
| | Cooling | 0.2609 | 0.10 Btu/ft2·°F |
| South Central | Heating | 0.1304 | 0.20 Btu/ft2·°F |
| | Cooling | 0.1304 | 0.20 Btu/ft2·°F |
| Southern | Heating | 0.1304 | 0.20 Btu/ft2·°F |
| | Cooling | 0.1304 | 0.20 Btu/ft2·°F |

**Performance Target:** Performance characteristics vary by climate zone. The estimated savings per building were determined by simulating residential buildings in all climate zones (see **Table 13**).

**Table 13. Performance Targets for Superwindows**

| Region | Sector | End Use | New Building Savings | Existing Building Savings | Units |
|---|---|---|---|---|---|
| Northern | Residential | Heating | 10.80 | 11.15 | MMBtu/HH |
| | | Cooling | 4.29 | 4.31 | MMBtu/HH |
| North Central | Residential | Heating | 8.83 | 9.18 | MMBtu/HH |
| | | Cooling | 5.05 | 5.15 | MMBtu/HH |
| South Central | Residential | Heating | -0.08 | 0.02 | MMBtu/HH |
| | | Cooling | 10.10 | 10.32 | MMBtu/HH |
| Southern | Residential | Heating | 1.64 | 1.90 | MMBtu/HH |
| | | Cooling | 6.32 | 6.66 | MMBtu/HH |
| Weighted National Average | Residential | Heating | 6.24 | 6.51 | MMBtu/HH |
| | | Cooling | 6.34 | 6.44 | MMBtu/HH |

**Installed Cost:**—Incremental Cost Over Low-e Double-Pane Windows

2007: $6.00/ft$^2$
2020: $4.00/ft$^2$
2030: $3.00/ft$^2$

**Lifetime:** 30 years

**Expected Market Uptake.** The goal is to obtain 65% of window sales in new buildings and 33% in existing buildings by 2020. Penetration curves were developed based on market diffusion curves developed by PNNL and documented in the 2004 PNNL report, *Methodological Framework for Analysis of Buildings-Related Programs: The GPRA Metrics Effort* (Elliott, et. al). The "Accelerated" penetration curve represents the percent of superwindow sales with the DOE project; the "Net" penetration curve represents the percent of sales attributable to DOE, as PNNL assumed that the DOE project would accelerate market acceptance by 10 years. See penetration curves in **Figures 8 and 9**.

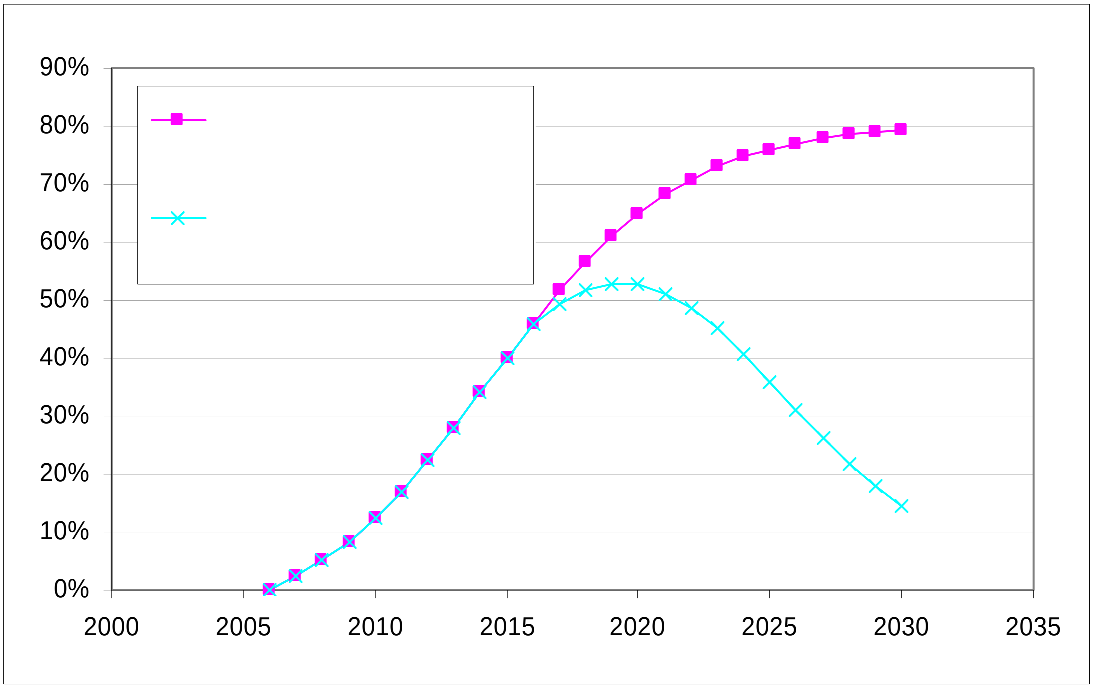


**Figure 8. Superwindows – New Residential Buildings Percent of Sales**

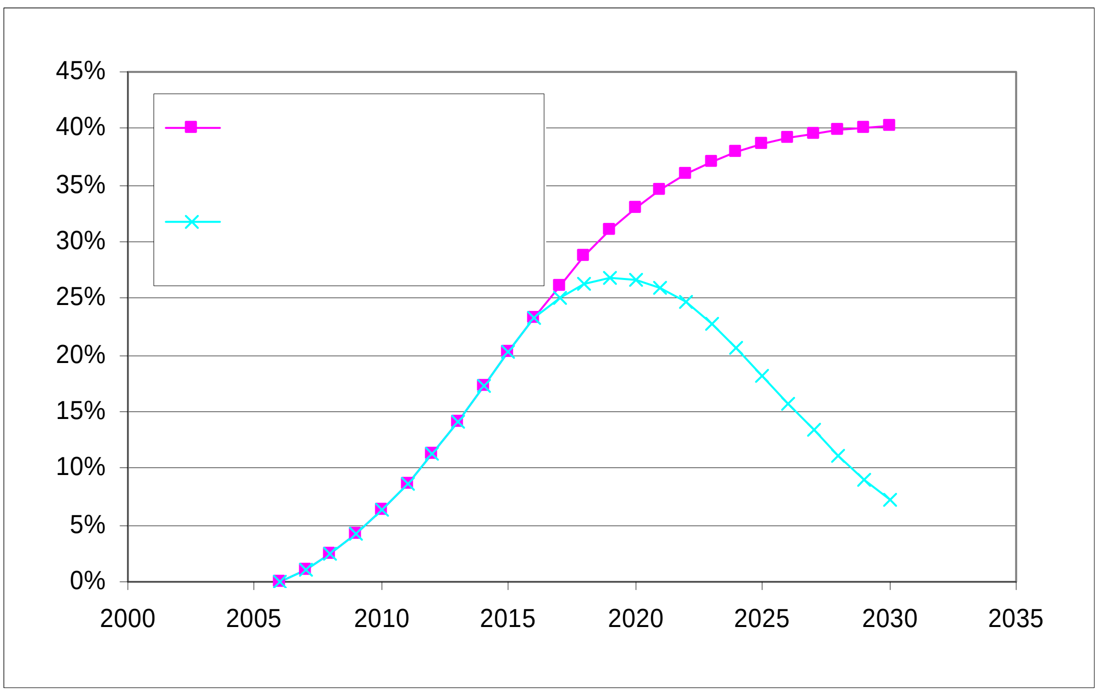


**Figure 9. Superwindows – Existing Residential Buildings Percent of Sales**

## Low-Emissivity Glass Acceptance(1)

Low-e windows have at least one surface coated with a thin, nearly invisible, metal oxide or semiconductor film that reduces the heat transfer through windows. The conventional windows that they replace have no coating. Currently low-e windows represent less than 20% of the commercial market and are not the default product for builders in the residential market, constituting about 40% of that market. Additional research that supports industry and nonprofit energy efficiency programs from FY05 through FY09 can significantly increase the penetration of these energy-efficient products. The purpose of the program is to increase the penetration of low-e glass from 40% in the residential market and 10% in the commercial market to 100% in both markets by 2020. Two programs, Low-e Market Acceptance and Energy Star Windows (funded under the Weatherization and Intergovernmental Program), form the joint means to achieving the low-e penetration goal; hence, the savings will be split equally. The performance of the low-e glass is as described for the Electrochromic and Super Windows baseline.

**Market Introduction:** The technology is commercially available. PNNL assumed that this project would accelerate the penetration in the marketplace by 10 years.

**Methodology and Calculations**

**Technical Characteristics**

**Performance Parameters:** Low-e Windows have maximum U-value and SHGC for four different climate zones. These climate zones do not directly correspond to the traditional climate zones used in CBECS or RECS; they also do not correspond to the census divisions used in NEMS. These new climate zones are based on the eight climate zones that were developed as part of the IECC 2003 code change cycle or Residential IECC Code Change (RICC). In general the Low-e zones map from the RICC zones as follows in **Table 14**.

**Table 14. Mapping of RICC Zones to Low-e Zones**

| RICC Zone | Low-e Zone |
|---|---|
| 1 | Southern |
| 2 | Southern |
| 3 | South/Central |
| 4 | North/Central |
| 5 | Northern |
| 6 | Northern |
| 7 | Northern |
| 8 | Northern |

To construct the four Low-e zones, there was a fair amount of smoothing required due to geo-political boundaries, existing codes, and commercial regions. For example, a strict adherence of the eight RICC zones to four Low-e zones shown above would have portions of California in all four Low-e zones and would result in discontinuities in the zones across the country. The final result is that California is wholly within the South/Central zone and all four Low-e zones are continuous across the country. Performance parameters are listed in **Table 15**.

**Table 15. Performance Parameter Maximums for Low-e Windows**

| Region | Shading Coefficient | U-Value |
|---|---|---|
| Northern | 0.60 | 0.35 Btu/ft2·°F |
| North Central | 0.55 | 0.40 Btu/ft2·°F |
| South Central | 0.40 | 0.40 Btu/ft2·°F |
| Southern | 0.40 | 0.65 Btu/ft2·°F |

**Performance Target:** Performance characteristics vary by building type and climate zone. The estimated savings per building were determined by simulating residential and commercial buildings in all climate zones (see **Table 16**).

**Table 16. Performance Targets for Low-e Windows**

| Region | Sector | End Use | New Building Savings | Existing Building Savings | Units |
|---|---|---|---|---|---|
| Northern | Residential | Heating | 8.17 | 8.30 | MMBtu/HH |
| | | Cooling | 0.06 | 0.19 | MMBtu/HH |
| | Commercial | Heating | 6.24 | 5.73 | MMBtu/ksf |
| | | Cooling | -0.45 | -0.58 | MMBtu/ksf |
| North Central | Residential | Heating | 2.88 | 2.94 | MMBtu/HH |
| | | Cooling | 1.72 | 1.79 | MMBtu/HH |
| | Commercial | Heating | 2.98 | 2.77 | MMBtu/ksf |
| | | Cooling | 0.74 | 0.68 | MMBtu/ksf |
| South Central | Residential | Heating | 0.09 | 0.00 | MMBtu/HH |
| | | Cooling | 10.50 | 10.39 | MMBtu/HH |
| | Commercial | Heating | 0.75 | 0.66 | MMBtu/ksf |
| | | Cooling | 5.91 | 5.62 | MMBtu/ksf |
| Southern | Residential | Heating | -1.48 | -1.77 | MMBtu/HH |
| | | Cooling | 9.18 | 8.77 | MMBtu/HH |
| | Commercial | Heating | -0.14 | -0.14 | MMBtu/ksf |
| | | Cooling | 5.21 | 4.98 | MMBtu/ksf |
| Weighted National Average | Residential | Heating | 3.82 | 3.82 | MMBtu/HH |
| | | Cooling | 4.43 | 4.42 | MMBtu/HH |
| | Commercial | Heating | 3.36 | 3.08 | MMBtu/ksf |
| | | Cooling | 2.25 | 2.07 | MMBtu/ksf |

**Installed Cost:—**Incremental Cost Over Conventional Double-Pane Windows

- 2005: $1.00/ft$^2$
- 2015: $0.50/ft$^2$

**Expected Market Uptake.** The purpose of the program is to increase the penetration of low-e glass from 40% in the residential market and 10% in the commercial market to 100% in the residential market by 2020 and in the commercial market by 2025. Both programs, Low-e Market Acceptance and Energy Star Windows, form the joint means to achieving the low-e penetration goal – the savings are to be split equally. Penetration curves were developed based on market diffusion curves developed and documented by PNNL[(2)]. The "Accelerated" penetration curve represents the percent of superwindow sales with the DOE project; the "Net" penetration curve represents the percent of sales attributable to DOE, as PNNL assumed that the DOE project would accelerate market acceptance by 10 years. The penetration rates are shown in **Figures 10 and 11**. For Low-e Market Acceptance/ Energy Star Windows, PNNL assumed that these projects would accelerate the acceptance of this technology in the marketplace by 10 years.

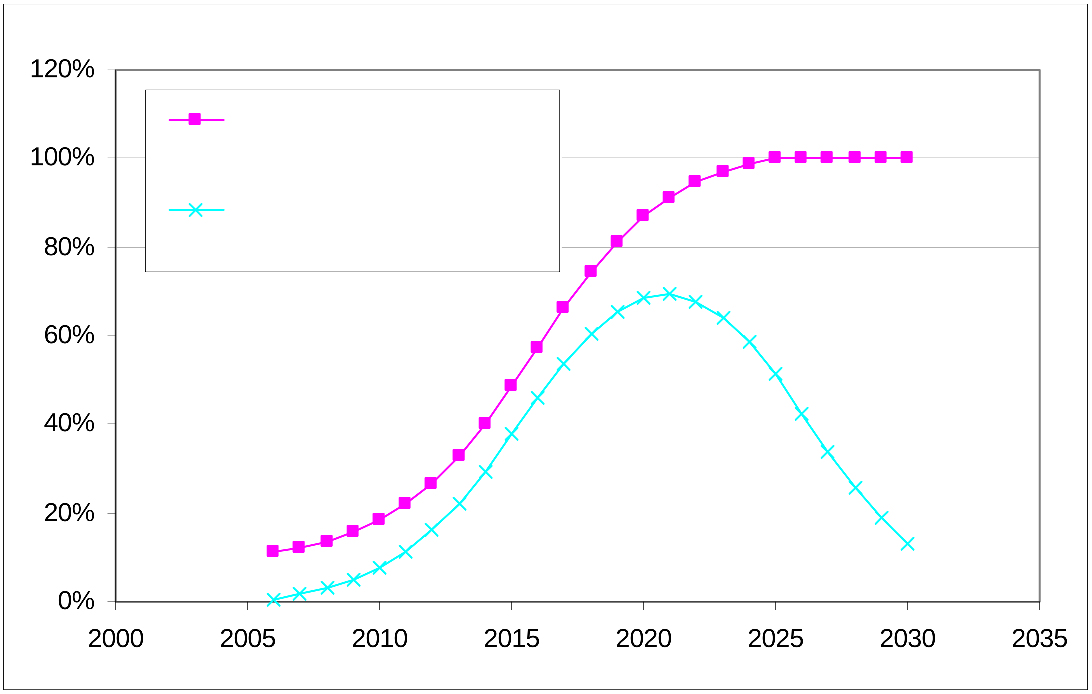


**Figure 10. FY06 Low-e Windows – Commercial Buildings Percent of Sales**

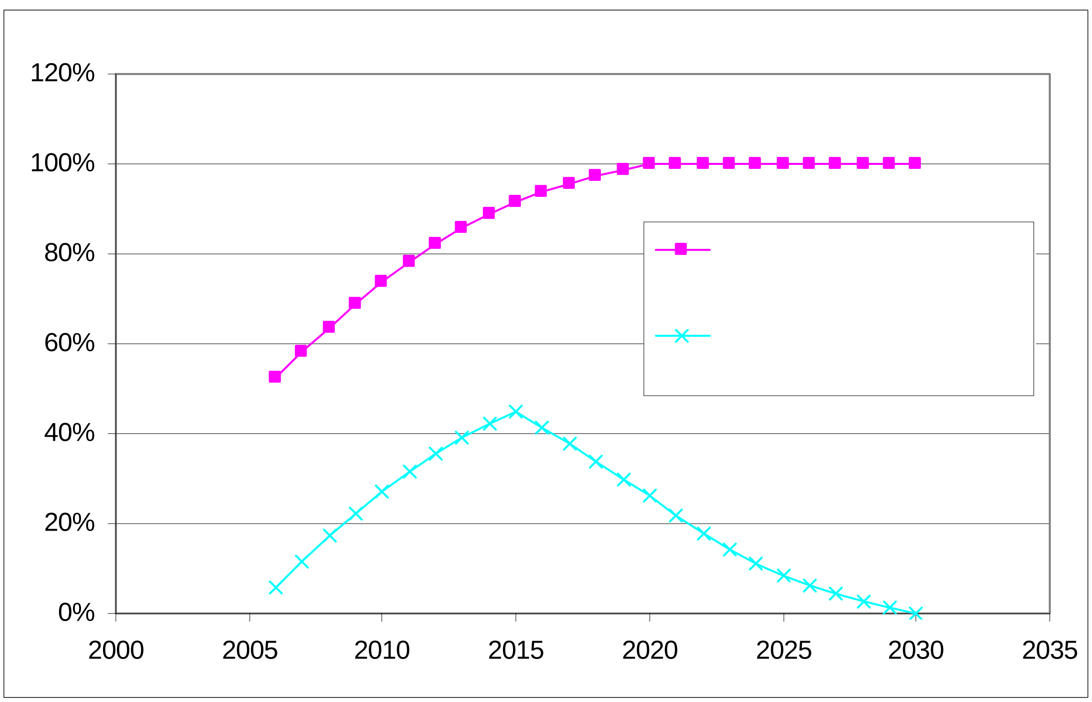


**Figure 11. FY06 Low-e Windows – Residential Buildings Percent of Sales**

### 4.3.4 Sources

(1) "Building Technology Program: Research, Development and Demonstration Plan, Planned Program Activities for 2004-2010." Final Draft. U.S. DOE, January 9, 2004.
(2) Elliott, D.B., D.M. Anderson, D.B. Belzer, K.A. Cort, J.A. Dirks, D.J. Hostick. 2004. *Methodological Framework for Analysis of Buildings-Related Programs: The GPRA Metrics Effort*. PNNL-14697. Pacific Northwest National Laboratory, Richland, Washington.

## 4.4 Lighting Research and Development

### 4.4.1 Lighting Controls

#### 4.4.1.1 Target Market

**Project Description.** The Lighting R&D project develops and accelerates the introduction of advanced lighting technologies.

**Market Description:** The market includes all commercial buildings, with some technologies being introduced into residential buildings.

**Size of Market:** Lighting consumes 26% (3.9 quad) of the primary energy used in commercial buildings, which had a building stock of about 69 billion $ft^2$ in 2000[(1)].

**Baseline Technology Improvements.** For this analysis, PNNL did not suggest any changes in technology improvements, apart from the EIA baseline.

#### 4.4.1.2 Key Factors in Shaping Market Adoption of EERE Technologies

**Price.** PNNL assumed a 4-year payback period on investment to develop incremental investment costs (i.e., an annual energy cost savings of $1 implies an initial investment of $4).

**Key Consumer Preferences/Values.** The following nonenergy characteristics were not considered in developing energy output estimates:

- Develops U.S. leadership in lighting technology
- Reduces pollution and contributes to U.S. climate-change goals
- Improves U.S. productivity from better lighting in work environments
- Responds to an industry-initiated collaborative.

#### 4.4.1.3 Methodology and Calculations

**Inputs to Base Case.** The base case was developed based on an assortment of sources, including AEO 2003, CBECS 95, RECS 97, and several other sources, all of which are documented by PNNL[(3)].

**Technical Characteristics.** Various field studies[(2)] have shown a very large energy savings potential for lighting controls, primarily using occupancy and daylighting controls. These studies have shown that aggressively implementing controls can save 20% to 40% of lighting energy use. BT supports the development of more advanced systems—through both research and field testing—that will further reduce energy used for lighting in commercial buildings. BT support of research to evaluate the interrelationship between human vision and efficient light use will also contribute to future energy savings.

For FY 2006, the impact of the BT activities in lighting controls and efficient lighting practices was assumed to yield an incremental 5% reduction in lighting energy use compared with current practice. (By *incremental*, the BT activities are assumed to lead to further savings over and above the control technologies that the private sector offers now and are likely to offer.)

**Expected Market Uptake.** PNNL assumed that up to 60% of new commercial buildings could incorporate these technologies and that 20% of the existing stock could be retrofitted with these systems by 2020. A time profile of penetration rates was based on the historical pattern of market penetration observed for electronic ballasts. An S-shaped penetration curve was fit to historical market shares for electronic ballasts and then applied to project future adoption of advanced lighting distribution systems and controls. This curve indicated that nearly 50% of the ultimate market penetration was achieved after nine years.

#### 4.4.1.4 Sources


(1) *Annual Energy Outlook 2002*. 2002. Energy Information Administration, Washington, D.C.
(2) See http://eande.lbl.gov/btp/450gg/publications.html and www.cmpco.com/services/pubs/lightingfacts/controls.html
(3) Elliott, D.B., D.M. Anderson, D.B. Belzer, K.A. Cort, J.A. Dirks, D.J. Hostick. 2004. *Methodological Framework for Analysis of Buildings-Related Programs: The GPRA Metrics Effort*. PNNL-14697. Pacific Northwest National Laboratory, Richland, Washington.


### 4.4.2 Solid State Lighting

#### 4.4.2.1 Target Market

**Project Description.** The Solid State Lighting activity develops and accelerates the introduction of solid-state lighting and seeks to achieve the following for lighting:

- Significantly greater efficacy than conventional sources, such as T8 fluorescents
- Easy integration into building systems of the future
- Ability to provide the appropriate color and intensity for any application
- Ability to last 20,000 to 100,000 hours
- Ability to readily supplement natural sunlight.

**Market Description:** The market includes all commercial buildings, with some technologies being introduced into residential buildings.

**Size of Market(1):** Lighting consumes 26% (3.9 QBtu) of the primary energy used in commercial buildings, which had building stock of about 69 billion ft$^2$ in 2000.[h]

**Baseline Technology Improvements.** For this analysis, PNNL did not suggest any changes in technology improvements, apart from the EIA baseline.

#### 4.4.2.2 Key Factors in Shaping Market Adoption of EERE Technologies

**Key Consumer Preferences/Values.** The following nonenergy characteristics were not considered in developing energy output estimates:

- Helps maintain U.S. semiconductor leadership
- Develops U.S. leadership in lighting technology
- Reduces pollution and contributes to U.S. climate-change goals
- Improves U.S. productivity from better lighting in work environments
- Responds to industry-initiated collaborative.

#### 4.4.2.3 Methodology and Calculations

**Technical Characteristics.** Key assumptions concerning the likely dates of introduction and the expected efficacies were influenced by two sources: 1) "The Case for a National Research Program on Semiconductor Lighting,"(2) a white paper prepared by Hewlett-Packard and Sandia National Laboratories and presented in late 1999 at an industry forum; and 2) a more extended study(3) by A.D. Little for BT in early 2001; the study used some of the basic assumptions in the white paper(2) in developing some scenarios related to solid-state lighting.

NEMS characterizes each lighting technology by source efficacy level (lumens/watt), capital cost ($/1000 lumens or $/kLumen), and annual maintenance cost of lamps. For new technologies, the capital costs can be reduced along a logistic-shaped curve. The NEMS model divides the commercial lighting market into four major groups: 1) incandescent CFL (point source), 2) 4-foot fluorescent, 3) 8-foot fluorescent, and 4) high-intensity point source (outdoor lighting). Solid-state lighting was assumed to penetrate the first three market groupings.

Given the cost assumptions, the NEMS model chooses among these technologies for each building type in each census division. For each group, the market is assumed to be further segmented, with each segment characterized by a different discount rate in its decision-making criteria. Within each segment, a lighting technology is selected based on minimum annualized cost.

Solid-state lighting was also assumed to be available in the residential lighting market, where it competes with conventional incandescent and compact fluorescent options.

[h] According to a recent report completed for DOE by Navigant Consulting ("U.S. Lighting Market Characterization, Volume I: National Lighting Inventory and Energy Consumption Estimate," September 2002), the amount of energy used for lighting is greater than EIA has traditionally estimated. The report estimates that commercial lighting requires 4.2 QBtu and residential lighting requires 2.2 QBtu.

**Table 17** summarizes the cost and performance inputs for the solid state lighting technologies used in NEMS-GPRA06 for FY 2006.

**Table 17. Solid-State Lighting Cost and Efficiency Assumptions – FY 2006 GPRA**

| Year | Efficacy (lumens/watt) | Price ($/klm) |
|---|---|---|
| 2005 | 45 | 160.80 |
| 2006 | 45 | 160.80 |
| 2007 | 45 | 160.80 |
| 2008 | 50 | 152.35 |
| 2009 | 55 | 141.11 |
| 2010 | 60 | 126.93 |
| 2011 | 66 | 110.21 |
| 2012 | 72 | 92.00 |
| 2013 | 78 | 73.79 |
| 2014 | 84 | 57.07 |
| 2015 | 90 | 42.89 |
| 2016 | 96 | 31.65 |
| 2017 | 102 | 23.20 |
| 2018 | 108 | 17.11 |
| 2019 | 113 | 12.84 |
| 2020 | 118 | 9.91 |
| 2021 | 123 | 7.93 |
| 2022 | 128 | 6.60 |
| 2023 | 132 | 5.72 |
| 2024 | 136 | 5.13 |
| 2025 | 140 | 4.75 |
| 2026 | 143 | 4.49 |
| 2027 | 146 | 4.32 |
| 2028 | 148 | 4.21 |
| 2029 | 151 | 4.14 |
| 2030 | 153 | 4.09 |

#### 4.4.2.4 Sources


(1) *Annual Energy Outlook 2002*. 2002. Energy Information Administration, Washington, D.C..

(2) Haitz, R., and F. Kish (Hewlitt-Packard Co) and J. Tsao and J. Nelson (Sandia National Laboratories). 1997. "Case for a National Research Program on Semiconductor Lighting," White paper presented at the 1999 Optoelectronics Industry Development Association forum in Washington D.C., October 6, 1999.

(3) A.D. Little. 2001. *Energy Savings Potential of Solid State Lighting in General Lighting Applications*. Prepared for DOE's Office of Building Technology, State and Community Programs by A.D. Little, Cambridge, Massachusetts.

## 4.5 Space Conditioning and Refrigeration R&D

### 4.5.1 General Target Market

**Project Description**[1]**.** Over the next five years, space-conditioning activities will focus on the following areas:

1. Developing and demonstrating low-cost, commissioning and remote fault detection and diagnostics systems for HVAC systems, including commercial rooftop and residential systems. These packages aid in commissioning, and can continuously monitor performance and detect faults such as charge leakage, economizer malfunction, heat exchanger fouling, burner condition, and controls malfunctions. New sensor, electronics, and software technologies that leverage wireless networks, mobile computers, and the Internet, will be implemented to provide user-friendly, low-cost systems. Potential DOE regulations may ensure factory installation of these systems, and DOE efficiency standards may address efficiency degradation over time.
2. Developing technologies such as intelligent wireless controls, and low cost thermal storage to reduce peak electricity demand from HVAC.
3. Because future efficiency gains in HVAC systems will flow increasingly from electronic components, R&D will focus on leveraging advances in electronics, controls and low cost computing power to improve system efficiency. Examples of possible research topics include: development of variable speed motor and drive technologies with low applied costs, using adaptive/fuzzy logic controls to enhance comfort and indoor environmental quality while reducing energy consumption, providing real-time feedback to consumers on energy consumption in order to change usage patterns, optimizing operations based on outdoor and occupancy conditions, or developing modules to be integrated with HVAC systems that can respond to price and peak demand signals.
4. Developing low-cost, high efficiency unitary air conditioners and heat pumps, especially in the lower capacities needed for ZEH, and in larger commercial systems where the market does not currently focus on part load efficiency. A key element of this effort will involve reducing the cost of components to improve part-load efficiency (e.g. variable speed motors and drives, new concepts for modulating compressors).
5. Commercializing low-nergy approaches to reduce ventilation loads, such as natural or hybrid ventilation; pre-cooling with cool, dry nighttime air (with integrated energy storage); demand control ventilation that is simple to implement, widely accepted, and cost-effective; and low-cost air-leaning technologies that allow a reduction in ventilation rates.
6. Creating products and identifying practices that substantially reduce distribution losses through better duct installation and sealing techniques, reduction in losses in partially conditioned spaces, and consideration of novel distribution approaches, and evaluating the energy savings potential of ductless systems.

**Baseline Technology Improvements.** For this analysis, PNNL did not suggest any changes in technology improvements, apart from the EIA baseline.

## 4.5.2 Unitary DX System

### 4.5.2.1 Target Market

**Project Description[1].** Develop prototypes for two-three concepts that have the long-term potential to reduce annual HVAC energy consumption by 50%, with a modest installed cost premium over conventional systems.

**Market Description.** Residential and Commercial Buildings.

**Market Introduction:** 2007; this project was assumed to accelerate the introduction of this technology into the marketplace by 10 years.

### 4.5.2.2 Key Factors in Shaping Market Adoption of EERE Technologies

**Price.** Installed cost initially will be double the cost of conventional systems, declining to less than 10% greater than conventional systems by 2025.

### 4.5.2.3 Methodology and Calculations

**Inputs to Base Case.** The base case was developed based on an assortment of sources, including AEO 2003, CBECS 95, RECS 97, and several other sources, all of which are documented by PNNL[3].

**Technical Characteristics.** 50% reduction in heating and cooling over conventional systems.

**Expected Market Uptake.** This activity targets all residential cooling equipment and heat pumps, and all commercial DX cooling equipment and heat pumps.

## 4.5.3 Ventilation Load Reduction

### 4.5.3.1 Target Market

**Project Description.** The objective of this project is to apply advanced technologies to reduce ventilation energy used in commercial buildings, including both fan energy and conditioning of outside air, by 50% in the long term.

**Market Description:** Commercial buildings.

**Market Introduction:** 2007; this project was assumed to accelerate the introduction of this technology into the marketplace by 10 years.

### 4.5.3.2 Key Factors in Shaping Market Adoption of EERE Technologies

**Price.** Installed cost will be 15%-20% greater than conventional systems

#### 4.5.3.3 Methodology and Calculations

**Inputs to Base Case.** The base case was developed based on an assortment of sources, including AEO 2003, CBECS 95, RECS 97, and several other sources, all of which are documented by PNNL [3].

**Technical Characteristics.** 50% reduction in ventilation and 50% reduction in the conditioning (heating and cooling) of outside air (i.e., make-up air)

### 4.5.4 Commercial Refrigeration

#### 4.5.4.1 Target Market

**Project Description.** DOE is working to improve the efficiency of refrigerated display cases and developing methods of recovering reject heat for space conditioning. This project was modeled as an advanced supermarket refrigeration system that would target heating, cooling, and refrigeration end-use loads in the commercial food sales sector. The heating and cooling reductions occur because commercial refrigeration equipment draws a large amount of heat from the conditioned space, which must be made up by the heating equipment. In addition, heat energy can be recovered and used by the heating equipment, thus reducing the heating energy consumption and cost. These end uses comprise about 66% of total building, 67% of electric, and 61% of total natural gas end-use energy consumption.[2]

**Displaced Technology:** Conventional refrigeration equipment in food-sales buildings.

**Performance Target:** Reduced energy for building HVAC and refrigeration equipment during the next 15 to 20 years, specifically at least 15% for supermarket refrigeration and HVAC while reducing refrigerant needed. For FY 2006, PNNL assumed an overall 22.5% reduction in HVAC end-use energy consumption.

**Market Description:** All commercial food-sales buildings.

**Market Introduction:** 2004; PNNL assumed this project would accelerate the introduction of this technology into the marketplace by 10 years.

### 4.5.5 Remote Fault Detection and Diagnostics

#### 4.5.5.1 Target Market

**Project Description[1].** This project will develop and demonstrate low-cost commissioning and remote fault detection and diagnostics (FDD) systems for unitary HVAC systems, including commercial rooftop and residential systems.

**Market Description.** Residential and commercial space conditioning equipment.

**Market Introduction:** 2008 (Commercial), 2009 (Residential); this project was assumed to accelerate the introduction of this technology into the marketplace by 10 years.

#### 4.5.5.2 Key Factors in Shaping Market Adoption of EERE Technologies

**Price.** $50-100 increase in cost per piece of equipment

#### 4.5.5.3 Methodology and Calculations

**Inputs to Base Case.** The base case was developed based on an assortment of sources, including AEO 2003, CBECS 95, RECS 97, and several other sources, all of which are documented by PNNL [3].

**Technical Characteristics.** 20% reduction in Cooling and Heating (heat pumps and integrated gas heating – i.e., rooftop package units).

**Expected Market Uptake.** The market penetration goal is to enter the commercial market in 2008 with 10% penetration by 2010 and 50% penetration by 2015; and to enter the residential market in 2009 with 10% penetration by 2011 and 50% penetration by 2015.

### 4.5.6 Sources

(1) "Building Technology Program: Research, Development and Demonstration Plan, Planned Program Activities for 2004-2010." Final Draft. U.S. DOE, January 9, 2004.
(2) Belzer, D.B and L.E. Wrench. 1997. *End-Use Consumption Estimates for U.S. Commercial Buildings, 1992*. PNNL-11514, Pacific Northwest National Laboratory, Richland, Washington.
(3) Elliott, D.B., D.M. Anderson, D.B. Belzer, K.A. Cort, J.A. Dirks, D.J. Hostick. 2004. *Methodological Framework for Analysis of Buildings-Related Programs: The GPRA Metrics Effort*. PNNL-14697. Pacific Northwest National Laboratory, Richland, Washington.