Potential for governmental policies to improve U. S. lighting energy efficiency in commercial and residential buildings

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1. SYNOPSIS

We examine alternative governmental policies for improving U.S. lighting energy efficiency considering technological opportunities, economic costs and benefits, and existing utility and government programs.

2. ABSTRACT

Lighting accounts for about 19 percent of U.S. electricity consumption and 7 percent of all national energy use. This paper summarizes an analysis of policy options available to the U.S. government for improving lighting energy efficiency in U.S. buildings. Lighting markets are already undergoing dynamic changes, including technology shifts, electric utility incentive programs, state building codes, and national government programs. Additional opportunities for national policies are identified, including education and labelling, tax credits or rebates, building codes, and component efficiency standards. Most policies are interpreted in terms of adoption of specific technologies - including lamps, lamp/ballast combinations, fixtures, and controls - based upon detailed engineering and economic analysis. Energy savings of 5-63 percent of cumulative U.S. commercial indoor lighting energy consumption in the period 1995-2030 are projected, depending upon the policy. Significant savings are also found in the residential sector. Economic analysis indicates that combined energy and maintenance savings offset increased equipment costs for most policies, resulting in net present values of $40-200 billion in the commercial sector. Some government incentive programs may be ineffective, if preceded by incentives offered by other governmental agencies and by electric utility companies. Other important differences among policies are discussed, including: (1) the certainty of projected savings, related to participation/compliance/enforcement; (2) equity issues (the extent to which participants in the energy savings also bear the costs, rather than sharing costs with non-participants); (3) administrative burden (large for government incentive programs and for enforcement of building codes, but small for education and component efficiency standards) and (4) impact on manufacturers.

3. INTRODUCTION

This study was undertaken to estimate the potential national impacts of several governmental policies for improving lighting energy efficiency in residential and commercial buildings beyond existing programs. Many private and public electric utility companies have already implemented demand-side management (DSM) programs which are improving energy efficiency of lighting, and some progress has been made in developing U.S. lighting policies at both the national and state levels. The U.S. DOE's Office of Building Technologies has evaluated lighting efficiency incentives as part of its analysis for the National Energy Strategy. Fluorescent and incandescent lamp standards are included in the national Energy Policy Act of 1992 (P.L. 102-486, October 24, 1992). Previous legislation[1] requires that all fluorescent lamp ballasts

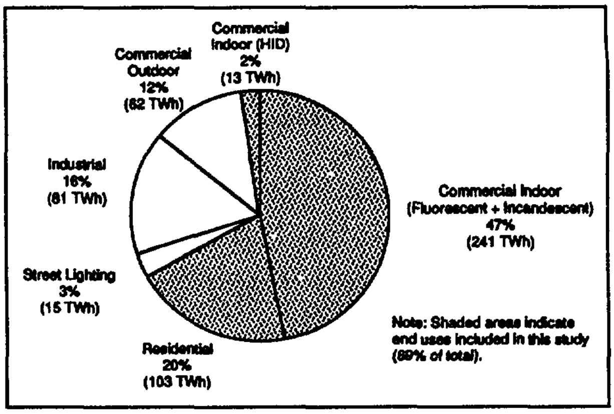


Figure 1. *U.S. lighting electricity*

meet a minimum ballast efficiency factor, with a possible update effective in 1996. A few states have analyzed or implemented lamp and luminaire standards. Both the national industry consensus (ASHRAE/IES) building energy code and DOE's voluntary code incorporate lighting regulations, and several states have adopted these model codes.

3.1 Current consumption

In 1990, lighting was responsible for 515 TWh_e of energy use in the U.S. (worth US $36 billion to consumers), excluding interactions with heating and cooling energy use.[2] The energy used for lighting is equivalent to 19 percent of total U.S. electricity use and 7 percent of total U.S. primary energy use. Figure

Table 1. *Fluorescent lamp technology options modeled (commercial sector)*

Technology Option	4-Foot	8-Foot	8-Foot High-Output
Baseline	Standard F40T12	Standard F96T12	Standard F96T12 HO
Eliminate Highest Wattage	34 W T12 Reduced-Wattage	60 W Reduced-Wattage	95 W Reduced-Wattage
Minimum LCC Lamp	F32 T8 w/ Magnetic Ballast	60 W Reduced-Wattage	95 W Reduced-Wattage
Minimum LCC Lamp/Ballast (Min LCC Comb)	F32T8 w/ Electronic Ballast	60 W Reduced-Wattage w/ Electronic Ballast	95 W Reduced-Wattage w/ Electronic Ballast
Maximum Technology Lamp	Maximum Technology	T-8 w/ Electronic Ballast	Maximum Technology
R&D Lamp, R&D Combination	Research & Development	Research & Development	Research & Development

Notes: For the 4-foot and 8-foot high output product classes, the Maximum Technology option is a hypothetical lamp whose characteristics are based on an efficacy of 100 lumens/watt when used with an HF ballast, as estimated to be achievable by the year 1995. The Research and Development lamp is a hypothetical lamp based on an efficacy of 110 lumens/watt with an HF ballast, as estimated by manufacturers as likely to be achievable by the year 2000.

1 shows the end-use breakdown of lighting electricity consumption. Interior lighting is studied for the commercial sector, while both interior and exterior lighting are considered for the residential sector.

3.2 Technological opportunities

Analysis and implementation of energy-efficient lighting systems is multifaceted. Many different technologies are involved that interact with each other—lamps (incandescent, compact fluorescent, and HID), ballasts (for fluorescent and HID lamps), and fixtures with their reflectors and lenses. Control systems and operation patterns must also be considered (timers, automated dimming, and occupancy sensors). Lighting applications are diverse, ranging from offices, restaurants, hallways, to hospital operating rooms. Lighting energy use influences heating and cooling requirements in buildings. Successful lighting system design must also address interactions between architectural design elements and daylighting availability. Proper system installation and ongoing operation and maintenance are crucial to the performance of a lighting system over its lifetime. The economic aspects of the preceding points must also be considered for policy making.

In this analysis, lighting quality issues are considered mainly from a technological perspective. That is, when lamps, ballasts, or fixtures are replaced, the new components or luminaire system must provide equivalent light output to the old; calculations are performed to "normalize" the light output of the two lighting systems.

Technology options include eliminating the highest-wattage product, adopting the minimum life-cycle-cost option, adopting the "maximum technology" product that could be on the market by 1995, and the adopting "research and development" technology that could be commercialized by the year 2000. The energy and economic characteristics of one technology (fluorescent lamps) are presented in Section 4 as an example.

3.3 Market uncertainties

Projecting the future, even without new national lighting policies is difficult. Electric utility and other incentive programs could permanently change the set of available technologies as suppliers phase out older, less-efficient (unsubsidized) designs. As newer technologies increase market share, their prices are expected to decline from current levels. To the extent that local incentive programs and other market forces lead to increased production and lower prices of more efficient lighting equipment, national policies (e.g., those considered here) will have less impact because there will be fewer energy savings to pursue. Alternatively, if these forces are short-lived or ineffective, greater savings with greater certainty can be captured by national policy. In either case, national policy would *ensure* significant improvements in the efficiency of lighting systems and would indirectly support voluntary programs by stimulating market availability.

With these factors in mind, three baselines have been created from which energy, economic, and environmental benefits and costs are measured.

1. *No-Programs Baseline*: Assumes that consumer decisions on efficiency level are altered only by energy price changes. Results are virtually identical to a frozen-efficiency baseline because projected electricity prices rise only slightly in real terms. Increased floorspace (100 percent by 2030) becomes the primary determinant of lighting energy demand.

2. *Low-Efficiency Baseline*: Assumes that significant lighting efficiency improvements are stimulated in the near-term by utility demand-side management (DSM) programs, and existing federal and state building codes and standards.[3] Most of the incentive programs are assumed present from 1990-1995, but removed thereafter; only state building codes remain.

3. *High-Efficiency Baseline*: Savings from current programs and standards are assumed to persist throughout the analysis period to 2030. Equipment costs continue to fall after 1995 (more than in the Low-Efficiency Baseline). This baseline is considered the "most likely" scenario.

The High- and Low-Efficiency Baselines are not *technical potential* scenarios, nor are they *achievable* *potential* scenarios. Forecasts of policy impacts compared to these baselines reveal savings potential *beyond* existing programs.

3.4 Policy options

The following policy options are considered in the analysis (see Figure 2 for more detail):

- Mandatory component performance and prescriptive standards
- Mandatory system performance standards
- Voluntary component standards
- National incentive programs
  - consumer rebates
  - consumer tax credits
- Education/information programs
  - consumer/designer education
  - component labeling

Component *performance* standards studied for the commercial and residential sectors set minimum efficiency limits for specific technologies (e.g. lamps) while *prescriptive* standards require the use of specific equipment (e.g. programmable timer controls). Mandatory and voluntary component performance and prescriptive standards are analyzed for incandescent lamps, fluorescent lamps, fixtures, and controls. Voluntary standards for the commercial sector are modeled as delayed mandatory standards. Ballasts are treated only as part of the lamp/ballast system for the lamp analysis.

System performance standards are typically implemented through building energy codes that impose limits on the installed Lighting Power Density (LPD), measured in watts/square meter. The impacts of the lighting provisions of two existing codes, ASHRAE/IES 90.1-1989 and DOE 1993, are studied as if the codes became mandatory nationwide.

National incentive programs and education/information programs are analyzed for the commercial sector. Impacts are estimated using assumptions for participation rates and effects on consumer behavior based on the limited amount of research available on these types of policies. Labeling programs alone are assumed to have minimal effect given the absence of evidence that existing labeling programs, which target other end uses such as appliances, influence consumer behavior. However, labeling or rating programs can enhance the effectiveness of standards, incentives, consumer education, and other policies.

4. METHODOLOGY

The method involves: (1) characterizing the technologies available in the near term (1995) and mid term (2000); (2) forecasting lighting energy consumption; (3) defining a set of potential governmental policies at the national level; and (4) quantifying the effects of implementing those policies.

The analysis begins with detailed characterizations of individual technologies, building up to projections of national lighting energy consumption. Engineering data on component energy consumption, performance, lumen output, lifetime, replacement cost, and price are gathered for standard and energy-efficient lighting technologies including lamps, their associated ballasts, fixtures, and controls. Eleven lamp product classes and four fixture product classes are examined for the commercial sector, and four lamp product classes are studied for the residential sector. For example, Table 1 presents some of the technology options analyzed for the fluorescent lamp product classes in the commercial sector, and Table 2 lists their efficacies, prices, and service lives.

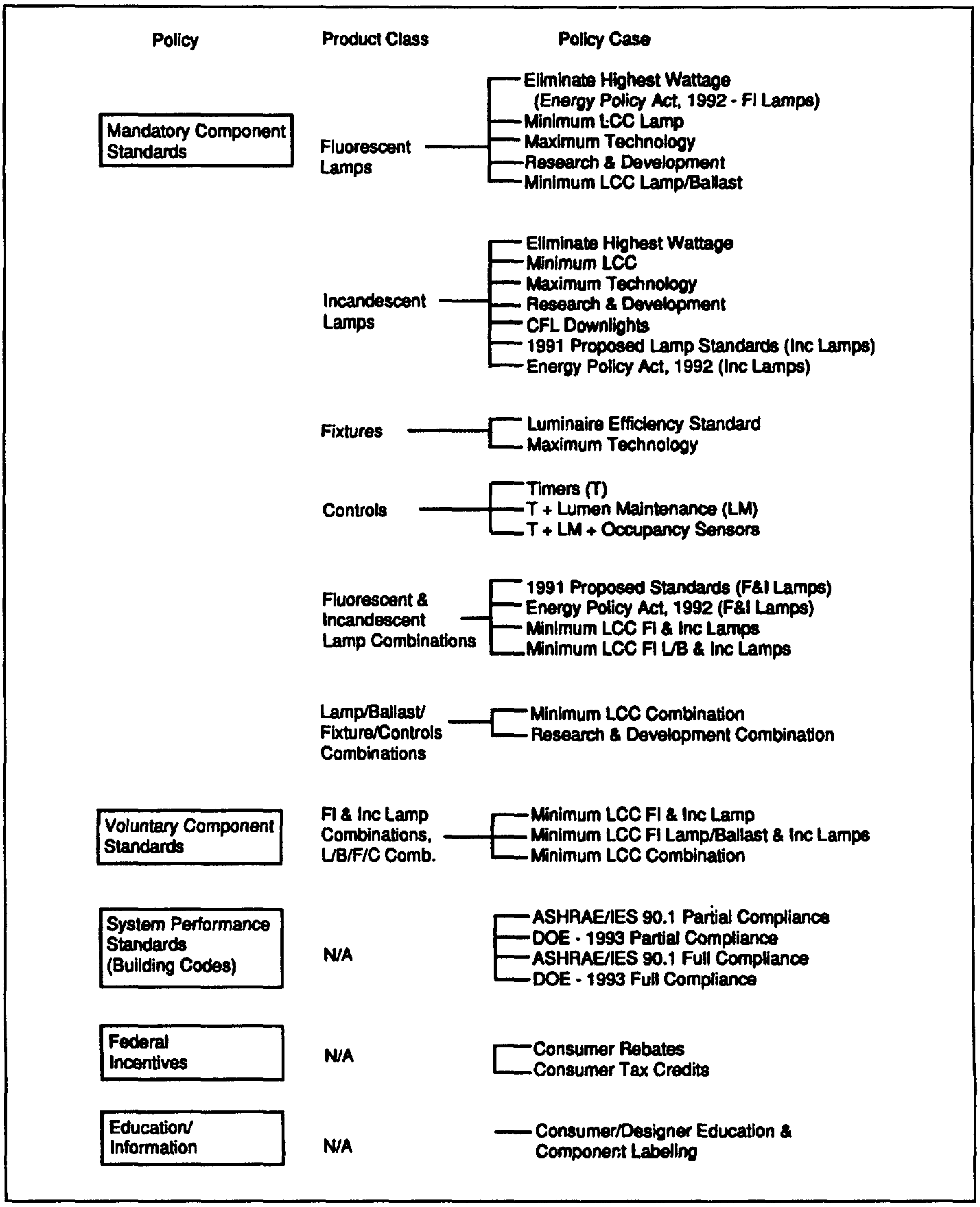


Figure 2. *Policies and technologies included in commercial sector analysis*

This specific engineering information is then mapped onto the existing and future lighting equipment stock. An analysis of aggregate lighting energy consumption, equipment sales, and current and future saturations of technologies is undertaken to characterize the breakdown of new equipment sales according to equipment

Table 2. *Fluorescent lamp efficacies, prices, and service lives (commercial sector)*

Product Class	Technology Option	Efficacy (Lumens/Watt) 2-lamp, 1-ballast		Lamp Price ($1990)	Service Life (Years)
		Magnetic Ballast	Electronic Ballast		
4-Foot Lamps	F40 T12	65	75	1.12	3.41
	34 W Reduced Wattage T12	64	75	1.56	3.41
	F32 T8	78	88	2.45	3.66
8-Foot Lamps	F96 T12	70	84	2.60	2.05
	60 W Reduced-Wattage	73	90	3.27	2.05
8-Foot HO	F96 T12 HO	68	84	3.52	2.05
	95 W Reduced-Wattage	72	84	4.50	2.05

types (e.g., incandescent, fluorescent, HID lamps), and into sub-categories within those types (e.g., four-foot vs. eight-foot lamps, F40 vs. F32 lamps, etc.). To extrapolate from individual technologies to aggregate energy consumption for commercial lighting, the Commercial Buildings Energy Consumption Survey (CBECS) data on operating hours by technology are used, disaggregated by building types. In the residential sector, lighting equipment stock and operating hours are derived from a compilation of utility surveys and manufacturer estimates. No reductions in lighting levels are assumed.

Policies are modeled by altering the available mix and efficiencies of technologies. For lamp component standards, for example, those lamp designs that are less efficient than the standard are prohibited, and more efficient designs must be chosen. Changes in equipment and operating costs caused by each policy are also analyzed.

The study uses end-use forecasting models to project future U.S. energy consumption for lighting (and other end uses): for the commercial sector, the Electric Power Research Institute's COMMEND 3.1 model; and for the residential sector, Lawrence Berkeley Laboratory's Residential Energy Model (LBL-REM). The national demand for lighting energy is modeled for eleven commercial building types and for three residential building types. The forecasting models do not contain detailed technology information but utilize weighted-average consumption in the form of EUIs (Energy Use Intensities), kWh/m^2-year, or UECs (Unit Energy Consumption, expressed as kWh/household-year), for each building type. Interactions between lighting and space-conditioning energy use (HVAC), are not included in the results reported here.

5. RESULTS

Figures 3 and 4 illustrate different projections for commercial indoor lighting energy intensity and consumption in the U.S.. The top three lines are the baselines used in this analysis. The next line shows the impact of the Energy Policy Act of 1992 fluorescent and incandescent lamp standards.

The lowest two lines show that substantial additional energy savings are achievable from the economic- and technical-potential cases. These two potentials use results of the Minimum Life-Cycle Cost (Min LCC) Combination and the Research and Development (R&D) Combination policy cases. In the Min LCC case, baseline technologies are replaced by minimum-life-cycle cost components presently available in the U.S. For 4-foot (1.22 m) lamps, T8 (26 mm) lamps with high frequency electronic ballasts are used in high-efficiency fixtures, and for 8-foot (2.44 m) lamps, reduced-wattage lamps with HF ballasts are used. Compact fluorescent lamps (twin-tube with magnetic ballast) are substituted for 2/3 of the incandescent socket stock and the remainder are halogen general service and halogen infrared reflector incandescent. Programmable timers, lumen maintenance, and occupancy sensor controls provide savings fractions that are achievable and cost-effective with estimated 1995 controls technologies and prices. In the R&D case, higher-efficacy lamp/ballasts in super-efficient (specular reflector) fixtures are used for 4- and 8-foot lamps. Quad-tube compact fluorescents with HF electronic ballasts are used in 90 percent of the incandescent sockets, with the remainder coated filament lamps (an R&D technology). The three types of controls used in the Min LCC case, with the addition of daylight/dimming controls, provide savings fractions achievable with technologies and prices estimated available by the year 2000. In both cases the components are used in combination and interactive effects are calculated.

In this study, the scope of technical and economic savings potentials is defined as follows:[4]

- For the commercial sector, the difference between the Low-Efficiency Baseline and the R&D Combination case represents the *technical* potential energy savings from the energy-efficient technologies considered, measured with respect to the most conservative estimate of market trends in the absence of new policies. The difference between the Low-Efficiency Baseline and the Minimum Life-Cycle Cost Combination case represents the maximum *economic* potential.

- For the residential sector, the difference between the Frozen-Efficiency Baseline and the R&D Combination case represents the *technical* potential energy savings from the energy-efficient technologies considered. The difference between the Frozen-Efficiency Baseline and the Minimum Life Cycle Cost Combination case represents the maximum *economic* potential savings.

Figure 5 shows the commercial sector energy savings, expressed as a range over the two baselines. All national commercial policies analyzed in this study save energy, peak power, and money, and reduce emissions beyond the High-Efficiency Baseline. Tables 3 (at the rear of the paper) and 4 present a summary of results. Table 5 presents results for the residential sector for two baselines.

System performance standards, or building codes, are applied only to new construction and substantial renovations. Savings from system performance standards are similar to those from single-component "Eliminate Highest Wattage" or "Minimum LCC" fluorescent or incandescent cases. The component combination case shows larger savings because fixtures and controls are included, whereas system performance standards specify maximum lighting power densities that do not embody all possible efficient technologies and do not achieve full compliance. The costs of system performance standards are not estimated because building codes allow substantial flexibility in choice of technologies.

For consumer rebates, tax credits, education, and labeling, the zero-percent savings estimates in Figure 5 are based on the assumption that national programs beyond aggressive utility rebate programs in the High-Efficiency Baseline will save no marginal energy, whereas the high estimates (relative to the Low-Efficiency Baseline) assume additional savings from these policies, represented by dotted lines to reflect the greater uncertainties.

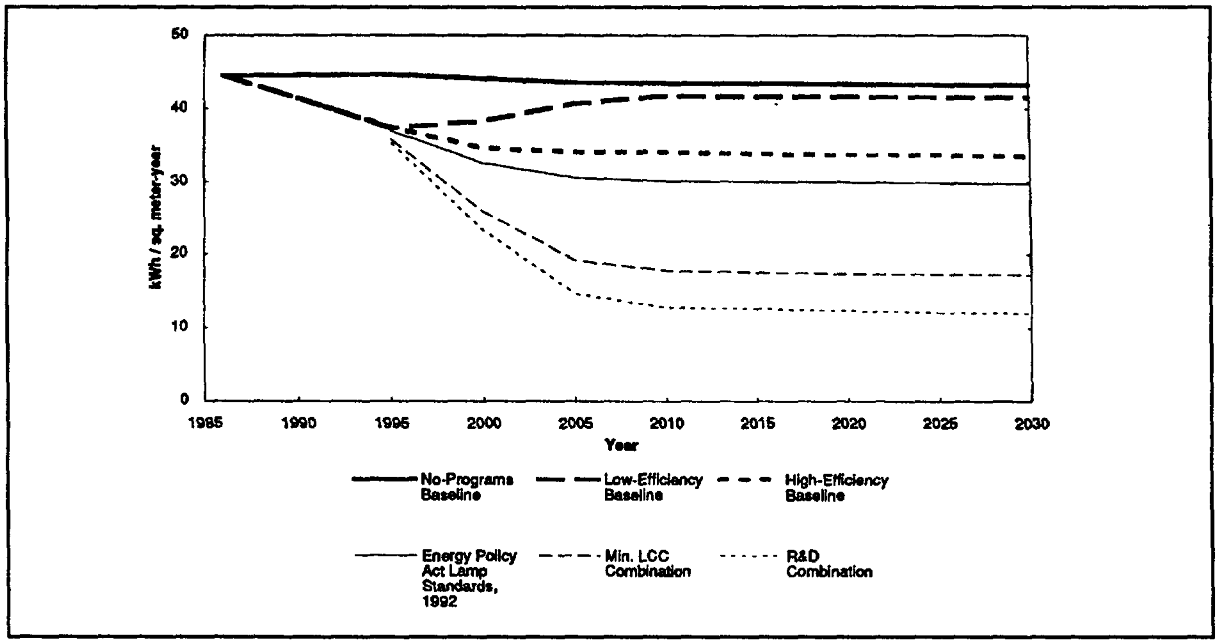


Figure 3. *Annual lighting energy use intensity, baselines and illustrative policy cases, commercial sector*

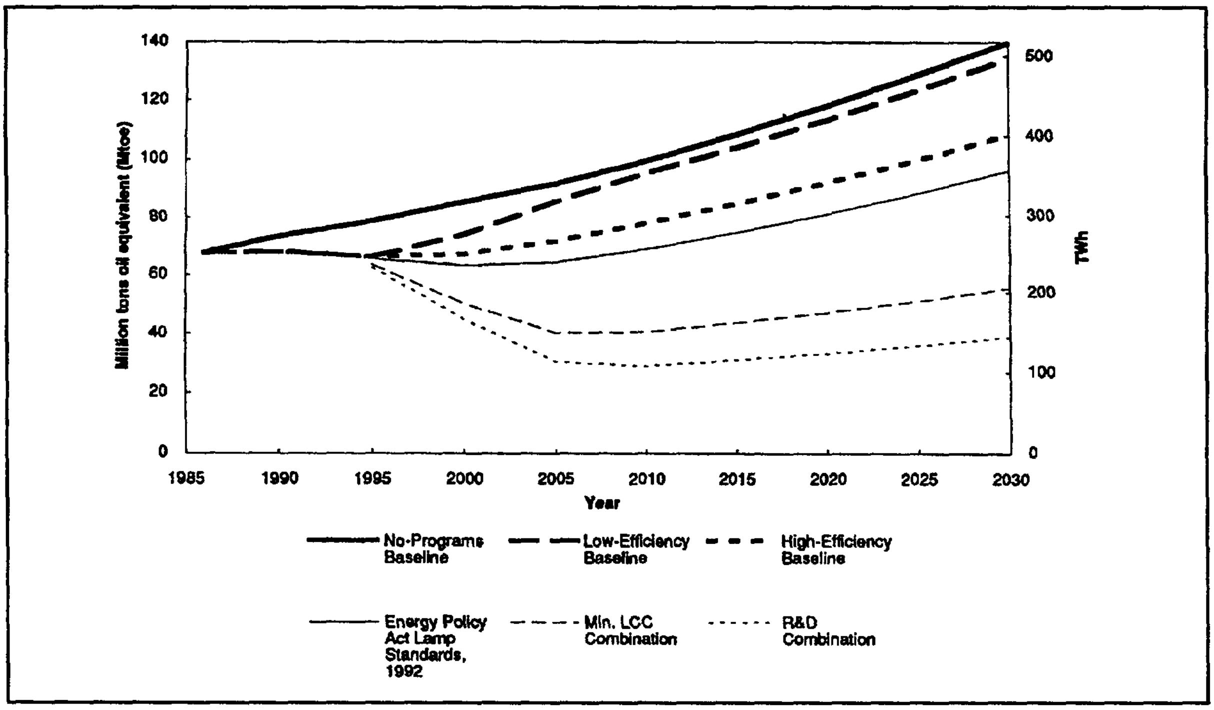


Figure 4. *Annual lighting energy consumption, baselines and illustrative policy cases, commercial sector*

5.1 Policy Discussion

The magnitude of the savings depends upon the extent to which other forces (utility programs, other incentive programs, technological development, and pricing effects) operate. Nonetheless, in most policy approaches, a positive role for national action is identified.

5.1.1 Advantages and Disadvantages of Specific Policy Options

Selecting the appropriate policy or mix of policies will involve considerations beyond the quantification of projected energy and economic savings (Table 3).

- *Mandatory component performance standards* have the advantages of relative certainty of energy savings per component, ease of monitoring, small administrative burden, and costs equitably borne by the participants. The disadvantages are restriction of the range of technologies that can be manufactured and of designer and consumer choices of lighting components, and enforcement.

- *Voluntary component standards* are less restrictive than mandatory standards, but energy savings are projected to be achieved more slowly and with much less certainty.

- *Mandatory system performance standards* (or building codes) have the potential to achieve significant energy savings with costs borne by participants, but disadvantages include less certainty of compliance, difficulty in enforcement, and a large administrative burden.

- *National incentive programs* (rebates or tax credits) have significant potential savings, but carry a large administrative burden, and are assumed in this study to be inconsequential if other incentives have already been offered on a large scale.

- *Education/information programs* target the largest population, but the timing, magnitude, and reversibility of savings are uncertain. Nonetheless, education programs are important to ensure longer-term savings from better lighting design, higher participation rates in programs, and more rational economic decisions.

A diversity of policy options applied collectively are likely to achieve the greatest levels of cost-effective energy savings.

5.1.2 Implications for Policy Making

Implementation of national policy options can influence only some of the factors necessary to achieve comprehensive energy-efficient lighting. The inherently systems-based nature of lighting highlights the importance of proper system design and commissioning, ongoing operation and maintenance, thorough understanding of the interactions between lighting and space conditioning systems, and integrating artificial and daylighting technologies. These aspects of lighting are difficult to directly (and predictably) influence through formal policy mechanisms.

Within the realm of policy options examined in this study, the following observations help place the results in context with the concerns, tools, and objectives of policy makers:

Market trends may yield significant energy savings (but with considerable uncertainty) and new policies can cost-effectively achieve even more.

- The Low- and High-Efficiency Baselines shows substantial cumulative energy savings even in the absence of new national policies (4 percent to 22 percent, respectively) in comparison to the No-Programs Baseline.

- New national policies based on minimum life-cycle cost offer absolute savings exceeding the maximum future savings likely from current programs and policies.

A mixture of strategies promises to be the most sound approach for increasing lighting energy efficiency.

- Important synergies can operate among policy options. For example, financial incentives such as rebates are likely to be more effective when complemented with strong education/information programs. Mandatory standards in turn serve as a potentially valuable "safety net" in the event that the other policies fail to attain the intended energy savings. In addition, financial incentive mechanisms can be used to reward manufacturers or consumers that exceed the standards.

No single form of standards is universally applicable.

- System performance standards (e.g. building codes) may be more difficult to implement and enforce than component standards, requiring post-evaluation of individual buildings for compliance.

- Component and system performance standards can be used in combination to ensure both the availability of efficient technologies and a flexible design framework in which they can be applied. However, experience in state efforts shows that policies using both types of standards must be carefully designed from both technical and political standpoints.

Comprehensive standards offer a cost-effective savings potential well in excess of that anticipated from the Energy Policy Act of 1992 lamp standards.

- While national efficiency standards for lamps have recently been legislated, they capture only a fraction of the full cost-effective savings potential from lighting component standards. As shown in Tables 2 and 3 with respect to the High-Efficiency Baseline in 2030, the Energy Policy Act of 1992 standards for incandescent and fluorescent lamps are projected to achieve *one-fourth* of the potential commercial energy savings and *one-seventh* of the potential residential energy savings in comparison to the Minimum Life Cycle Cost Combination cases. The difference in net present values for the commercial and residential sectors is US $57 billion and the peak-power difference is 34,000 megawatts.

Low program participation or incomplete standards compliance can have significant opportunity costs.

- Higher participation may result from a consensus standard-setting process, involving collaboration among policymakers, the lighting industry, energy conservation advocates, designers, and other interested parties.

- Estimates derived in this study show approximately two-thirds as much energy savings for mandatory building code standards than would be the case with perfect compliance.

The lighting industry can adapt to efficiency policies given sufficient lead time, particularly if there is broad participation in developing the specific policies.

- Standards have costs as well as benefits for the lighting industry. Manufacturers are projected to be able to adjust to the policies analyzed, given sufficient advance notice. On the one hand, standards lead to increased requirements for capital investment and changes in product mix and technology market shares. Conversely, standards create an environment in which manufacturers have much greater certainty about the level of demand for efficient products without regulation.

Considerable reductions in airborne emissions from electric power production can be achieved by utilizing energy-efficient lighting. Research and development is essential for a continued supply of conservation resources.

- Significant past progress in lighting technology has made possible the large savings identified in this study. Ongoing R&D can ensure a continued supply of conservation opportunities. Technologies just now approaching market readiness offer a savings potential of approximately one-third beyond current minimum life-cycle cost options for the commercial sector (Table 4) and approximately one-half in the residential sector (Table 5). Additional technical advances are on the horizon.

5.1.3 Policy Approaches Not Examined

Following is a brief discussion of additional policy approaches—applicable to both the commercial and residential sectors—not examined in this study because of modeling difficulties and/or lack of field experience upon which to estimate impacts.

Increased Research and Development — The effort expended on R&D by industry and by the public sector will strongly influence the rate of commercialization of new energy-efficient lighting products.

Market Transformation — The concentrated government and corporate purchasing power can increase the availability and penetration of efficient lighting technologies.

Table 4. ***Summary of cumulative impacts of selected commercial lighting policies measured with respect to the High- (Low-) Efficiency Baseline****

Type of Impact	Energy Policy Act of 1992 Lamp Standards	Minimum Life-Cycle Cost Combination [Max. Econ. Pot'l]	Research & Development Combination [Technical Potential]
Lighting Energy Intensity in 2030:			
Energy Use Intensity, (kWh/ft^2-year)	2.76 (2.93)	1.59 (1.59)	1.11 (1.11)
Primary Energy Savings (Mtoe) (1995-2030)	306 (729)	1247 (1812)	1624 (2188)
Electricity Savings in 2030 (TWh$_e$)	45 (117)	197 (291)	258 (351)
(Percent Savings)	11% (24%)	49% (59%)	64% (71%)
Peak Power Savings by 2030 (GW, 10^9 W)	9 (23)	37 (54)	49 (66)
Net Present Value ($1990 billion)$^+$	23 (56)	47 (97)	65 (109)
Avoided Emissions (1995-2030)			
- CO_2 (Billion tonnes)	1.0 (2.5)	3.9 (6.5)	4.5 (7.6)
- SO_2 (Million tonnes)	2.0 (5.1)	7.5 (12.8)	8.2 (16.0)
- NO_x (Million tonnes)	1.8 (4.6)	7.1 (11.9)	7.9 (14.5)

*Excludes interactions with heating, ventilating, and air conditioning (HVAC) energy use.

$^+$Real electricity prices increase only slightly between 1995 and 2030. Real discount rate = 4 percent.

Utility Shareholder Incentives — Recent experience in California and New England has shown that electric utilities promote energy efficiency much more aggressively (and cost-effectively) when they are given a financial incentive for doing so.

"Golden Carrots" — Rebates to manufacturers can accelerate the commercialization of new efficient products, or increase the marketing effort expended on existing efficient ones.

Fleet-Averaging — Rather than regulating the efficiency of each product, a standard (target) is set such that the sales-weighted average efficiency of all products of a certain type/class sold must meet or exceed the target.

"Feebates" — Complement a voluntary lighting component standard or mandatory fleet-average standard by paying a rebate to buyers of more efficient products and assessing a fee on buyers of less efficient products.

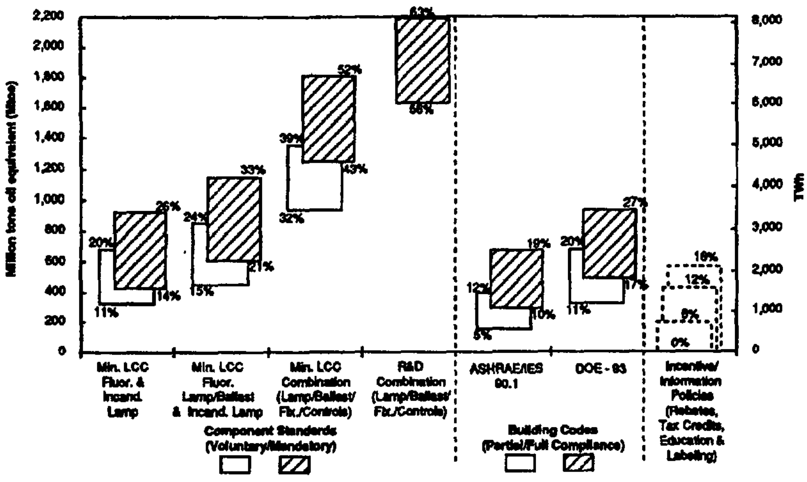
Mandatory Efficiency Renovation at Time of Resale — Require that lighting efficiency be improved when a building is resold, renovated, or refinanced.

Raising Electricity Prices — Price increases (taxes) would, in principle, encourage increased efficiency investment for lighting and other end uses, although the effects are difficult to predict.

6. CONCLUSIONS

The major conclusions of this study are:

1. *The transition from older technologies to more energy-efficient designs is already underway,* spurred by electronics advances, market forces, state building codes, utility programs, and national programs. The future rate of efficiency improvement in the marketplace is uncertain, and depends upon government policies and electric utility programs.



Notes: Percentages are portion of respective baseline lighting energy
Tops of bars represent savings under Low DSM Baseline, bottoms of bars represent savings under High DSM Baseline

Figure 5. *Range of cumulative lighting energy savings by policy, 1995 to 2030, commercial sector*

2. *All national policies analyzed save energy, reduce electric peak demand, and reduce emissions of CO_2, SO_2, and NO_x* from electric power plants, and most save money. In some cases, these prospective benefits are substantially greater than those anticipated from current market forces and the standards contained within the U.S. Energy Policy Act of 1992.

3. *The national policy alternatives are qualitatively different* and not mutually exclusive. Important differences include issues of equity, certainty of savings, and relative administrative burden.

4. *Many research and development needs exist.* Concerted efforts in this area will help to commercialize improvements in existing technologies in the near term and to introduce fundamental innovations, with corresponding additional energy savings potential, in the longer term.

ACKNOWLEDGMENTS

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Table 5. ***Summary of cumulative impacts of selected residential lighting policies measured with respect to the High- (Frozen-) Efficiency Baseline****

Type of Impact	Energy Policy Act of 1992 Lamp Standards	Minimum Life-Cycle Cost Combination [Max. Econ. Pot'l]	Research & Development Combination [Technical Potential]
Lighting Energy Intensity in 2030:			
Unit Energy Consumption, UEC (kWh/household-year)	1,039 (1,249)	839 (839)	467 (467)
Primary Energy Savings (Mtoe) (1995-2030)	23 (47)	259 (518)	682 (941)
Electricity Savings in 2030 (TWh$_e$)	4 (6)	29 (58)	78 (107)
Percent Savings	3% (4%)	21% (35%)	56% (64%)
Peak Power Savings by 2030 (GW, 10^9 W)	0.4 (0.6)	3.2 (6.4)	8.6 (11.7)
Net Present Value ($1990 billion)$^+$	1 (2)	34 (39)	20 (26)
Avoided Emissions (1995-2030)			
- CO_2 (Billion tonnes)	0.1 (0.2)	0.8 (1.6)	2.3 (3.1)
- SO_2 (Million tonnes)	0.3 (0.4)	2.1 (3.9)	5.5 (7.6)
- NO_x (Million tonnes)	0.2 (0.4)	1.7 (3.5)	4.6 (6.5)

*Excludes interactions with heating, ventilating, and air conditioning (HVAC) energy use.

$^+$Real electricity prices increase only slightly between 1995 and 2030. Real discount rate = 6 percent.

We thank the many researchers, manufacturers, lighting designers, equipment designers, lighting maintenance companies, energy conservation organizations, regulators, utility officials, and government agencies who provided ideas, data and review comments for the full report.

ENDNOTES

1. The Energy Policy and Conservation Act (P.L. 94-163), as amended by the National Appliance Energy Conservation Amendments of 1988 (P.L. 100-357).

2. One TWh$_e$ (terawatt-hour) equals 10^{12} watt-hours. One Quad = 10^{15} Btus (source) = 23.53 Mtoe (toe x 10^6) = 1.055 Joules x 10^{18} = 87 TWh$_e$ of electricity, based on a typical heat rate of 11,500 Btus/kWh, measured at the point of final end use. In converting between site electricity ("at the meter") and energy input at the power plant, a thermal efficiency of 32 percent and a transmission and distribution loss of 7.5 percent are assumed.

3. Lighting Research Institute (LRI) and Plexus Research, Inc. 1992. "*Survey and Forecast of Marketplace Supply and Demand for Energy-Efficient Lighting Products.* Phase I Report. Electric Power Research Institute, Palo Alto, CA.

4. These savings potentials could also be defined with respect to the No-Programs Baseline. Quantitatively, the No-Programs and Low-Efficiency Baselines are similar.

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Table 3. Summary of alternative policies to promote greater lighting energy efficiency, commercial sector
Cumulative values for 1995 to 2030 (2010 values in parentheses)

Policy Option		1995 to 2030 Lighting Energy Use (Mtoe) High-Efficiency		1995 to 2030 Lighting Energy Use (Mtoe) Low-Efficiency	1995 to 2030 Lighting Energy Savings (Mtoe) High-Efficiency		1995 to 2030 Lighting Energy Savings (Mtoe) Low-Efficiency	1995 to 2030 Net Present Value ($1990 billions) High-Efficiency		1995 to 2030 Net Present Value ($1990 billions) Low-Efficiency	Scope	Certainty of Savings	Administrative Burden	Equity Impacts
Baseline		2,900 (78.1)	to	3,500 (95.3)	NA			NA			NA	NA	NA	NA
Mandatory Component Standards	Min LCC Fl & Inc Lamps	2,500 (64.9)	to	2,600 (67.1)	400 (13.2)	to	900 (28.2)	83	to	194	New and existing buildings	High and easily monitored	Small	Not significant
	Min LCC Fl L/B & Inc Lamps	2,300 (59.8)	to	2,300 (60.7)	600 (18.4)	to	1,200 (34.6)	99	to	210				
	Min LCC Combination *	1,700 (40.7)	to	1,700 (40.7)	1,200 (37.4)	to	1,800 (54.6)	47	to	97				
Voluntary Component Standards	Min LCC Fl & Inc Lamps	2,600 (70.4)	to	2,800 (79.5)	300 (7.8)	to	700 (15.8)	67	to	141	New and existing buildings	No assurance that participation will be widespread	Minimal	Some program costs would be borne by non-participants
	Min LCC Fl L/B & Inc Lamps	2,500 (67.5)	to	2,600 (75.5)	400 (10.6)	to	900 (19.8)	91	to	171				
	Min LCC Combination *	2,000 (56.0)	to	2,100 (63.1)	900 (22.1)	to	1,400 (32.2)	20	to	59				
System Performance Standards	(DOE 1993, Partial Compliance)	2,600	to	2,800	300	to	700	NA			New construction only	Level of compliance difficult to monitor	Large	Not significant
Consumer Rebates #		2,900	to	2,900	0	to	600	0	to	47	New and existing buildings	Effectiveness a function of program cost (size of rebate, program promotion, free riders)	Large	Some program costs would be borne by non-participants
Consumer Tax Credits #		2,900	to	3,000	0	to	500	0	to	35	New and existing buildings	Effectiveness a function of program cost (size of rebate, program promotion, free riders)	Large	Some program costs would be borne by non-participants
Consumer/Designer Education and Component Labels #		2,900	to	3,300	0	to	200	0	to	16	Policy can be targetted	Most difficult to forecast effectiveness	Minimal	Some program costs would be borne by non-participants

Mtoe = million (mega) tons oil equivalent
* Includes lamps, ballasts, fixtures and controls
# NPVs only include the cost to utilities (or the government) of providing rebates (up to 3.5 to 4.0 ¢/kWh saved); consumers may incur additional costs in some cases