

Thus, the optimum level of illumination for such a task would be considered as 10 or 20 footcandles. Obviously, for other more difficult industrial tasks the optimum footcandle level will be considerably higher.

As the level of illumination is increased above the optimum, the task becomes easier to perform even though production of useful work may not increase appreciably. Less useless energy is expended by the worker. This is illustrated by the upper broken line curve of Figure 1. Obviously, when seeing is extremely difficult

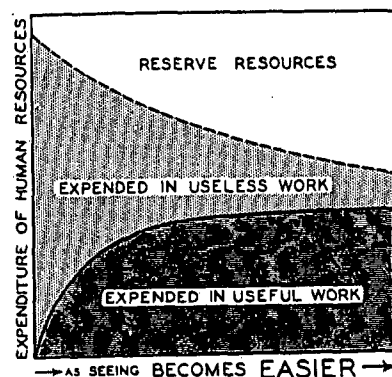


Figure 1. A diagrammatic view of the expanded concept of lighting and seeing. Even if production ceases to improve appreciably, seeing becomes easier and fewer human resources are expended in performing useless work. The true measure of human efficiency is the ratio of resources expended in useful work to the total expended in useful and useless work.

we must call upon a large portion of our resources that are involved in seeing. As seeing becomes easier, our reserve resources increase and the nonproductive work decreases. Thus, the worker becomes a far more efficient human seeing machine at levels of illumination well above those that will permit him to perform at an optimal rate. In other words, a truer index of over-all human efficiency is the ratio of the resources expended in useful work to the total resources expended in useful and useless work. Tangible benefits from applying this broader concept include greater safety, decreased spoilage and rework, decreased fatigue, improved morale, lower labor turnover, and so forth.^{3,4}

I. Lighting Terms and Units

There are many terms and units used in illuminating engineering.⁵ However, it is only necessary to have a clear understanding of certain basic ones.

³ H. Kuhn, *Eyes and Industry*. Mosby, St. Louis, 1950.

⁴ Value of good lighting in war production (Committee Report), *Trans. Illum. Eng. Soc.*, 38, 13 (1943).

⁵ Illuminating Engineering Nomenclature and Photometric Standards, Z7.1-1942, American Standards Association, New York, 1942.

The *lumen* is the unit of luminous flux emitted through a unit solid angle (steradian) from a uniform point source of one candle. It is used to represent the total light output of light sources.

Candlepower is luminous intensity expressed in candles. An ordinary candle about an inch in diameter produces about one candle in a horizontal direction.

Illumination is the density of light flux incident upon a surface.

The *footcandle* is the unit of illumination when the foot is the unit of length. It is the illumination on a surface, one square foot in area, on which is uniformly distributed a flux of one lumen. It equals one lumen per square foot.

Photometric brightness, or *luminance*, is a measure of the light emitted by a luminous body or reflected from a surface. It may be expressed in terms of the lumens being emitted or reflected from a perfectly diffusing source. The term brightness, alone, usually refers to the sensation that results from viewing surfaces from which light comes to the eye; it often is used interchangeably with luminance, since the context usually indicates whether the sensory or photometric meaning is intended.

The *footlambert* is the unit of photometric brightness and is equal to the uniform brightness of a perfectly diffusing surface emitting or reflecting one lumen per square foot. The brightness in footlamberts is equal to the illumination on a surface multiplied by its reflectance.

Reflectance is the ratio of light reflected by an object to the incident light.

II. Visibility

Not all things that can be seen are equally visible. Many factors combine to make details visible and recognizable, but four of them may be considered as fundamental characteristics of visual tasks.⁶ Perhaps the most obvious one is the visual size of an object expressed in terms of visual angle. A telephone pole is physically large, yet when viewed from a long distance its apparent size is small. Visual acuity is a measure of the sensitivity of the eye in terms of the size threshold. This is equal to the reciprocal of the angular size in minutes of the critical detail that can be just barely seen.

The *contrast* between the details of an object and their immediate background has a considerable bearing on visibility. For a given set of conditions, visibility is highest when contrast is at a maximum. Black print on white paper is much more visible than the same print on a dark gray paper.

Many industrial tasks involve motion. Thus, *time* is an important factor. The speed of a moving object must be slow enough that the eye can take a visual snapshot or follow its movement. The spokes of a rapidly rotating wheel appear blurred, but when it is turned slowly, accurate visual impressions can be registered.

The fourth fundamental factor is *brightness*. Without brightness, sight would be impossible, all objects would remain invisible, and, in effect, we should be blind.

⁶ P. W. Cobb and F. K. Moss, Four fundamental factors in vision, *Trans. Illum. Eng. Soc.*, 23, 406 (1928).