Lighting Fundamentals for Daylighting

ABS 731 Spring 2006
Mike Kroelinger
Introduction

- Without a source of light, we cannot see; without surfaces to reflect light, there is nothing to see.
- To understand this relationship between a source of light, the surfaces that reflect light, and how we see light, we need lighting language.
- Quantifying and qualifying the nature of daylight calls for a basic understanding of key lighting terms.
The Lumen

- The lumen is the unit that quantifies the total amount of light emitted by a source.
- This unit is typically used to rate the output of lamps. For example, the flame of a candle generates about 12 lumens.
- A standard 60-watt incandescent lamp, is rated at 890 lumens.
The Candela

- The candela is the unit used to measure the intensity of light in a particular direction.
- The familiar candle flame generates one candela in all directions.
- The candle is actually the historical basis for defining the candela.
- Candelas are used to rate the output of luminaires and can also be used to rate the output of certain kinds of lamps where directional light output is a concern.
- Represents the candlepower of a source.
The Footcandle

- The footcandle is the unit for illuminance, the amount of light that falls on a surface (sq. ft.).
- It is equal to the number of lumens striking a surface, divided by the area of the surface.
- Footcandle values can be determined for both horizontal surfaces, like a desktop, and vertical surfaces, like a chalkboard.
- Lux is the international unit for illuminance falling on a surface (sq. meter).
The unit sphere is a sphere with a one-foot radius, which defines the relationship among lumens, candela, and footcandles.

Imagine a candle flame centered within a sphere that is one foot in radius.

That point source, of uniform intensity equal to one candela, produces an amount of light flowing through one square foot of the sphere's area that is defined as one lumen.
The Unit Sphere

- The amount of light falling on that one square foot of the sphere is equal to one footcandle.
  - Since the area of the sphere is equal to $4\pi$, then the amount of light flowing through the sphere is $4\pi$ lumens, or about 12.57 lumens.
  - A one candela source produces 12.57 lumens and an illuminance of one footcandle at a distance of one foot.
Inverse Square Law

- Illuminance is inversely proportional to the square of the distance from the source.
- \[ E = \frac{CP}{d^2} \]
- \( E \) = Illuminance in footcandles
- \( CP \) = Candlepower in candela
- \( d \) = Distance from source to target
- Formula varies based on horizontal & vertical surfaces.
Cosine Law of Incidence

- Illuminance is proportional to the cosine of the angle of incidence -- the angle between the direction of the incident light and the perpendicular to the surface.
- Experiment -- get a flashlight with a narrow beam spread; from the same distance aim perpendicular to a wall; repeat at an angle to the wall.
- What happens to the cone of light?
Daylight Availability

- Compare clear & overcast skies
- Impact of direct sunlight
- Horizontal vs. vertical surfaces
Brightness

- Brightness is the subjective impression of the amount of light leaving a surface & reaching the eye.
- Since brightness is based on human response & is dependent on the adaptation level of the eye, it cannot be directly measured.
- To determine brightness, lighting designers use luminance and exitance values, which can be measured or calculated.
Brightness

- Luminance values are measured in candela/sq. ft. (the nit is most used) & are used to measure light leaving a surface in a directional manner.
- Exitance values are measured in lumens/sq. ft., but relate to light leaving a surface in a diffuse manner.
- Comparing luminance or exitance values of surfaces within the field of view allows lighting designers to determine the overall comfort of a lighting system.

Figure 6. Directional Light Quantified by Luminance and Diffuse Light Quantified by Exitance
Contrast

- Contrast is the difference between the brightness of an object and that of its immediate background.
- Objects with high contrast are easier to see than objects with low contrast.
Brightness Ratios

- Surface contrast is the relationship between the luminance of an object (e.g. print) and that of its immediate background (e.g. paper).
- Tasks with high surface contrast are easier to see than tasks with low surface contrast.

- Outline contrast is the relationship between the luminance of the immediate background (e.g. paper) and that of the surrounding area (e.g. desk).
- Excessive outline contrast may make the task harder to see.
Brightness Ratios

2:1 Perceptible brightness difference for focus
3:1 Between task and adjacent darker surroundings
10:1 Between task and remote darker surfaces; clearly noticeable brightness difference for focus and transition between adjoining spaces
20:1 Between lighting fixtures (or windows) and sizable adjacent surfaces
40:1 Should not be exceeded anywhere within normal field of view (exceptions would include crystal chandeliers)
50:1 Will highlight objects to exclusion of everything else in field of view
Finishes

- Task finishes are the component of the lighting system that allows us to see and recognize the objects and the materials of which they are made.
- Understanding the properties of the task surface is important when considering proper lighting solutions.
Visual Task

- The size of the visual task is determined by the physical size of the task and the distance of the task from the observer.
- In this case, size is measured by the visual angle that the object being viewed subtends on the eye. Larger objects can be seen at longer distances.
- Small objects must be relatively close for the eye to discern them in detail.
Glare

- Excessive contrast causes glare.
- An extremely bright object against a dark background causes discomfort and can interfere with our visual perception.
- Discomfort or interference with our visual perception is generically termed glare.
- There are many types of glare (high angle direct, low angle direct, reflected or veiling reflections, and VDT screen glare).

- Generally, glare is something we would like to eliminate. In some cases, controlled glare creates a sense of brilliance or sparkle.
- Finding the balance between glare and sparkle is critical for good lighting design.
Reflectance

- Reflectance is the fraction of light reflected from a surface compared to the amount of light falling on that surface.
- Dark and/or textured surfaces absorb a lot of light and therefore have low reflectances, while light and/or smooth surfaces reflect light and therefore have high reflectances.

- Reflectance is a property of the surface material and is independent of the amount of light that reaches the surface.
Transmittance

- Transmittance is the fraction of light that passes through an object compared to the amount of light falling on that object.

- It is an important property to consider for glazing design since the transmittance will impact the amount of daylight available for natural illumination.

- Like reflectance, transmittance is a property of the surface material and is independent of the amount of light that reaches the object.
Specularity describes the nature of reflected or transmitted light.

A specular surface reflects light in a directional manner such that the angle of reflection is equal to the angle of incidence.

A mirror is a specular surface. In contrast, a matte surface, such as a swatch of fabric, reflects light in a non-directional manner.

Most surfaces are semi-specular. They reflect some light specularly and some light diffusely.

Since semi-specular surfaces are difficult to describe mathematically, they are typically treated intuitively in lighting design practice.
Control

- Thermal control treated differently from glare control, depending on strategy
- Exterior shading
- Interior shading
- Low-transmittance glass & other technologies
- Light reflected vs. light absorbing surfaces
Efficacy

- Efficacy, measured in lumens/watt, describes how efficiently a light source converts electric power to light.
- A standard 100-watt incandescent lamp produces 17.5 lumens/watt.
- High pressure sodium, one of the most efficacious light sources, provides up to 110 lumens/watt.
- Efficacy of sunlight varies with solar altitude. For example, at 50 degrees solar altitude, lumens per watt is approximately 116 (Lam, p. 50).
Calculations

- Common methods:
  - Point-by-point method
  - Lumen method
  - Nomographs & other graphical methods
- Computer programs
  - Lumen Micro/Designer
  - AGI 32
  - Lightscape (best for rendering; now in Viz)
  - Radiance (research tool)
  - Rayfront (Radiance front-end)
Room Surfaces

- The reflectances & textures of room finishes affect the lighting levels & apparent brightness of the room.
- Dark finishes & heavy textures absorb light so that it is not reflected back into the room.
- Light finishes help to reflect more light into the space, thus making the lighting system more efficient.
- The effect of lighter wall & ceiling finishes is to increase the measured light level & to make the space appear even brighter.
The Room

- The room boundaries have the most effect on how a space is perceived & how a lighting system will perform.
- Since long narrow spaces have different proportions than large open areas, the efficiency of selected lighting systems will depend largely on the geometry of the room.
- The Room Cavity Ratio (RCR) is the ratio of the surface area of walls to the floor area.
- Used in lighting calculations in determining how well luminaries will perform for given room proportions.

- The spatial characteristics strongly influence how we react to a space.
- Lighting components must interact with the envelope to help define & create the way the space is perceived.
Windows

- Windows & skylights admit daylight into a space.
- Natural lighting has an effect on the perception of time & place, which is psychologically beneficial in work environments.
- Windows present a challenge in work environments due to the potential for glare and/or contrast between the windows & the surrounding space.
- Diffuse skylights can contribute significant amounts of light into a space, offsetting the need for electric light.
Sources of Info

- http://www.pge.com
- http://www.agi32.com
- http://www.lighting-technologies.com
Summary