EFFICIENT USE OF LIGHTING IN BUILDINGS

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Summary

Good illumination is essential for numerous everyday tasks. For many applications, natural lighting is insufficient, and needs to be augmented with artificial lighting systems. Consequently, lighting systems are widely employed in buildings, and they account for a substantial portion of total building energy consumption. Therefore, it is more important than ever that lighting systems are designed to provide for optimum energy use, as well as to provide for human “seeability” (i.e., comfort and productiveness). This article describes the planning, design, and operation of new and existing lighting systems so as to achieve optimum energy use.

1. Introduction

In the United States, lighting systems accounts for between 5% and 10% of total energy consumption in residential buildings, about 10% of total energy consumption in industrial buildings, and nearly one-third of total energy consumption in commercial buildings. Worldwide, artificial illumination is estimated to demand 20–25% of all electric energy in developed countries.

This value of electric energy consumption corresponds to approximately 5% of total energy consumption. In developing nations, artificial illumination is often the first use that newly electrified communities embrace. As a result, its importance may be even greater in the developing world.

Because of lighting’s importance to both developed and developing countries, as well as the large share of total energy consumption that lighting systems comprise, the implementation of effective and efficient lighting designs is a critical element in the goal of achieving a sustainable energy future.

This article addresses the factors involved with designing for effective illumination and energy efficiency. It also details specific measures for improving energy efficiency and performance in existing lighting systems.

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2. Illumination

Illumination as a quantity is expressed and measured in footcandles or lux. There is, however, more to the quantity of illumination than simply turning on the lights. Some light is often not enough light, and enough light may be poorly distributed and in other ways diminished before it reaches the eyes. The eye sees brightness, not illumination. In fact, most artificial illumination is reflected by one or more surfaces before building occupants see it. The result is a varying reduction in the amount of usable illumination from a source. This reflected light is referred to as brightness, and it is measured in footlamberts (or candela per square meter).

2.1. Visual Task and Performance

The concept of a visual task conventionally designates the sum total of all the things that have to be seen at a given moment. The character of a visual task may change from moment to moment. Hence, in determining whether illumination is adequate for a given task, it is necessary to consider the nature of the task during each phase—ideally each instant—of its performance, so as to design lighting for the most critical visual phase.

In determining the amount of illumination required for any task, four basic visual factors must be considered:

1. The size of the task and all its component parts,
2. The time it takes to see the task or the time allowed for viewing it,
3. The brightness of the task itself, and
4. The contrast of brightness and colors within the task and with other surfaces in the visual surroundings.

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The primary purpose of most lighting systems is to provide enough illumination for the efficient and accurate performance of visual tasks.

Technological progress has taken most people’s work inside. Today’s tasks have become more complex and visually demanding, but the indoor illumination levels encountered are usually only a fraction of those found outdoors, where the tasks are much less exacting. Studies have indicated that visual performance is significantly improved on light-colored tasks when the illumination levels are raised up to about 500 footcandles (5400 lux). This level of illumination is about the same as that found under the shade of a tree on a sunny day—certainly, a pleasant spot to read. There are also many dark-colored or lower reflectance tasks, where visual performance continues to improve when levels up to 10 000 footcandles (108 000 lux) are utilized. This is the level of illumination under full sunlight.

People who “work with their eyes” not only accept, but instinctively desire, the hundreds of footcandles that can be available to them today. Whether we consider visual tasks that have remained the same or those that have become more demanding, minimum recommended footcandle levels for them have changed over the years.

There are many reasons for this updating of recommendations. Research into the functioning of human sight and perception has more firmly established the basic criteria on which the recommendations are based. Practical experience with new forms of lighting equipment, concepts, and higher illumination levels continuously confirms expectations of the benefits of better lighting. Improved light sources, lighting equipment and electrical systems have steadily decreased the cost per footcandle of lighting systems. The decreased costs, combined with increased efficiency of visual performance because of better lighting, make light an excellent investment for raising the productivity and quality of human performance. Today's illumination recommendations, then, are the result of demonstrated visual need, increasing practicability of installation, and a relative decrease in the cost per footcandle.

In addition to the basic factors of demonstrated visual need and practicability of installation and cost, there are a number of other considerations that modify the minimum recommended footcandle levels:

- Age and subnormal vision have definite effects on visual performance.
- Depreciation of a lighting system (less light output over time) is not taken into consideration when making general footcandle recommendations.
- Supplementary lighting is also an important consideration, especially where there is a special need for higher footcandles on a task compared with general illumination.
- Glare is often the result of higher illumination levels, but footcandle recommendations are made on the basis of "glare-free" illumination produced in laboratories and achieved in actual operations.

Adequate quantity of light alone does not insure good illumination. Good quality is as important as quantity, and usually more difficult to achieve. The quality of illumination refers to the proper distribution, color, and control of light, so as to achieve a proper balance of brightness in the whole visual environment as well as proper lighting for each type of task. Quality is used in a positive sense and implies that the brightness distribution and color rendition of a lighting system contribute favorably in any visual environment to improving visual performance, assuring visual comfort, and creating a visual atmosphere that is esthetically beneficial. Just as one cannot live by bread alone, so too one cannot work by light alone. This implies that simply raising the raw amount of illumination may temporarily bring about improved task performance, but only at a much greater human cost in the long run. The quality of illumination cannot be neglected, in order to achieve the desired benefits from higher illumination levels.

The visual environment includes not only the immediate task area, but also all the other areas that will be viewed countless times during a typical time period. Physically, the visual environment is a three-dimensional pattern of brightness and colors visible to a person within the environment. However, it is not only the problems of transient eye adaptation, but also the emotional and aesthetic values, though less easily measured, that must be considered in lighting design.

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Visual comfort is another important quality factor that greatly influences the success of a lighting installation. Visual comfort is a term that describes the environment's freedom from a number of complex and difficult-to-control conditions.

3. Energy Efficiency in Lighting

Lighting is highly visible and easily conserved. Lighting systems can be designed to provide the required illumination levels when and where required with maximum utilization of the available energy. This section will illustrate this. The Illuminating Engineering Society of North America (IESNA), after many years of research and development, has established and updated standards that direct themselves to the fundamental seeing needs of people rather than lighting solutions. These basic standards, or recommendations, relate to the quantity and quality of light that enable designers to develop new approaches that are more esthetically pleasing, lower in cost, and energy efficient.

As early as 1972, IESNA offered 12 recommendations for the better utilization of energy expended for lighting. These are still applicable today. They are as follows:

1. Design lighting for expected activity (light for seeing tasks with less light in surrounding nonworking areas).
2. Design with more effective luminaires and fenestration.
3. Use efficient light sources (higher lumen/watt output).
4. Use more efficient luminaires.
5. Use thermal-controlled luminaires.
6. Use lighter finishes on ceilings, walls, floors, and furnishings.
7. Use efficient incandescent lamps.
8. Turn off lights when not needed.
9. Control window brightness.
10. Utilize daylighting as practicable.
11. Keep lighting equipment clean and in good working condition.
12. Post instructions covering operation and maintenance.

IESNA prepared a lighting power budget determination procedure based on the state of the art in lighting that is consistent with the concepts utilized in *The IESNA Lighting Handbook*. This procedure was initially adopted as Section 9 of the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) Standard 90-75. The lighting power budget establishes the upper limits of power to be available for lighting in accordance with a given set of criteria and given calculation procedures. It is not intended that this procedure be used for the final lighting design. Its purpose is solely to determine the maximum power limit of lighting. After this limit has been established, the lighting designer is then free to arrive at a pleasing visual environment in accordance with the use of the space, as long as the budget limit is not exceeded.

3.1. Design Lighting for the Expected Visual Task or Function of Space

In establishing lighting requirements it is necessary to determine what types of activities are expected, their duration, and the concentration of people and where they are

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expected to occur. Whenever there is a concentration of people such that the tasks are not really separated, it is usually reasonable to light such an area with a uniform lighting system. However, the concept of filling a space with uniform light levels may often be an inefficient lighting approach. In the latter case, it can be much more productive to graduate illumination as required by the task at hand, and to keep the surroundings in appropriate balance. Adequate lighting should be provided for the seeing tasks with less light on surrounding nonworking areas such as corridors, storage, and pedestrian or vehicular areas.

Quantity: IESNA recommends values of illumination for visual tasks or a group of tasks in an area. *The IESNA Lighting Handbook* sometimes lists locations rather than tasks; however, the recommended footcandle values have been arrived at for specific visual tasks. Also, supplementary luminaires may be used in combination with general lighting to achieve the recommended levels. However, the general lighting should not be less than 20 footcandles (216 lux) and should contribute at least one-tenth the total illumination level. Refer to the current *Handbook* for minimum footcandle level recommendations.

Quality: Whatever the visual task is, or the required level of illumination, quality must be built into the system. There are generally accepted principles that should be followed. A review of the standards and practices regarding such things as accepted brightness ratios and contrast between objects is in order. IESNA has developed systems of evaluation to help assure quality lighting. Two such procedures for quality evaluation are:

- *Visual comfort probability (VCP).* VCP considers effects of the directly viewed glare associated with a light source and luminaire. VCP is a system that evaluates, according to statistical predictions, the percentage of large numbers of people who would be visually comfortable in the most undesirable location with a particular type of luminaire. It thus allows for the great differences between people in their reactions to discomfort glare. In the VCP system a luminaire in its environment is given a numerical rating so that by consulting a table of VCP values the lighting designer can obtain a useful indication of how comfortable the luminaire will be in a particular space.
- *Equivalent spherical illumination (ESI).* Reflections of a light source in a task reduce contrast and visibility. Such reflections are often referred to as “veiling reflections.” It has been established that such reflections are almost eliminated when a flat task is placed at the center of an illuminated white sphere, with light coming to the task from all directions. ESI is the illumination produced by a referenced lighting situation that will provide the same visibility for a task as when illuminated by an actual lighting system (i.e., 70 footcandles (756 lux) of reference lighting).

Where task positions are fixed and known and of high occupancy, lighting should be designed for uniform illumination. In cases where the task locations are not known in advance of design, it may become necessary to install task lighting levels at all probable task locations using a general overall lighting system. Where task lighting is provided,

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recommendations concerning luminance (brightness) ratios should be considered in determining levels for nontask area lighting.

The ability to predict specific footcandle levels at specific points has become increasingly important as the practice of nonuniform lighting has been accepted. This will be difficult in some cases, particularly with fluorescent luminaires.

Another form of nonuniform type lighting is supplemental lighting: that is, lighting equipment that is used in conjunction with a general lighting system. Typical examples of supplemental lighting are an incandescent fixture placed above an industrial machine, or a fluorescent light fixture used at a workbench. Another concept of supplemental lighting is modular office furniture where the lighting is incorporated into the furniture units, such as a desk.

3.2. Consider the Physical Characteristics of the Area

The size of an area, and methods of partitioning and separating work areas, will affect the amount of light at the tasks. Within specific areas these factors will affect the amount of lighting available:

- *Use light (high reflectance) finishes on ceilings, walls, floors, and furnishings.* Lighter finishes are the most efficient in reflecting light, and darker finishes absorb light that could otherwise be utilized. Selection of finish reflectance is very important in the design efficiency of the system and proper control of brightness ratios.
- *Optimize window design for daylighting.* Windows, skylights, and other apertures allow natural light to enter a building and provide illumination. In many cases, daylighting not only reduces lighting energy use, but also reduces cooling loads that would otherwise be generated from electric lights. However, daylight may not always be the most efficient light source in conditioned buildings. Unless they are well-designed, daylighting systems can contribute to unwanted heat gain or loss, resulting in a greater increase in HVAC energy use than corresponding savings in lighting energy (see *Building Envelope Efficiency Measures*, which contains a more detailed treatment of daylighting and heat gain through fenestration).

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Biographical Sketch

Clark W. Gellings's 30-year career in energy spans from hands-on wiring in factories and homes to the design of lighting and energy systems to his invention of "demand-side management" (DSM). He coined the term DSM and developed the accompanying DSM framework, guidebooks, and models now in use throughout the world. He provides leadership in EPRI, an organization that is second in the world only to the US Department of Energy (in US dollars) in the development of energy efficiency technologies. He has demonstrated a unique ability to understand what energy customers want and need, and then implement systems to develop and deliver a set of R&D programs to meet the challenge. Among his most significant accomplishments is his success in leading a team with an outstanding track record in forging tailored collaborations—alliances among utilities, industry associations, government agencies, and academia—to leverage R&D dollars for the maximum benefit. He has published 10 books, more than 400 articles, and has presented papers at numerous conferences. Some of his many honors include seven awards in lighting design and the Bernard Price Memorial Lecture Award of the South African Institute of Electrical Engineers. He has been elected a fellow in the Institute of Electrical and Electronics Engineers and the Illuminating Engineering Society of North America. He won the 1992 DSM Achiever of the Year Award of the Association of Energy Engineers for having invented DSM. He has served as an advisor to the US Congress Office of Technical Assessment panel on energy efficiency, and currently serves as a member of the Board of Directors for the California Institute for Energy Efficiency.

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