MICHAEL STILLER

QUALITY LIGHTING FOR HIGH PERFORMANCE BUILDINGS

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Introduction

According to the U.S. Department of Energy's *Buildings Energy Data Book*, in the United States the buildings sector accounted for over 40% of primary energy consumption in 2010. Lighting in our homes accounted for 10% of this usage, and in our commercial buildings it accounted for 17.4%. These are significant numbers, and there can be no doubt that reducing our energy use will carry with it a myriad of benefits, be they economic (saving us money), environmental (reducing our carbon footprint), or political (reducing our dependence on foreign oil). There are many strategies we can employ to this end, but the real challenge comes in reducing our usage while simultaneously retaining, and even improving, our quality of life.

Quality Lighting for High Performance Buildings is an introduction and guide to the considerations and principles all lighting designers, architects, and engineers should apply to their projects when specifying a lighting system that is meant to be energy-efficient, sustainable, visually comfortable, and generally pleasing to a building's occupants. This book is written in non-technical language wherever possible, so that it may be read by building design professionals, students, and interested members of the general public alike. The practice of lighting design is a complex craft, as much art as it is science, and in that sense it cannot be taught solely through books, or in the classroom. But it is my belief that any of us can begin to participate in this most engaging of pursuits with a little knowledge and an observant eye.

Starting with a primer on the basics of lighting design, this book provides an introduction to the properties of different lighting sources (including LED lighting), lighting fixture efficiencies, relative and absolute photometry, daylighting, lighting controls, and energy codes.

High performance buildings are energy-efficient, have low short-term and long-term life cycle costs, are designed and situated in such a way as to minimize disturbance to their natural surroundings, and are constructed from and operated with materials whose manufacture and disposal have a low impact on the natural environment. In addition to being the product of a sustainable design process, high performance buildings must also provide a healthy and productive indoor environment for their occupants. Quality lighting for high performance buildings is lighting designed with all of these principles in mind, and it must take into account economics, energy efficiency, sustainability, and the needs of those who live and work within our built environment.

Part I

Quality Lighting

Chapter 1

What is Lighting Design?

A DEFINITION

Lighting design is the specification of a system of luminaires and controls to create illumination appropriate to a given environment. This means that lighting designers choose which lighting fixtures should go where (specification of a system of luminaires), as well as how they are grouped and which should be on at a given time and at what levels of intensity (controls). But how does the designer determine what illumination is "*appropriate to a given environment*"? Historically, architectural lighting designers, and to a great degree electrical engineers performing in this capacity, have been concerned with providing enough illumination for a specific visual task. Quantity was the key. And the question was, simply: how much light is enough? It's been a long time since we've considered lighting design in such simple terms. As a culture we accept that good lighting is important in many other ways, whether it's to create a comfortable, productive environment, or to set a mood. Many other factors are central to the design of a quality lighting system: color temperature, accurate color rendering, volumetric quality, and contrast ratios, to name a few. Yet even so, many of those outside of the profession—and some within it—still focus on the quantity rather than the quality of light delivered by a given system. And it's easy to see why. Lighting is ethereal. It has physical properties but we can't touch it. It helps us see, but outside the context of the world of objects, which reflect light back to us to create an image of those objects in our minds, light is, by itself, invisible.

A CASE IN POINT

Recently, at a visit to a medical office comprised of a very well designed suite of examination rooms, I had a brief conversation with one of the staff members about the lighting. This is a facility which clearly has benefited from an integrated design process, with a lot of indirect lighting positioned so as to illuminate appropriately reflective surfaces and light the space with pleasing contrast ratios and as little direct light and glare as possible. The designer specified cove treatments, wall washers, recessed vertical fluorescent lighting in the hallway walls with acrylic diffusers, and backlit mirrors in the restrooms. The examination rooms each contained a fluorescent fixture with diffusing lenses and shielding louvers over the exam area, where higher illuminance levels are necessary. The consultation areas were bathed in an ambient light that helped the doctors to accurately see their patient's skin tones and facial expressions. The staff's work-stations were outfitted with under-shelf task lighting. There were decorative pendants that simultaneously provided a gentle accent as well as task lighting on the public-facing counters. The ambient illuminance levels were low—between ten and fifteen footcandles in the circulation areas—yet there was plenty of light for patients of all ages to negotiate their way around. When I asked the staff member whether she liked the lighting in these new offices, and if she thought it was good, she readily agreed that it was. But the way she described the complex, layered, low-ambient lighting design was to simply say it felt "brighter" than her old office—which it undoubtedly wasn't. What she clearly meant was that she could see better. Maybe she was aware that the lighting in her present facility went a long way towards setting a mood. This was a modern, clinical research facility in New York City. The design was one that lent a serious and reassuring air to a place where visitors bring their greatest anxieties and concerns for their own well-being—a doctor's office. It was clear from our conversation that the staff member had an awareness of these factors. She knew good lighting when she saw it, but thinking about lighting and articulating her thoughts in terms other than "brightness" was something she had difficulty doing.

Such is the case for many of us in the design professions. Most architects, interior designers, and engineers are aware that a well-designed lighting system is important for many reasons, and that while having enough light is necessary for us to be able to see, lighting can also greatly affect the way we experience our environment in numerous other ways. Anyone who has walked into a poorly maintained store where the fluorescent lighting is a hodgepodge of different color temperatures, or where the lamps have not been changed in many years, and after burning way past their expected lifespan emit only a fraction of their original light output, will tell you that their experience of that store was diminished as a result of the lighting quality. We all know that poor lighting can make a customer feel uncomfortable buying a product that might require advanced support from a store owner; or prompt a client to hire one business over another for a project; or tip the balance for a tenant deciding whether or not to lease a particular apartment or office. But for most of us, the only way we are able to discuss lighting is in terms of whether

Figure 1-1. Too much light from a flashbulb creates direct glare and obscures the faces of a crowd at a sporting event, Photo credit: Arcimboldo (Own work) [CC-BY-3.0 (www.creativecommons.org/licenses/by/3.0)], via Wikimedia Commons

or not there is enough of it, when in fact the quality of the lighting is as important as the quantity of lighting.

The fact is, in certain situations too much light, coming from the wrong direction, can make it difficult to see. Glare from a direct line of sight to a light source, or lighting that produces high contrast ratios within an environment, can inhibit our ability to discern objects or features that fall within the shadows. Anyone who has had the experience of talking with someone who is standing with their back to a window on a brightly lit day will recognize this right away. Though there may be plenty of light, we still struggle to see those objects that are right in front of us. But though this is a common phenomenon, and one we take for granted in our everyday experience, understanding the nuances of light, and how we experience the lit environment in terms other than brightness, remains a challenge for most people.

Now, let's circle back to our definition of lighting design: *"The specification of a system of luminaires and controls to create*

Figure 1-2. Light pouring in a window obscures the face of a painter at work, Photo Credit: Hugh Downs, Nancy Bea Miller at Window, 2009

illumination appropriate to a given environment." What constitutes appropriate illumination? Clearly having the right amount of light is important. We need a certain amount of light to see, and, as we will discuss later in the book, more light to see fine details, and even more light as we get older. We may also need different amounts of light depending on the mood we want to convey. Certainly a romantic restaurant will be lit a good deal less brightly than an automobile showroom. Most of us can recall visiting both brightly and dimly lit environments where our visual experience was good, and those where it was not. So if it's not just about the quantity, what then constitutes quality lighting?

WHAT IS QUALITY LIGHTING?

Quality lighting is the result of an integrative design process in which the building design, interior design, and lighting design evolve together to create a built environment that is sustainable, productive, and healthy for the people who occupy it. Quality lighting must support the human activities that each environment is designed for. As designers we start with the assumption that lighting is for people, not just buildings, and so quality lighting must satisfy the needs of the occupants even as it provides aesthetic appeal and reveals and enhances the building's architectural form.

WHAT IS SUSTAINABLE DESIGN?

A building design is sustainable when it results in lowered energy use and lessened environmental damage during the construction phase and operational lifetime of the building. The concept of sustainability is based on an understanding that there are finite resources, and space, at our disposal, and that we need to limit our consumption of these resources to the amount that can

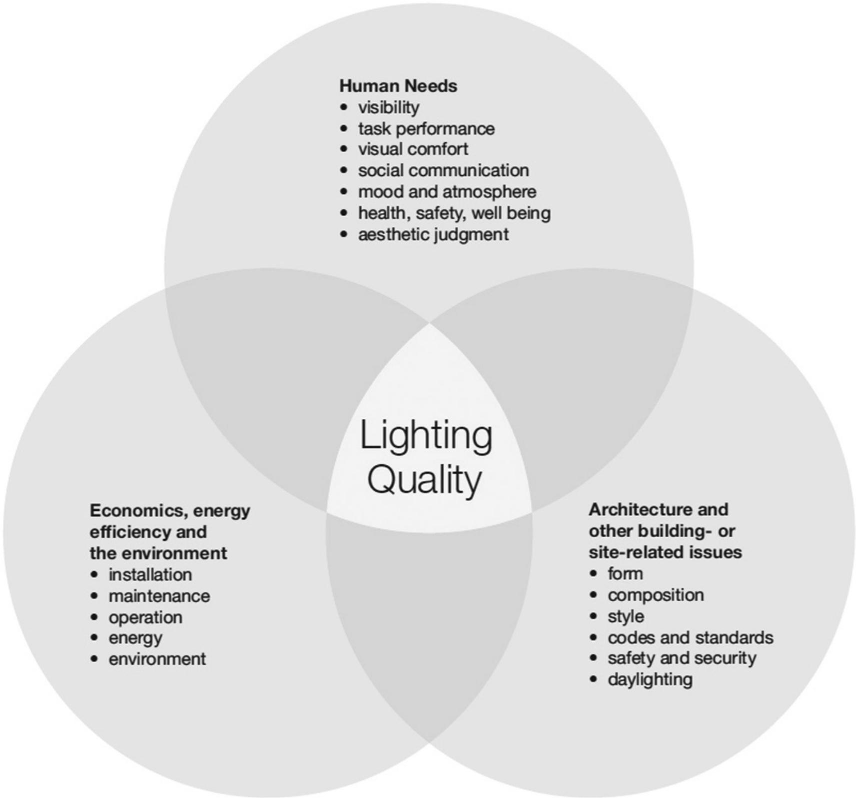

Figure 1-3. From the IESNA Lighting Handbook, 9th Edition by permission from the Illuminating Engineering Society of North America

be regenerated, both for our health and to insure we do not run out. This applies to energy, potable water, air, and arable land. To be sustainable, a quality lighting design must be energy-efficient. But using high efficiency lighting and avoiding wasted energy is not enough. The lighting equipment should also be manufactured in a sustainable way that doesn't waste resources or emit pollutants into the water or atmosphere. It should include as few toxic materials as possible, generate as little waste as possible, and it should be sourced as close to the construction site as possible to avoid expending unnecessary energy in transport.

Good design is key to keeping sustainable lighting sustainable. If lighting is for people, and not just buildings, then it follows that if it does not satisfy their human requirements a building's occupants may modify the lighting in ways that are often contrary to the designer's intent, and in doing so they may negate any energy efficiencies that would otherwise be realized. These modifications can, and often do, take the form of additional electric lighting that may be from inefficient sources, or disabled energy efficiency controls. An incorrectly commissioned occupancy sensor that automatically turns the lights off in a room while the occupants are still present is a prime example. This will not have to happen more than once or twice before the people who regularly use this room find a way to disable the occupancy sensor, negating any benefit that control device may have brought to the design in the first place. A poorly designed lighting layout

Figure 1-4. An office worker who has taken the task-lighting of his workspace into his own hands. Photo Credit: Hayden McKay

that wastefully directs too much light to an open office's circulation areas, and not enough to the employee's desks, may result in the facility manager or the employees themselves developing ad-hoc task lighting solutions that are not energy-efficient, and that may push the office out of compliance with the local energy code. And a lighting design that only takes into account the work-plane lighting levels, with no consideration for the contrast ratios between the task area and surrounding surfaces, may have the negative result of creating an uncomfortable environment that leads to employee fatigue and reduced productivity.

So what are the elements of a quality lighting design? As we will discuss in this book, in addition to being energy-efficient and providing the right amount of light, a quality lighting design must minimize glare and manage contrast to create a visually comfortable environment. It must also take into account the color temperature or color quality of the lighting sources employed so that colors are rendered accurately, and the occupants, and the environment itself, look good. It must provide the right amount of light to set the correct tone and to support the visual tasks that will be performed. It should make effective use of any available natural daylight. And it should incorporate a system of controls that allows the lighting to be dimmed, or switched off, as required to suit individual preferences and minimize energy use as much as possible throughout the day.

Chapter 2

Understanding Light:
(Luminance, Illuminance and Lumens)

LUMENS & CANDELAS

It's important to clarify some of the terms we will use throughout this book, and in doing so develop a clearer understanding of how electric lighting works. First, let's start with the light source and luminaire. The light source, or lamp (commonly called the light bulb), produces a certain amount of visible radiant energy, or light, which we measure in *lumens*. The lamp, in combination with the luminaire (a fancy term for a lighting fixture), will direct and define how these lumens are projected. Some lamps and luminaires will project the lumens in an omnidirectional pattern (in all directions), like a household light bulb in a table lamp with a translucent lampshade; and some will project them as a narrow beam of light or a well-defined spot, like a reflector lamp in a directional track light. If the number of lumens is the same in both of these cases, the light striking the nearby surfaces (provided they are of an equally reflective color and equally far from the light source) will appear brighter in the case of the reflector lamp and track light, and the illuminance will be greater, as the same amount of light, or lumens, will essentially be concentrated in a smaller area.

A further discussion of brightness, luminance, and illuminance will follow, but first let's talk a little more about the light coming from our luminaire and source. The overall light coming from our luminaire, the lumens, can be further defined as *candelas*, or candlepower. A candela is really a measure of the concentration of lumens in a particular direction. To use our previous examples of a table lamp and a directional track light: though the number of lumens might be the same, when they are concen-

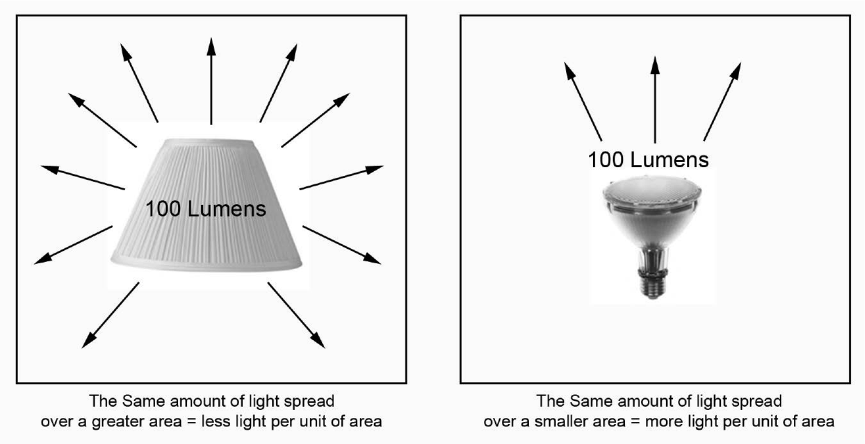

Figure 2-1. As the projection of light, or lumens are spread over a greater area, the illuminance will decrease, as each unit of area of the surrounding surfaces receives a lesser concentration of the overall light that is emitted.

trated into a narrower beam by the track light, the candlepower, or the number of candelas, will be greater in the direction of that beam than when they are projected in an omnidirectional pattern, or a greater number of directions, around the room. Candlepower is a constant measurement, and does not change with distance. Even as the light will spread over distance, the number of lumens, and therefore candelas, coming from the source in that particular direction will remain the same.

Once the light has left our luminaire, it spreads over a larger area as it travels through space. We have all had the experience of shining a flashlight on the ground in front of us, and then shining it on an object some distance away; the beam of light widens out and it appears less bright. Though the number of lumens in the beam of light are constant, as the beam spreads over a greater area the same lumens are also spread over a greater area and fewer will fall in any one place. The result is a dimmer appearance of light. In addition, certain objects will appear more or less bright depending on their color and their other qualities of reflectance. These are examples of both illuminance and luminance.

ILLUMINANCE & LUMINANCE

Illuminance is the amount of light per unit area that is projected *onto* a given surface, while luminance is the amount of light per unit area that is emitted or reflected back to the viewer *from* a given surface. Illuminance has both a metric and imperial expression. The metric expression, lux, is the measure of the amount of light, or number of lumens, that falls onto a surface the size of a square meter; and the imperial expression, footcandles, is the amount of light that falls onto a surface the size of a square foot. Both the illuminance on a surface and the luminance of a surface will vary as the distance is varied between the surface and the source of light, as they are both dependent on the concentration of light, or lumens, that falls that surface. As we have demonstrated with our flashlight, the number of lumens falling on a given area will decrease as we move our light source farther from the object being lit, and the beam, made up of a constant number of lumens, spreads out to cover a greater and greater area. The luminance of a surface will also be affected by other factors, namely that surface's translucence (in the case of back-lit materials), reflectance (or color) and specularity (or glossiness).

Luminance is measured on a metric scale: candelas per square meter (cd/m^2), and is the amount of light that is emitted or reflected from a square meter of a given surface in a given direction. Luminance is also sometimes defined as the perceived brightness of an object. Brightness is not a precise technical term, but it's one we use every day. What many people may not realize is that our experience of brightness does not necessarily relate in a direct way to the amount of light in a particular environment. A fully lit room with dark walls and a dark ceiling may not feel very bright though there is plenty of light (or a high level of illuminance) on all of the room's surfaces. It's just that most of it is being absorbed by the dark surrounding surfaces, which have a low luminance. As we've said, what we call brightness, or luminance, is really the amount of light that is reflected, or emitted,