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ENERGY AND ECONOMIC EFFICIENCY ALTERNATIVES FOR ELECTRIC LIGHTING IN COMMERCIAL BUILDINGS

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MASTER

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PREFACE

The daylighting laboratory of the Solar Energy Research Institute (SERI) under the auspices of Oak Ridge National Laboratory (ORNL) investigated the energy and economic efficiencies of various energy conserving lighting alternatives. The various alternative lighting strategies were grouped into three categories:

1. Use of a renewable resource (daylighting) to replace or supplement electric lighting
2. Use of task/ambient lighting in lieu of overhead task lighting
3. Lighting equipment changes to improve energy efficiency.

This report presents the results of the study in terms of energy savings, economic efficiency, and peak electricity demand reduction.

The authors would like to thank Robert Shelton and David Bjornsted at Oak Ridge National Laboratory and Richard Holt at DOE for their assistance in this effort.

Claude L. Robbins

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SUMMARY

Objective

This report presents the results of an investigation to determine the energy savings potential, economic efficiency, and energy demand reduction of various energy conserving lighting alternatives.

Discussion

Three categories of lighting alternatives are examined for their effectiveness in terms of energy savings, economic efficiency, and peak demand reduction:

1. Use of a renewable resource (daylighting) to replace or supplement electric lighting
2. Use of task/ambient lighting in lieu of overhead task lighting
3. Lighting equipment changes to improve energy efficiency.

The technologies included in this study are examined and ranked in terms of their effect on the energy use of a typical base building. Energy efficiency is expressed as a lighting energy ratio and a total energy ratio. The lighting energy ratio is the ratio of the lighting energy use of the technology to the lighting energy use of the base building; the total energy ratio takes the heat addition or extraction of the lighting technology into consideration and is expressed as the ratio of the total energy use for the technology to the total energy use of the base case.

Economic efficiency is defined as the simple payback for each technology. The first costs for each technology are based upon the cost differential between the base building system, and the new technology and the energy costs are considered as a combination of various energy costs plus peak demand costs.

The peak demand reductions presented are based on reduced unit power density requirements and are expressed as lighting peak demand and total peak demand, which takes heat addition or extraction into consideration.

Conclusions and Recommendations

All of the lighting concepts analyzed reduce the lighting energy use and costs in the base building by varying degrees. In addition to the reduced lighting energy use comes a subsequent reduction in cooling energy use and capacity, impacting positively the total energy use and peak demand.

Additional work to examine the technologies against a range of base building types and sizes and to look at a wider range of lighting strategies may help to better understand the impact of various lighting technologies.

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SECTION 1.0

INTRODUCTION

This report examines several alternative technologies that can be used to improve or supplement the energy efficiency of electric lighting systems in commercial buildings. Each technology is considered in terms of its impact upon the energy use of a typical base building, with the fraction of energy savings being defined as the energy efficiency of the technology. In addition, each technology is considered in terms of the first (construction or installation) costs of the technology with regard to the costs of the energy savings, which will be defined as the economic efficiency of the technology.

In general, the objectives of this study were to

- Identify a set of alternative technologies and to determine the energy and economic attractiveness of each technology
- Determine the impact of each technology upon current electricity demand in commercial buildings.

In this study we do not seek out all possible alternative technologies, analyze in detail the energy use patterns of the chosen base building, or evaluate all factors that might be considered in determining energy or economic efficiency. The report is limited to three specific sets of technologies and attempts to identify the impact of these technologies upon total lighting energy use, as well as the heat addition and heat extraction from the building directly associated with lighting.

Section 2.0 characterizes the method of analysis used to study energy and economic efficiency in the base building. Section 3.0 details the development and analysis of the base building and a detailed description of each lighting alternative. Section 4.0 details how the three alternative lighting concepts were analyzed. The alternatives analyzed were (1) use of a renewable resource (daylighting) to replace or supplement electric lighting; (2) use of task/ambient lighting in lieu of overhead task lighting; and (3) lighting equipment changes to improve electric lighting energy conservation. Section 5.0 details the energy savings characteristics and economic efficiency of each alternative technology analyzed. Section 6.0 establishes the impact of each technology on building peak demand, and Section 7.0 summarizes the work and suggests future efforts.

SECTION 2.0

METHOD OF ANALYSIS

Electric lighting represents a reasonable constant load during the operating hours of a commercial building. Since the operating efficiency of the lighting equipment is well understood and the impacts of lighting on other end uses such as heating and cooling can be analyzed without performing detailed computer simulations, it is possible to isolate energy use associated with lighting from other energy uses in the building. In this way, it is possible to determine the impact of various conservation or alternative energy strategies by altering the lighting energy needs of the base building.

A base building can be defined to represent a large segment of the standing stock of commercial (i.e., nonresidential) buildings. Parametric analysis of the base building can be used to establish the impact of lighting on energy use and costs, as well as electricity demand. This is accomplished by varying the lighting power budget in the form of a unit power density (UPD) of the base building and determining the resulting impact on total energy use, lighting energy use, and the heating and cooling energy use directly associated with lighting.

Alternatives to the base building lighting system can be analyzed based on the impact the strategy has upon the average lighting power budget of the building.

SECTION 3.0

DEFINING AND ANALYZING THE BASE BUILDING

The base building chosen for this analysis is a 9510-m^2 (100,000-ft^2), 22.2-m x 71.4-m (72-ft x 232-ft), six-story office building. Assumptions about the building envelope, HVAC, and lighting equipment are shown in Table 3-1. A large office building was chosen for this analysis because such buildings represent some 33% of the total floor area of the existing standing stock of all commercial buildings in the continental United States as shown in Table 3-2 [1,2].

Using the DOE 2.1A simulation [3], extensive parametric analysis of the base building can be performed to determine regression equations to establish the total building energy use, lighting energy use, lighting impact on cooling energy use, and lighting impact on heating energy use. All of these are analyzed in terms of the lighting power budget, or lighting load, in watts per square meter. The base case lighting power, in the form of a unit power density (UPD), was 26.4 W/m^2 (2.5 W/ft^2), which is consistent with both the Illuminating Engineering Society [4] and Department of Energy [5] criteria for lighting loads in commercial buildings used primarily for office type functions. The specific method of analysis used in this report was developed especially to study large groups of buildings rather than an individual case. This approach is based upon a simplified energy analysis method developed by Turiel et al. [6] at Lawrence Berkeley Laboratory.

The total energy use E_T, in kWh/m^2, as a function of the lighting unit power density can be estimated from the following quadratic equation:

$$E_T = 92.2 + (1.86\ \text{UPD}) + (0.017\ \text{UPD}^2)\ (\text{kWh/m}^2), \quad (3\text{-}1)$$

where UPD is the unit power density, in W/m^2. For the base case the UPD was 26.4 W/m^2.

The annual lighting energy use, in kWh/m^2, assumes the building operates on an 0800-1700 hour schedule. Lighting energy consumption can be determined from an equation taking on the following linear form:

$$E_L = 2.8713\ \text{UPD} \quad (\text{kWh/m}^2)\,. \quad (3\text{-}2)$$

The impact of the heat output by the lighting system on heating and cooling energy consumption can be determined from the following quadratic equations:

$$E_H = 54.7 - (1.27\ \text{UPD}) + (0.01\ \text{UPD}^2) \quad (\text{kWh/m}^2) \quad (3\text{-}3)$$

$$E_C = 7.29 + (0.34\ \text{UPD}) + (0.005\ \text{UPD}^2) \quad (\text{kWh/m}^2)\,. \quad (3\text{-}4)$$

These equations are not used to determine the total energy consumption for heating or cooling, as they only establish the heating addition or extraction to or from the building due to an increase or decrease in energy input to the building lighting.

The application of these equations to the base building is shown in Table 3-3.

Table 3-1. Base-Case Values for Large Office Buildings

Location and Orientation	
City	Denver
Size	22.2 m x 71.4 m (72 ft x 232 ft) (6 stories)
Orientation	Long axis points 60^{o} east of north
Ground reflectance	0.20
Materials	
Average mass density	298 kg/m^2 (62 lb/ft^2)

Structural Component	Materials	Width (cm)	(in.)	R Value (m^2 ^{o}C/W)	($h\ ft^2$ ^{o}F/Btu)
Walls					
External	Heavyweight concrete	10.2	(4)		
	Polystyrene insulation			1.62	(9)
	Gypsum board	1.59	(5/8)		
Total R				1.71	(9.5)
Internal	Gypsum board	1.59	(5/8)		
	Air layer	10.2	(4)		
	Gypsum board	1.59	(5/8)		
Total R				0.49	(2.7)
Roof	Roof gravel	1.27	(0.5)		
	Built up roofing	0.95	(3/8)		
	Polystyrene insulation			2.7	(15)
	Heavyweight concrete	15.2	(6)		
	Air layer	10.2	(4)		
	Acoustic tile	1.27	(0.5)		
Total R				3.42	(19)
Ground floor	Fiberglass batt insulation			4.3	(24)
	Heavyweight concrete	15.2	(6)		
	Lightweight concrete	8.3	(3.25)		
Total R				5.4	(30)

Solar Absorptivity	
Walls	0.65
Roof	0.30
Windows and lighting	
Glass solar transmission	0.40
Glass conductance	3.2 W/m^2 ^{o}C (0.574 Btu/h ft^2 ^{o}F) (double glazing)
Window-to-wall ratio	0.22
Window shading setback/ window height	0.125 (0.32-m setback)
Heat of lights to space	0.50
Lighting power	26.4 W/m^2 (2.5 W/ft^2)
Infiltration	0.6 air changes/h
Systems	
Outside air/person	12.25 m^3/h person (7 cfm/person)
Thermostat setpoints	
Heating	22.2^{o}C (72^{o}F)
Cooling	25.6^{o}C (78^{o}F)
Night setback	
Heating	15.6^{o}C (60^{o}F)
Cooling	37.2^{o}C (99^{o}F)
Economizer	None

Table 3-2. Commercial Building Characteristics

Building Size (ft^2)	Commercial Buildings[a] (%)	Commercial Building Floor Area[b] (%)	Number of Buildings (1000s)	Amount of standing ft^2 (10^6 ft^2)
≤1,000	17	1	1020	377
1,001-5,000	40	9	2400	3,393
5,001-10,000	18	10	1080	3,770
10,001-25,000	14	18	840	6,786
25,001-50,000	7	15	420	5,655
50,001-100,000	3	15	180	5,655
≥100,000	2	33	120	12,441
	101	101	6060	38,087

[a]Percentage of all existing buildings that are commercial
[b]Percentage of the total floor area represented by various sizes of commercial buildings

Table 3-3. Performance Characterization of the Base Building

UPD	2.50 W/ft^2				
	26.90 W/m^2				
E Total	154.54 kWh/m^2				
E Light	77.24 kWh/m^2				
E Lit C	20.05 kWh/m^2				
E Lit H	27.77 kWh/m^2				
Peak Dem					
Total	354.17 kW				
Cool	104.17 kW				
Light	250.00 kW				
	A	B	C	D	($ x 1000)
Cost Tot	44.41	35.41	24.29	15.29	
Cost Lit	31.60	24.45	16.25	9.10	
Cost CL	9.38	7.52	4.61	2.75	
Cost HT	3.43	3.43	3.43	3.43	

UPD = unit power density
A = high energy cost + high demand costs
B = high energy costs + low demand costs
C = low energy costs + high demand costs
D = low energy costs + low demand costs

SECTION 4.0

LIGHTING ALTERNATIVES

4.1 DAYLIGHTING

Daylighting is the use of natural light from the clear or overcast sky as a replacement or supplement for electric lighting in buildings. Two specific daylighting scenarios were considered: (1) using daylight as a task illuminant throughout the building; and (2) using daylight as a task illuminant in the perimeter, to a depth of 20 ft, of the building.

For either of these scenarios, five different electric lighting control strategies were analyzed to determine possible energy savings, impact on peak demand, and economic efficiency. The five different control strategies can be grouped into two categories: (1) step control and (2) dimming control. It is assumed, for either category, that the control system is automatic rather than manual.

Step control systems analyzed include (1) two-step (i.e., on/off), (2) three-step, (3) four-step, and (4) five-step controllers. A two-step (2S) controller is one in which a photosensor in the room or space being illuminated measures the illuminance level provided by daylight and turns the electric lighting system on or off depending on whether there is sufficient daylight to provide task illuminance. In the base-case building task illuminance was set at 540 lux (50 fc).

Multi-step controllers, such as the three-step (3S), four-step (4S), and five-step (5S) systems, use a photosensor to measure interior illuminance in the same manner as the 2S system. However, multi-step controllers have intermediate steps between the electric lighting being either all on or off. The three-step system has one intermediate step and requires a luminaire (fixture + lamps + ballast) with a minimum of two lamps or multiples of two lamps. The three steps are all lamps off (step 1), half of the lamps on (step 2), and all of the lamps on (step 3). The four-step system has two intermediate steps and requires a luminaire with a minimum of three lamps, or multiples of three. The four steps are all lamps off (step 1), one-third of the lamps on (step 2), two-thirds of the lamps on (step 3), and all of the lamps on (step 4). A five-step controller has three intermediate steps and requires multiples of four lamps in the luminaire. The five steps are all lamps off (step 1), one-fourth of the lamps on (step 2), half of the lamps on (step 3), three-fourths of the lamps on (step 4), and all of the lamps on (step 5).

The only dimming control system analyzed was a continuous linear dimming device. The power cutoff was assumed to be 15%. That is, the lamps can be dimmed to within 15% of power input. This type of control system does not turn off the lamps when the interior illuminance level is greater than or equal to the design illuminance. When this occurs the lamps are dimmed to 15% of input power and remain on during those periods when daylight can be used to replace electric lighting in the building.

Daylighting systems were analyzed using the DAYLITE computer program. This program performs an hourly simulation of the daylight performance characteristics for 12 days (one per month) for the year. Energy use is calculated on an hourly basis depending on the particular lighting control option being analyzed [8].

4.2 TASK/AMBIENT LIGHTING

The second alternative lighting concept analyzed was task/ambient lighting. Task/ambient lighting is divided into two components—an overhead illumination system used to provide background illuminance while task illuminance is provided by a "task luminaire" of some sort. This is different from the base building where an overhead task lighting system is used in which task illuminance is provided by luminaires in the ceiling of each room of the building.

A task/ambient lighting system is used only in work areas of a building. For this study it was assumed that 70% of the building could be illuminated with a task/ambient system while the remaining portion of the building was illuminated with the overhead task lighting system used in the base building [9].

In those portions of the building where the task/ambient lighting system was used it was assumed that the overhead background luminaires provided 180 lux (15 fc) of light using a single lamp recessed fluorescent luminaire. The remaining light necessary to maintain 540 lux of task lighting was provided by some type of "desk lamp."

Three lamp types were considered for the desk lamp. It is assumed that the lamps can be either incandescent or gaseous discharge (such as fluorescent). The three lamps considered varied in their input wattage. They were: 60 W, 40 W, and 20 W per work station. It is assumed that each of these can provide the necessary light to insure task illuminance of 540 lux. The three task lamp power assignments were based on a range of realistic lighting options. The 20 W per work station represents an optimistic conservation level and the 60 W corresponding to current practice. The 40 W midvalue is considered reasonably efficient and clearly achievable.

In addition to analyzing three task lighting systems of varying input wattage, we analyzed the building lighting power requirements for three different occupancy densities. A high density work environment allowed 9.3 m^2 (100 ft^2) per person; the medium density work environment allowed 13.9 m^2 (150 ft^2) per person, and the low density environment allowed 18.6 m^2 (200 ft^2) per person throughout 70% of the building [10]. These work densities correspond to 700, 470, and 350 people working in the building, respectively.

4.3 ALTERNATIVE EQUIPMENT CONCEPTS

Alternative equipment concepts can be grouped into two broad categories: (1) alternative luminaire concepts and (2) other equipment alternatives. A luminaire shall be defined as that part of the lighting system consisting of the light fixture, the lamps in the fixture, and (if needed) the ballasts used in conjunction with the lamping of the fixture. Alternative luminaire concepts, therefore, consist of making changes to the various parts of the luminaire to make it more energy efficient or more efficient as a lighting system, thereby reducing the input energy. Changes to the luminaire encompassed varying, individually, the ballast, lamping, or fixture type.

A ballast is a device used to control the voltage, current, and waveform conditions for the proper start and operation of gaseous discharge and high intensity discharge (HID) lamps. Three ballast types were considered in this analysis: (1) a standard core-coil ballast, used with the base building fluorescent lighting; (2) an electronic ballast; and (3) a hybrid core-coil/electronic ballast.

Because some ballasts may decrease light output as well as energy consumption the ballasts were normalized in terms of the unit power density necessary to provide 540 lux (50 fc) in the base case building [11]. The Illumination Engineering Society (IES) zonal cavity method of analysis was used to determine the resulting unit power density of each alternative [4]. The base building was assumed to use an IES type 41 luminaire in clean rooms with a one-year cleaning cycle. Lamping in each ballast test was F40T12RS-CW fluorescent, with the exception of two cases in which an energy-saving F40T12RS-CW was used in conjunction with electronic ballasts. The specific luminaire cases studied for the ballast equipment changes were

- IES type 41 fixture, F40T12RS-CW lamping with standard core-coil ballast (base case)
- IES type 41 fixture, F40T12RS-CW lamping with electronic ballast (case ESav 1)
- IES type 41 fixture, energy-saving F40T12RS-CW lamping with electronic ballast (case ESav 2)
- IES type 41 fixture, energy saving F40T12RS-CW lamping with a hybrid core-coil/electronic ballast (case hybrid).

Lamping scenarios were studied to achieve a lower unit power density. Three specific scenarios were considered: (1) changing the lamp type in the luminaire; that is, using a more energy efficient fluorescent lamp; (2) changing the light source from gaseous discharge (i.e., fluorescent) to another energy-saving light source such as high intensity discharge HID lamping; or (3) dummy lamping.

For the first scenario, changing to energy-saving fluorescent tubes in the base-case fixture was analyzed. For the second scenario, three specific HID lighting systems were analyzed: mercury vapor, high pressure sodium (HPS), and multivapor lamps. These were called lamping strategies HID 1, HID 2, and HID 3, respectively, in the computer analysis. Although HID lighting has not been commonly used in the past in commercial buildings because of lighting quality and color rendering issues, recent research and development by several lamp manufacturers has improved the spectral content of many HID lamps making them acceptable in many cases. In addition, changing the lamping to HID required changing the fixture to one appropriate for HID lamping.

The final lamping scenario considered was using dummy lamping as a replacement for some of the base-case lamping. A dummy lamp is a nonlight producing lamp that replaces one or more lamps in the luminaire. The dummy lamp provides an electrical impedance to the circuit and reduces both the wattage and light output of the luminaire. Because the light output is affected, a dummy lamp should only be used in cases where a decrease in light level is acceptable.

Light fixtures are available that may increase the light output or improve the light delivery of the luminaire. Changing the fixture does not require a change in lamping or ballasting with respect to the base case. The base-case fixture (IES type 41) is a 2-ft x 4-ft recessed unit with a flat bottom diffuser. It has a coefficient of utilization (CU) of 0.65 for the base-case room conditions. Two other fixtures were considered as part of the study: the IES type 42 and type 43. The type 42 fixture has a flat prismatic lens in lieu of the diffuser and has a CU of 0.71 for the base-case room conditions. The type 43 fixture uses a sharp cutoff (high angle, low luminance) prismatic lens with a CU of 0.75 for the base-case room. In all cases the 540 lux of task illuminance is maintained.

In addition to the luminaire changes discussed above, two other alternatives considered as equipment changes to the base building were automated controls and wattage reducers. Automated controls cover a wide range of devices from simple on/off time clocks to sophisticated energy management systems (EMS).

The specific automated control device analyzed was an occupancy sensor. An occupancy sensor turns the lights on or off depending on whether the room or space is occupied. This particular control system was chosen for study for two reasons. First, it is considered to be in the midrange between the on/off and EMS systems in terms of its energy savings capability and therefore more closely matches the average performance characteristics for all automated control systems. Second, the actual occupancy of large commercial buildings has been documented [12] and can be used to accurately estimate the energy conservation anticipated from such a control device. For this analysis the schedule shown in Table 4-1 was used.

Table 4-1. Building Occupancy Schedule for Occupancy Sensor Control Devices

Time of Day	Percentage of Full Occupancy
0600-0700	20
0700-0800	60
0800-0900	70
0900-1000	80
1000-1100	80
1100-1200	80
1200-1300	65
1300-1400	65
1400-1500	80
1500-1600	80
1600-1700	70
1700-1800	60
1800-1900	40
1900-2000	20
2000-0600	5

The wattage reducer is designed to reduce wattage on a 20-A circuit while maintaining the peak voltage necessary for proper ballast operation. The unit is intended for use with standard lamps and ballasts, as defined by the base-case building. The reducers lower the energy and light level proportionally, preserving the same lighting efficiency. It is assumed that each circuit controls a 16-A (20-A at a 0.8 safety factor) load.

SECTION 5.0

ENERGY AND ECONOMIC EFFICIENCY OF LIGHTING ALTERNATIVES

5.1 ENERGY EFFICIENCY

The energy efficiency of each lighting alternative is considered in terms of the lighting energy efficiency and the total energy efficiency. Lighting energy conservation for all concepts is based on the following procedure:

1. Determine the unit power density (UPD) of each alternative.
2. Calculate the lighting energy use, heat addition, heat extraction, and peak demand for each alternative.
3. Calculate the lighting energy ratio (LER) and total energy ratio (TER).

The UPD of each alternative strategy was determined based on accepted engineering practices given the necessary information about the input energy requirements of the strategy. The equation discussed in Section 3.0 was used to calculate the lighting energy use, heat addition, and heat extraction for each alternative. The lighting energy ratio LER is defined as either

$$LER = UPD_{technology}/UPD_{base} \qquad (5\text{-}1)$$

or

$$LER = \text{lighting energy use}_{technology}/\text{lighting energy use}_{base} .$$

Similarly, the total energy ratio TER is defined as

$$TER = \text{total energy use}_{technology}/\text{total energy use}_{base} . \qquad (5\text{-}2)$$

The lower the LER or TER the higher the energy efficiency of the technology as compared with the base building. Energy use for each daylighting strategy is shown in Table 5-1, energy use for each task/ambient strategy is shown in Table 5-2, and energy use for each equipment strategy is shown in Table 5-3.

A rank ordering of all alternative lighting strategies analyzed is shown in Table 5-4. From this table it can be seen that the daylighting strategies are clearly the most energy effective, reducing the lighting energy use to 13% of the base building and the total energy use to 64% of the base building. Similarly, the least effective alternatives are the fixture changes.

5.2 ECONOMIC EFFICIENCY

The first costs of each lighting alternative are based on estimating the cost differential between the base building lighting system and the necessary changes to that system to meet the requirements of the alternative being studied. First costs are based upon R. S. Means [13,14] costing techniques and common engineering practice. First costs are shown in Table 5-5.

Table 5-1. **Energy Use for Various Daylighting Concepts**

Technology	Energy Use				
	UPD (W/m^2)	Total (kWh/m^2)	Light (kWh/m^2)	Heat- (kWh/m^2)	Heat+ (kWh/m^2)
Base Building	26.90	154.54	77.24	20.05	27.77
Task, all					
2S	18.18	131.64	52.21	15.13	34.91
3S	11.41	115.63	32.75	11.82	41.52
4S	8.39	109.01	24.10	10.50	44.75
5S	6.67	105.37	19.16	9.78	46.67
CD	3.44	98.81	9.89	8.52	50.45
Task, perim					
2S	21.41	139.82	61.48	16.86	32.09
3S	17.11	129.00	49.12	14.57	35.90
4S	15.17	124.33	43.56	13.60	37.73
5S	14.10	121.80	40.47	13.08	38.79
CD	12.05	117.08	34.60	12.11	40.85

2S = two-step automatic step control
3S = three-step automatic step control
4S = four-step automatic step control
5S = five-step automatic step control
CD= continuous linear dimming

Heat- = heat extraction (cooling)
Heat+ = heat addition (heating)

Table 5-2. Energy Use for Various Task/Ambient Lighting Concepts

Technology	Energy Use				
	UPD (W/m^2)	Total (kWh/m^2)	Light (kWh/m^2)	Heat- (kWh/m^2)	Heat+ (kWh/m^2)
Base Building	26.90	154.54	77.24	20.05	27.77
High + 60 W	18.18	131.64	52.21	15.13	34.91
High + 40 W	16.68	127.95	47.89	14.35	36.30
High + 20 W	15.17	124.33	43.56	13.60	37.73
Med + 60 W	16.68	127.95	47.89	14.35	36.30
Med + 40 W	15.71	125.62	45.11	13.87	37.22
Med + 20 W	14.63	123.06	42.02	13.34	38.26
Low + 60 W	15.92	126.13	45.72	13.97	37.01
Low + 40 W	15.17	124.33	43.56	13.60	37.73
Low + 20 W	14.42	122.55	41.40	13.23	38.47

High = high density occupancy
Med = medium density occupancy
Low = low density occupancy

Table 5-3. Energy Use for Various Equipment Concepts

Technology	Energy Use				
	UPD (W/m^2)	Total (kWh/m^2)	Light (kWh/m^2)	Heat- (kWh/m^2)	Heat+ (kWh/m^2)
Base Building	26.90	154.54	77.24	20.05	27.77
Ballasts					
ESav 1	21.41	139.82	61.48	16.86	32.09
ESav 2	18.18	131.64	52.21	15.13	24.91
Hybrid	18.72	132.98	53.76	15.41	34.43
Lamping					
ESav 1	18.72	132.98	53.76	15.41	34.43
HID 1	19.80	135.69	56.85	15.98	33.48
HID 2	17.00	128.73	48.81	14.52	36.00
HID 3	13.34	120.04	38.31	12.72	39.54
Dummy	18.83	133.25	54.07	15.47	34.33
Fixtures					
IES 42	24.75	148.64	71.06	18.77	29.39
IES 43	23.13	144.33	66.42	17.83	30.67
Other					
Reduce	18.83	133.25	54.07	15.47	34.33
Automt	15.39	124.84	44.18	13.71	37.53

Ballast: ESav 1 = energy saving ballast + standard lamp
ESav 2 = energy saving ballast + energy saving lamp

Lamping: ESav 1 = enrgy saving fluorescent + hybrid ballast
HID 1 = multi-vapor
HID 2 = HPS
HID 3 = mercury

Other: Reduce = wattage reducer
Automt = automatic on/off, occupancy controller

Table 5-4. Rank Ordering by Lighting and Total Energy Use

Rank	Technology	UPD (W/m^2)	LE Ratio	TE Ratio
1	Daylight, all, CD	3.44	0.13	0.64
2	Daylight, all, 5S	6.67	0.25	0.68
3	Daylight, all, 4S	8.39	0.31	0.71
4	Daylight, all, 3S	11.41	0.42	0.75
5	Daylight, perim, CD	12.05	0.45	0.76
6	HID 3, mercury vapor	13.34	0.50	0.78
7	Daylight, perim, 5S	14.10	0.52	0.79
8	Low + 20 W, task/ambient	14.42	0.54	0.79
9	Med + 20 W, task/ambient	14.63	0.54	0.80
10	Low + 40 W, task/ambient	15.17	0.56	0.81
	High + 20 W, task/ambient	15.17	0.56	0.81
	Daylight, perim, 4S	15.17	0.56	0.81
11	Automatic controllers	15.39	0.57	0.81
12	Med + 40 W, task/ambient	15.71	0.58	0.81
13	Low + 60 W, task/ambient	15.92	0.59	0.82
14	High + 40 W, task/ambient	16.68	0.62	0.83
	Med + 60 W, task/ambient	16.68	0.62	0.83
15	HID 2, HPS	17.00	0.63	0.83
16	Daylight, perim, 3S	17.11	0.64	0.83
17	High + 60 W, task/ambient	18.18	0.68	0.85
	Daylighting, all, 2S	18.18	0.68	0.85
	Energy ballast and lamp	18.18	0.68	0.85
18	Hybrid ballast	18.72	0.70	0.86
	Energy lamp + hybrid ballast	18.72	0.70	0.86
19	Dummy lamping	18.83	0.71	0.86
	Wattage reducer	18.83	0.71	0.86
20	HID 1, multivapor	19.80	0.74	0.88
21	Daylighting, perim, 2S	21.41	0.80	0.90
	Energy saving ballast	21.41	0.80	0.90
22	IES luminaire 43	23.13	0.86	0.93
23	IES luminaire 42	24.75	0.92	0.96
B	Base building	26.90	1.00	1.00

Table 5-5. First Costs for Various Lighting Concepts

	First Cost (K$)	$/ft²	$/m²	$/ft²[a]	$/m²[a]
Base Case	127.38	1.27	13.67	0.00	0.00
Daylighting Concepts					
Task, all					
2S	179.49	1.80	19.37	0.53	5.70
3S	194.98	1.95	20.98	0.68	7.31
4S	194.98	1.95	20.98	0.68	7.31
5S	194.98	1.95	20.98	0.68	7.31
CD	196.86	1.97	21.20	0.70	7.53
Task, Perim.					
2S	160.33	1.60	17.22	0.33	3.55
3S	169.69	1.70	18.29	0.43	4.62
4S	169.69	1.70	18.29	0.43	4.62
5S	169.69	1.70	18.29	0.43	4.62
CD	171.32	1.71	18.40	0.44	4.73
Task/Ambient Lighting Concepts					
High + 60 W	156.20	1.56	16.79	0.29	3.12
High + 40 W	165.90	1.66	17.86	0.39	4.19
High + 20 W	160.70	1.61	17.32	0.34	3.65
Med. + 60 W	149.80	1.50	16.14	0.23	2.47
Med. + 40 W	156.20	1.56	16.79	0.29	3.12
Med. + 20 W	152.90	1.53	16.46	0.26	2.79
Low + 60 W	149.00	1.49	16.03	0.22	2.36
Low + 40 W	151.50	1.52	16.36	0.25	2.69
Low + 20 W	146.70	1.47	15.82	0.20	2.15
Equipment Concepts					
Ballasts					
ESav 1	141.95	1.42	15.28	0.15	1.61
ESav 2	144.70	1.45	15.60	0.18	1.93
Hybrid	210.63	2.11	22.70	0.84	9.03
Lamping					
ESav 1	210.63	2.11	22.70	0.84	9.03
HID 1	274.39	2.74	29.48	1.47	15.81
HID 2	283.00	2.83	30.45	1.56	16.78
HID 3	187.86	1.88	20.23	0.61	6.56
Dummy	139.33	1.39	14.96	0.12	1.29
Fixtures					
IES 42	127.38	1.27	13.67	0.00	0.00
IES 43	127.38	1.27	13.67	0.00	0.00
Other					
Reduce	154.68	1.55	16.68	0.28	3.01
Automt	167.47	1.68	18.07	0.41	4.40

[a]Difference between the alternative lighting concept cost and the base case cost

Energy costs were established based upon the combination of energy use costs plus peak demand costs. Four specific total energy cost scenarios were considered:

- High energy costs plus high peak demand costs (case A)
- High energy costs plus low peak demand costs (case B)
- Low energy costs plus high peak demand costs (case C)
- Low energy costs plus low peak demand costs (case D).

High energy costs were set at 9¢/kWh, low energy costs at 2¢/kWh. High peak demand costs were set at $12.00/kW, while low peak demand costs were set at $2.00/kW [10,15]. Energy costs for each set of alternative lighting concepts are shown in Tables 5-6, 5-7, and 5-8.

Lighting economic efficiency is defined as the simple payback for each combination of lighting strategy and utility cost structure. The simple payback for each concept is shown in Tables 5-9, 5-10, and 5-11. Finally, a rank ordering of each lighting strategy by simple payback is shown in Table 5-12.

Table 5-6. Energy Costs, Daylighting Concepts

Technology	UPD	Energy Costs ($ x 1000)			
		A	B	C	D
Base Building	26.90	44.41	35.41	24.29	15.29
Task, All Building					
2S controller	18.18	32.75	26.52	18.78	12.55
3S controller	11.41	24.06	19.93	14.74	10.62
4S controller	8.39	20.30	17.10	13.01	9.81
5S controller	6.67	18.18	15.50	12.05	9.37
CD controller	3.44	14.27	12.56	10.27	8.57
Task, Perimeter					
2S controller	21.41	37.00	29.76	20.78	13.53
3S controller	17.11	31.35	25.46	18.12	12.23
4S controller	15.17	28.85	23.56	16.96	11.67
5S controller	14.10	27.47	22.51	16.31	11.36
CD controller	12.05	24.87	20.55	15.11	10.79

A = high energy costs + high demand costs
B = high energy costs + low demand costs
C = low energy costs + high demand costs
D = low energy costs + low demand costs

Table 5-7. Energy Costs, Task/Ambient Lighting Concepts

Technology	UPD	Energy Costs ($ x 1000)			
		A	B	C	D
Base Building	26.90	44.41	35.41	24.29	15.29
High + 60 W	18.18	32.75	26.52	18.78	12.55
High + 40 W	16.68	30.79	25.03	17.86	12.10
High + 20 W	15.17	28.85	23.56	16.96	11.76
Med + 60 W	16.68	30.79	25.03	17.86	12.10
Med + 40 W	15.71	29.54	24.08	17.28	11.82
Med + 20 W	14.63	28.15	23.03	16.63	11.51
Low + 60 W	15.92	29.82	24.29	17.41	11.88
Low + 40 W	15.17	28.85	23.56	16.96	11.76
Low + 20 W	14.42	27.88	22.83	16.51	11.45

A = high energy costs + high demand costs
B = high energy costs + low demand costs
C = low energy costs + high demand costs
D = low energy costs + low demand costs

Table 5-8. Energy Costs, Equipment Concepts

Technology	UPD	Energy Costs ($ x 1000)			
		A	B	C	D
Base Building	26.90	44.41	35.41	24.29	15.29
Ballasts					
ESav 1	21.41	37.00	29.76	20.78	13.53
ESav 2	18.18	32.75	26.52	18.78	12.55
Hybrid	18.72	33.45	27.06	19.11	12.71
Lamping					
ESav 1	18.72	33.45	27.06	19.11	12.71
HID 1	19.80	34.87	28.13	19.77	13.03
HID 2	17.00	31.21	25.35	18.06	12.20
HID 3	13.34	26.51	21.79	15.87	11.15
Dummy	18.83	33.59	27.16	19.17	12.74
Fixtures					
IES 42	24.75	41.48	33.17	22.90	14.59
IES 43	23.13	39.30	31.51	21.86	14.07
Other					
Reduce	18.83	33.59	27.16	19.17	12.74
Automt	15.39	29.12	23.77	17.08	11.73

A = high energy costs + high demand costs
B = high energy costs + low demand costs
C = low energy costs + high demand costs
D = low energy costs + low demand costs

Table 5-9. Economic Efficiency, Simple Payback, of Daylighting Concepts

Technology	UPD	Simple Payback (years)			
		A	B	C	D
Base Building	26.90	0.0	0.0	0.0	0.0
Task, All Building					
2S controller	18.18	4.5	5.9	9.5	19.0
3S controller	11.41	3.3	4.4	7.1	14.5
4S controller	8.39	2.8	3.7	6.0	12.3
5S controller	6.67	2.6	3.4	5.7	11.4
CD controller	3.44	2.3	3.0	5.0	10.3
Task, Perimeter					
2S controller	21.41	4.5	5.9	9.4	18.7
3S controller	17.11	3.2	4.3	6.9	13.8
4S controller	15.17	2.7	3.6	5.8	11.7
5S controller	14.10	2.5	3.3	5.3	10.8
CD controller	12.05	2.3	3.0	4.8	9.8

2S = two-step automatic step control
3S = three-step automatic step control
4S = four-step automatic step control
5S = five-step automatic step control
CD= continuous linear dimming

Table 5-10. Economic Efficiency, Simple Payback, of Task/Ambient Lighting Concepts

Technology	UPD	Simple Payback (years)			
		A	B	C	D
Base Building	26.90	0.0	0.0	0.0	0.0
High + 60 W	18.18	2.5	3.2	5.2	10.3
High + 40 W	16.68	2.8	3.7	6.0	12.1
High + 20 W	15.17	2.1	2.8	4.5	9.0
Med + 60 W	16.68	1.7	2.2	3.5	7.1
Med + 40 W	15.71	1.9	2.6	4.1	8.3
Med + 20 W	14.63	1.6	2.1	3.3	6.8
Low + 60 W	15.92	1.5	1.9	3.1	6.3
Low + 40 W	15.17	1.6	2.1	3.6	6.8
Low + 20 W	14.42	1.2	1.6	2.5	5.1

High = high density occupancy
Med = medium density occupancy
Low = low density occupancy

Table 5-11. Economic Efficiency, Simple Payback, of Various Equipment Options

		Simple Payback (years)			
Technology	UPD	A	B	C	D
Base Building	26.90	0.0	0.0	0.0	0.0
Ballasts					
ESav 1	21.41	2.0	2.6	4.2	8.3
ESav 2	18.18	1.5	2.0	3.1	6.3
Hybrid	18.72	7.6	10.0	16.1	32.3
Lamping					
ESav 1	18.72	7.6	10.0	16.1	32.3
HID 1	19.80	15.4	20.2	32.5	65.1
HID 2	17.00	16.3	24.8	34.4	68.9
HID 3	13.34	3.4	4.4	7.2	14.6
Dummy	18.83	1.1	1.5	2.3	4.7
Fixtures					
IES type 42	24.75	0.0	0.0	0.0	0.0
IES type 43	23.13	0.0	0.0	0.0	0.0
Other					
Watt reducer	18.83	2.5	3.3	5.3	10.7
Auto control	15.39	2.6	3.4	5.6	11.3

Table 5-12. Rank Ordering, Lighting Strategies by Simple Payback for Four Energy Cost Scenarios

Rank	Technology	UPD	Simple Payback (years) A	B	C	D
1	Fixture, IES type 42	24.75	0.0	0.0	0.0	0.0
	Fixture, IES type 43	23.13	0.0	0.0	0.0	0.0
2	Dummy lamping	18.83	1.1	1.5	2.3	4.7
3	Ballasts, ESav 2	18.18	1.5	2.0	3.1	6.3
4	Low occupancy + 20 W	14.42	1.2	1.6	2.5	5.1
5	Low occupancy + 60 W	15.92	1.5	1.9	3.1	6.3
6	Med occupancy + 20 W	14.63	1.6	2.1	3.3	6.8
7	Low occupancy + 40 W	15.17	1.6	2.1	3.6	6.8
8	Med occupancy + 60 W	16.68	1.6	2.2	3.5	7.0
9	Med occupancy + 40 W	15.71	1.9	2.6	4.1	8.3
10	Ballasts, ESav 1	21.41	2.0	2.6	4.2	8.3
11	High occupancy + 20 W	15.17	2.1	2.8	4.5	9.0
12	Daylighting, perim, CD	12.05	2.3	3.0	4.8	9.8
13	Daylighting, all, CD	3.44	2.3	3.0	5.0	10.3
14	High occupancy + 60 W	18.18	2.5	3.2	5.2	10.5
15	Watt reducer	18.83	2.5	3.3	5.3	10.7
16	Daylighting, perim, 5S	14.10	2.5	3.3	5.3	10.8
17	Automatic control	15.39	2.6	3.4	5.6	10.7
18	Daylighting, all, 5S	6.67	2.6	3.4	5.7	11.4
19	Daylighting, perim, 4S	15.17	2.7	3.6	5.8	11.7
20	High occupancy + 40 W	16.68	2.8	3.7	6.0	12.1
21	Daylighting, all, 4S	8.39	2.8	3.7	6.0	12.3
22	Daylighting, perim, 3S	17.11	3.2	4.3	6.9	13.8
23	Daylighting, all, 3S	11.41	3.3	4.4	7.1	14.5
24	Lamping, HID 3	13.34	3.4	4.4	7.2	14.6
25	Daylighting, perim, 2S	21.41	4.5	5.9	9.4	18.7
	Daylighting, all, 2S	18.18	4.5	5.9	9.5	19.0
26	Hybrid ballast	18.72	7.6	10.0	16.1	32.3
	Lamping, ESav 1	18.72	7.6	10.0	16.1	32.3
27	Lamping, HID 1	19.80	15.4	20.2	32.5	65.1
28	Lamping, HID 2	17.00	16.3	24.8	34.4	68.9

A = high energy costs + high demand costs
B = high energy costs + low demand costs
C = low energy costs + high demand costs
D = low energy costs + low demand costs

SECTION 6.0

PEAK DEMAND REDUCTIONS DUE TO LIGHTING ALTERNATIVES

In addition to direct energy conservation in the building, the various lighting alternatives also reduce the need for peak generating capacity of the utility by reducing the building electricity capacity or peak demand requirements. For this study it was assumed that peak demand reduction was directly proportional to unit power density (UPD) as analyzed in Section 4.0. This is a reasonable approach when analyzing all of the equipment and task/ambient strategies, where the lighting power density is usually assumed to be a constant throughout the workday.

It is a very conservative method for analyzing the impact of daylighting upon the lighting and cooling peak demand. This is because the peak building energy usage is greatest on a hot summer day. The daylighting opportunity is also very high at that time; therefore, an average unit power density approach, representing an annual average, may not represent the conditions occurring in a daylighted building under a clear summer sky at peak [16,17].

The impact on peak demand of the various lighting alternatives is shown in Tables 6-1, 6-2, and 6-3, for daylighting concepts, task/ambient lighting concepts, and equipment alternatives, respectively. A rank ordering of all strategies is shown in Table 6-4. Because the differential in unit power density was used to establish peak demand, the rank ordering of concepts based on their reduction in the peak demand requirements of the base case building is identical to the ranking for energy use, as shown in Table 5-4. From this analysis it can be seen that alternative lighting strategies have a significant impact on the peak demand for a building and would positively impact the overall peak capacity requirements of a utility.

Table 6-1. Peak Demand for Various Daylighting Concepts

Technology	UPD (W/m^2)	Peak Demand Total (kW)	Light (kW)	Cool (kW)
Base Building	26.90	283	200	83
Task, All				
2S	18.18	239	169	70
3S	11.41	150	106	44
4S	8.39	111	78	33
5S	6.67	88	62	26
CD	3.44	45	32	13
Task, Perimeter				
2S	21.41	282	199	83
3S	17.11	225	159	66
4S	15.17	200	141	59
5S	14.10	186	131	55
CD	12.05	159	112	47

Table 6-2. Peak Demand for Various Task/Ambient Concepts

Technology	UPD (W/m^2)	Peak Demand Total (kW)	Light (kW)	Cool (kW)
Base Building	26.90	283	200	83
High + 60 W	18.18	239	169	70
High + 40 W	16.68	220	155	65
High + 20 W	15.17	200	141	59
Med + 60 W	16.68	220	155	65
Med + 40 W	15.71	207	146	61
Med + 20 W	14.63	193	136	57
Low + 60 W	15.92	210	148	63
Low + 40 W	15.17	200	141	59
Low + 20 W	14.42	190	134	56

Table 6-3. Peak Demand for Various Equipment Concepts

Technology	UPD (W/m^2)	Peak Demand Total (kW)	Light (kW)	Cool (kW)
Base Building	26.90	283	200	83
Ballasts				
ESav 1	21.41	282	199	83
ESav 2	18.18	239	169	70
Hybrid	18.72	247	174	73
Lamping				
ESav 1	18.72	247	174	73
HID 1	19.80	261	184	77
HID 2	17.00	224	158	66
HID 3	13.34	176	124	52
Dummy	18.83	248	175	73
Fixtures				
IES 42	24.75	326	230	96
IES 43	23.13	305	215	90
Other				
Reduce	18.83	248	175	73
Automt	15.39	203	143	60

Table 6-4. Rank Ordering, By Peak Demand

Rank	Technology	UPD	Peak Demand Total (kW)	Peak Demand Light (kW)
1	Daylight, all, CD	3.44	45	32
2	Daylight, all, 5S	6.67	88	62
3	Daylight, all, 4S	8.39	111	78
4	Daylight, all, 3S	11.41	150	106
5	Daylight, perim, CD	12.05	159	112
6	HID 3, mercury vapor	13.34	176	124
7	Daylight, perim, 5S	14.10	189	131
8	Low + 20 W, task/ambient	14.42	190	134
9	Med + 20 W, task/ambient	14.63	193	136
10	Low + 40 W, task/ambient	15.17	200	141
	High + 20 W, task/ambient	15.17	200	141
	Daylight, perim, 4S	15.17	200	141
11	Automatic controllers	15.39	203	143
12	Med + 40 W, task/ambient	15.71	207	146
13	Low + 60 W, task/ambient	15.92	210	148
14	High + 40 W, task/ambient	16.68	220	155
	Med + 60 W, task/ambient	16.68	220	155
15	HID 2, HPS	17.00	224	158
16	Daylight, perim, 3S	17.11	225	159
17	High + 60 W, task/ambient	18.18	239	169
	Daylighting, all, 2S	18.18	239	169
	Energy ballast and lamp	18.18	239	169
18	Hybrid ballast	18.72	247	174
	Energy lamp + hybrid ballast	18.72	247	174
19	Dummy lamping	18.83	248	175
	Wattage reducer	18.83	248	175
20	HID 1, multivapor	19.80	261	184
21	Daylighting, perim, 2S	21.41	282	199
	Energy saving ballast	21.41	282	199
22	IES luminaire 43	23.13	305	215
23	IES luminaire 42	24.75	326	230
B	Base building	26.90	354	250

SECTION 7.0

SUMMARY

7.1 CONCLUSION

In general, it can be seen that all of the lighting concepts analyzed reduce the energy use and costs in the base building. Further, all of the lighting alternatives had a positive impact on lighting and cooling peak demand.

To establish the viability of each alternative strategy in terms of economic efficiency, it is necessary to establish what economic criteria are used by different client types for making economic decisions about energy conservation. Using the approach taken in Ref. 10, the different client types and the approximate simple payback period considered reasonable by each are shown in Table 7-1.

Table 7-1. Client Type and Simple Payback Criteria

Client Type	Allowable Years, Simple Payback
Speculative developer	4
Owner-occupied building	8-12
Nonprofit organization	15-20
Government	15-50

Thus, if a speculative developer is going to consider a conservation alternative cost effective it must have a simple payback in less than four years.

Using daylight as an alternative to electric lighting is the most promising concept in terms of energy conservation and peak demand reduction. The difference in costs between a continuous dimming controller, multistep controller, and on/off (two step) controller accounts for the fact that daylighting is in the midrange for economic efficiency. Should daylighting become a more common design characteristic in commercial buildings, the cost of control options can be reduced because of larger production thereby making daylighting more economically attractive.

However, many of the daylighting options would look attractive to all of the various clients because the simple payback, under some cost scenarios, is quite short—less than four years. Conversely, in areas with low energy costs and low peak demand costs the payback is not attractive to speculative developers.

Using a task lamp in conjunction with reduced ambient lighting reduced total energy use between 15% and 21% in comparison with the base case building. A 20-W task lamp in conjunction with a low occupancy density provided the greatest energy savings, and a 60-W task lamp in conjunction with a high occupancy density provided the least energy savings.

Using a 20-W task lamp with all occupancy scenarios and using a 40-W task lamp with the low occupancy scenario ranked in the top ten energy reduction strategies in terms of the lighting energy and total energy ratios.

The energy rate structure in a locality will determine if a measure is cost-effective. The energy costs under the high energy costs/high demand cost rate structure are 2.5 to 3 times higher than under the low energy cost/low demand cost rate structure. The payback for the task/ambient lighting ranged from a low of 1.2 years for the 20-W task lamp/low occupancy scenario with a high energy cost/high demand cost rate structure to a high of 12.1 years for the 40-W task lamp/high occupancy scenario with the low energy cost/low demand cost rate structure.

In evaluating the impact of equipment changes in relation to the base building, the illuminance, in most cases, is maintained at the base-case level of 540 lux to ensure a fair comparison. For instance, several lamping and ballasting strategies save energy with a somewhat corresponding decrease in light output. The number of lamps required is then increased so that a 540-lux level is maintained. The equipment was evaluated in terms of both energy use or simple payback. Note that the ranking varies dramatically depending upon which criterion is being examined. For example, while fixture changes are the least successful in terms of energy savings, they fall at the top of the list in terms of simple payback scenarios.

If considering energy usage alone, equipment changes generally fall below both daylighting and task lighting scenarios. The exceptions are the HID-mercury vapor lamping, number 6 in the ranking, and automatic controllers, number 11.

If we examine each alternative in terms of simple payback, we see an entirely different scenario. Several of the options low in the previous ranking now fall at the top of the list. These measures include fixture changes, dummy lamping, and several of the ballast changes. Several measures being considered remain consistently low in both cases. These include several of the lamping and ballast strategies such as the multivapor high intensity discharge lamp and the hybrid ballast.

It should be noted that these items are considered from the viewpoint of simple payback and were a different method of analysis used, such as LCC, the ranking would undoubtedly change.

7.2 FUTURE WORK

It is clear from this study that lighting has a significant impact on energy use, costs, and peak demand in commercial buildings. However, important additional work is needed to better examine and understand the impact of lighting alternatives, especially daylighting, on commercial building energy use.

To begin with, this study was limited in scope of analyzing a "generic" base building that had load characteristics very similar to office buildings. It would be important to have a better understanding of lighting energy use and the impact of various lighting alternative strategies on a range of building types that vary in size.

Research at SERI and elsewhere has identified the composition of commercial building stock by building type to be like that shown in Table 7-2. A better understanding of the impact of lighting on commercial building energy use would be to analyze each type

Table 7-2. Commercial Building Characteristics [1]

Type	Average Floor Area (1000 ft^2)	Standing Stock of Commercial Buildings: Number of Buildings (%)	Standing Stock of Commercial Buildings: Total Floor Area (%)
Assembly	11.7	11	11
Auto sales/service	4.3	10	4
Education	40.1	4	13
Food sales	4.3	9	3
Health care	32.6	1	3
Lodging	19.3	3	5
Office	12.2	15	15
Residential	10.1	9	8
Retail service	9.8	18	15
Warehouse	14.7	11	14
Other	13.1	6	7
Vacant	9.4	4	3

separately. Further, rather than looking only at one size of building, it would be important to analyze a variety of building sizes. For most building types three sizes seem sufficient to determine the importance of size on energy use. These are

- Small (10,000 ft^2)
- Medium (50,000 ft^2)
- Large (100,000 ft^2).

In studying the impact of daylighting on building energy use it is critical to understand the regional differences in daylight availability and the impact resource availability would have upon the capability of daylighting to replace or supplement electric lighting. In addition, the economic analysis technique used in this study did not take into account the impact of daylighting, or any of the concepts studied, upon the cooling plant capacity (i.e., sizing). That is, if the lighting heat extraction represents 40% of the cooling load and daylight can reduce the peak lighting load by 70%, then there is a corresponding 28% reduction in the size, or capacity, of the cooling plant for the building. The interaction between equipment sizing and a given conservation strategy should be more closely analyzed. In fact, some technologies may be able to be paid for from the first costs savings differential in cooling plant capacity.

It was assumed that 70% of the building could be illuminated using a task/ambient lighting system in that portion of this study. The fraction of the building that could be lighted in this manner will vary from building type to building type. A series of parametric studies, by building type, should be done to analyze the impact of task/ambient lighting over a range of lighting options.

Task ambient lighting concepts can also be used in conjunction with other lighting concepts. For example, the combination of daylighting and task/ambient electric lighting would appear to be very energy conserving and cost-effective. Further, using nonstandard ballasts, energy conserving fixtures, and lamps in combination with task/ambient lighting should also be analyzed.

It would be impossible to analyze the impact of all equipment changes that could be made to improve the lighting energy characteristics of the base building; however, additional equipment strategies that could be studied include

- Various energy management systems
- Additional lamping and ballasting scenarios
- Dim-down lighting controls
- Improved reflector and luminaire technology
- Light piping systems.

Finally, this study has been limited to new construction commercial buildings. Performing a similar study on the impact of lighting concepts on energy use and costs as a retrofit strategy is needed.

SECTION 8.0

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15. Supplementary Notes

16. Abstract (Limit: 200 words) This report investigates current efficient alternatives for replacing or supplementing electric lighting systems in commercial buildings. Criteria for establishing the economic attractiveness of various lighting alternatives are defined and the effect of future changes in building lighting on utility capacity. The report focuses on the energy savings potential, economic efficiency, and energy demand reduction of three categories of lighting alternatives: (1) use of a renewable resource (daylighting) to replace or supplement electric lighting; (2) use of task/ambient lighting in lieu of overhead task lighting; and (3) equipment changes to improve lighting energy efficiency. The results indicate that all three categories offer opportunities to reduce lighting energy use in commercial buildings. Further, reducing lighting energy causes a reduction in cooling energy use and cooling capacity while increasing heating energy use. It does not typically increase heating capacity because the use of lighting in the building does not offset the need for peak heating at night.

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