## Appendix C

# Equipment Technical Characteristics

For this analysis, technical ratings were developed for broad categories of common lighting equipment. Exotic technologies and elaborate reconfigurations of lighting systems were not considered. The general framework developed here could be used to analyze other technologies, given the necessary technology specifications.

## Lamps

For the present implementation of the framework, seven types of lamps with four different conservation features define the possible lighting categories. For each lamp type **L**, the base efficacy $\mathbf{Q_L}$, absent any special conservation features, was determined from the literature.

The lamp types considered and efficacies assigned are given in Table C1. The efficacies for most lamps and lamp/ballast combinations were taken directly or derived from the ALTAG series.[2] This series consists of several pamphlets reporting data on different types of lighting equipment.

There was no ALTAG pamphlet for incandescent bulbs, but the efficacy of the standard incandescent bulb was reported in the "Conventional Shape Tungsten Halogen Lamps" pamphlet as 18 lumens per watt. The New York State energy Research and Development Authority (NYSERDA) reported that the energy-efficient incandescent bulb reduces electricity use by 10 percent.[13] This reduction corresponds roughly to replacement of a 75-watt bulb by a 70-watt energy-efficient bulb, or a 60-watt by a 55-watt. Applying the 10 percent factor, the efficacy for the energy-efficient incandescent bulb was obtained by adding 10 percent to the efficacy of the standard incandescent bulb.

The ALTAG series did contain a pamphlet on compact fluorescent lamps. The efficacy for the compact fluorescent lamp was taken directly from that pamphlet.

Determining the efficacy for full-size fluorescent lamps was somewhat problematic in that the data on the full-size fluorescent lamps given in the ALTAG "Full-Size Fluorescent Lamps" pamphlet referred to fluorescent lamps using magnetic ballasts. These are the current minimum standard under California law. However, magnetic ballasts are not likely to be the standard equipment in newer buildings in other parts of the country.

For this report it was assumed that the standard ballast for fluorescent lamps would be the standard core-coil ballast. The ALTAG "Full-Size Fluorescent Lamps" pamphlet did report that the magnetic (or "energy- efficient") ballast would cause the lamp/ballast system to draw approximately 10 percent fewer watts than the core-coil ballast (96 watts for the core-coil versus 86 for the magnetic). Using that information, the efficacy ratings obtained from the ALTAG pamphlet were adjusted to represent the fluorescent lamps with core-coil ballasts. This adjustment was done by taking the efficacy of the lamp/magnetic ballast system and subtracting the 10 percent difference.

The ALTAG series also does not give efficacies for high-intensity discharge (HID) lamps. Efficacies for metal halide and high-pressure sodium HID lamps were taken from tables prepared by the LBL Lighting Research Group. The CBECS data do not specify the type of HID lamp used. The analysis assumes that HID lamps currently in place are all metal halide, and uses high-pressure sodium as a conservation conversion option.

## Table C1. Lamp Types and Efficacies

| Lamp Type | Percent of Lighted Floorspace (1986) | Efficacy (lumens/watt) |
|---|---|---|
| **Fluorescent** | | |
| Standard | 41.7 | 59 |
| Compact | 0.0[1] | 52 |
| Energy-Efficient | 34.5 | 62 |
| Very High Efficiency | 0.0[1] | 68 |
| **Incandescent** | | |
| Standard | 13.7 | 18 |
| Energy-Efficient | 5.1 | 20 |
| **High-Intensity Discharge** | | |
| Metal Halide | 6.2[1] | 69 |
| High-Pressure Sodium | 0.0[1] | 88 |

[1] Assumed for the analysis. The 1986 Commercial Buildings Energy Consumption Survey collected no data on the presence of this equipment or feature. This analysis assumes the current floorspace for each of these categories is zero, except that metal halide lamps are assumed to be the only type of high-intensity discharge lamps currently in place.

Note: See the Glossary for explanations of abbreviations and definitions used in this report.

Sources: Energy Information Administration, Office of Energy Markets and End Use, Nonresidential Buildings Energy Consumption Survey: *Characteristics of Commercial Buildings 1986*; California Energy Commission, *Advanced Lighting Technologies Application Guidelines*; and Lawrence Berkeley Laboratory Lighting Research Group, personal communication, Barbara Atkinson.

## Table C2. Conservation Features and Deflation Factors

| Conservation Feature | Percent of Lighted Floorspace in Buildings with Feature[1] | Assumed Deflation Factor | |
|---|---|---|---|
| | | Optimistic | Modest |
| No Features | 45.6 | 1.00 | 1.00 |
| Lighting Controls | 27.7 | 0.70 | 0.90 |
| **Fluorescent Lamp Features** | | | |
| High-Efficiency Ballast | 34.9 | 0.80 | 0.92 |
| Reflector | 0.0 | 0.67 | 0.73 |
| Delamping | 22.5 | 0.75 | 0.90 |

[1] Percent of lighted floorspace that was in buildings where the indicated feature was present. The 1986 Commercial Buildings Energy Consumption Survey collected no data on the presence of reflectors.

Note: See the Glossary for explanations of abbreviations and definitions used in this report.

Sources: Energy Information Administration, Office of Energy Markets and End Use, Nonresidential Buildings Energy Consumption Survey: *Characteristics of Commercial Buildings 1986*; Lawrence Berkeley Laboratory Lighting Research Group, personal communication, Barbara Atkinson and Francis Rubinstein; California Energy Commission, *Advanced Lighting Technologies Application Guidelines*; New York State Energy Research and Development Authority, *The Potential for Electricity Conservation in New York State*; Goldstein and Watson, *Deriving and Testing Power Budgets for Energy Efficient Lighting in Nonresidential Buildings*; Piette et. al., *Technology Assessment: Energy-Efficient Commercial Lighting*; Lighting Research Center, *Commercial Lighting Efficiency Resource Book*; and Dubin et. al., *How to Save Energy and Cut Costs in Existing Industrial and Commercial Buildings.*

## Conservation Features

Four types of conservation features are considered: controls, high-efficiency ballasts, reflectors, and delamping. Controls include occupancy sensors, daylight sensors, timers, and any other controls that could be used to turn lights off at times when they are not needed. High-efficiency ballasts are assumed to apply only to non-compact fluorescent lamps. Reflectors are assumed to apply only to fluorescent lamps, either compact or standard dimension.

Delamping as defined for the 1986 CBECS refers to the removal of lamps and disconnecting associated ballasts. This process is often associated with installation of more efficient lighting equipment efficiency, so that the original lighting levels are maintained. However, the CBECS did not determine the context in which any reported delamping occurred. For purposes of the savings analysis, delamping means a reduction in illuminance, as discussed further below.

For each of the conservation features **f**, a modest (high) and an optimistic (low) deflation factor $\mathbf{d_f}$ was obtained from the literature. The deflation factor is the fraction of the base energy the lamp would use if the conservation feature were added. Estimates of the effects of the different features vary, in part because the applications of these features are not as standard as the energy requirements of different types of lamps. To account for the range of possible effects, a high and a low deflation factor $\mathbf{d_f}$ were considered for each feature (Table C2).

The deflation factor represents an average over all the floorspace the feature applies to. Thus, the factor is applied uniformly to all applicable space in the building.

## Controls

A wide range of lighting control devices and strategies is available for commercial buildings. The 1986 CBECS collected information on the presence of daylighting controls and on the presence of other lighting controls. For this analysis, controls are grouped together as one broad category. It is assumed that a building where controls are present may have a variety of different types of controls in place in different areas, depending on the use and location of the space.

Because the effectiveness and applicability of each type of lighting control is site-specific, the estimates of how much these devices can save varies widely. The ALTAG pamphlet on "Lighting Design Practice" states that a 10-percent reduction can be achieved by daylight controls, 15 to 30 percent by occupancy sensors. NYSERDA report a range of savings for various control systems, from 9 to 57 percent.[14] Included in the range is are estimates of 50 to 60 percent savings for occupancy sensors, 10 to 30 percent for daylight sensors. An earlier NYSERDA report indicated a savings of 40 to 55 percent for daylighting, 50 percent for occupancy sensors where installed.[13]

The deflation factor used here represents an average over all lighted floorspace in a building where lighting controls are assumed. Even in the optimistic case, reductions of 50 percent are not assumed to be achievable as an overall average. The modest effect is set at a 10 percent reduction (0.9 deflation factor), and the optimistic effect at 30 percent reduction (0.7 deflation factor).

## High-Efficiency Ballasts

High-efficiency ballasts constituted one category of lighting conservation features identified on the 1986 CBECS. When this feature was reported for a building, however, it was not clear whether it was understood as a magnetic ballast or as an electronic ballast. The ALTAG series indicates efficacies of 60 l/w for a standard core coil, 65 l/w for magnetic, and 75 l/w for an electronic ballast of "A" rating (low hum). These efficacies give deflation factors of 60/65 = 0.92 or 60/75 = 0.80 relative to the standard core coil. Goldstein and Watson also indicate that electronic ballasts can save 20 percent.[10] For this feature, 0.80 and 0.92 are taken as the optimistic and modest deflation factors, respectively.

## Reflectors

Piette et al.[15] report a 27-percent improvement in efficacy when a specular reflector is added to a 4-lamp fluorescent fixture. NYSERDA [13] indicate an efficacy improvement of 50 percent, which would imply a deflation factor of 1/1.5 = 0.67. The Lighting Research Center [12] states that reflectors reduce energy requirements by 50 percent, with a loss of illumination of 25 to 40 percent, implying deflation factors of 0.5/0.75 = 0.83 to 0.5/0.6 = 0.67. Rubinstein [17] suggests 0.73 as a moderate deflation factor for typical applications. For the savings analysis presented here, the optimistic and modest deflation factors for reflectors are set at 0.67 and 0.73, respectively.

## Delamping

Delamping in the context of the savings analysis refers to reducing illumination levels. That is, the analysis is not concerned with the number of fixtures in place, but with the lumens per square foot and the efficacy of the equipment providing that illumination. Implicitly, it is assumed that if lamps and/or fixtures are replaced by more efficient equipment, the illumination level is retained and the number of fixtures required are reduced. For example, if the efficacy is improved by one-third, an average of one in four fixtures would be disconnected. This implied reduction in fixtures is accounted for in the analysis by the efficacy improvement, and is not represented as a delamping effect.

The delamping conservation cases implicitly assume that illuminances in place are unnecessarily high for the functions in place. The extent to which existing floorspace is currently overly lighted is difficult to determine.

In practice, illuminance reductions in many places would be linked to lumen maintenance strategies, which are not explicitly addressed here. Lighting installations generally call for higher than necessary illuminance to provide tolerance for lighting loss as equipment degrades over time. Goldstein and Watson report that typical lighting systems are overdesigned by 43 percent to allow for equipment degradation.[10] Piette et al. indicate overdesign at 20 to 40 percent, and suggest a possible savings of 10 to 15 percent with lumen maintenance.[15] Dubin et al.[3] cite examples of savings of 28 percent and 50 percent by reducing lighting levels.[3]

For this analysis, 10-percent savings (deflation factor of 0.90) is taken as the modest delamping effect. A savings of 25 percent (deflation factor of 0.75) is the optimistic case. This level of delamping corresponds to disconnecting one fixture in every four.