VITAL SIGNS

# INTERIOR ILLUMINANCE, DAYLIGHT CONTROLS AND OCCUPANT RESPONSE

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VITAL SIGNS

# TABLE OF CONTENTS

# VITAL SIGNS

VITAL SIGNS

## PREFACE

**"The real subject of every painting is light." - Claude Monet**

**"For the rest of my life I want to reflect on what light is." - Albert Einstein (Clark, p.252)**

**"Architecture is the masterly correct and magnificent play of masses brought together in light. Our eyes are made to see forms in light; light and shade reveal these forms; cubes, cones, spheres, cylinders or pyramids are the great primary forms which light reveals to advantage." - Le Corbusier**

Vision is the primary sense by which we absorb information about a building. The light which we perceive then, is the definer of the architecture. This makes the architect particularly interested in understanding light. Furthermore, most of what goes on inside of buildings requires light. This means that the engineer, owner, user and interior designer are all interested in understanding the way light behaves within a building.

The common English word "light" actually covers several different aspects of the behavior and sensing of a narrow but common portion of the electromagnetic spectrum. The following exercises are designed to convey a progressive understanding of these phenomenon, and how they may be measured, quantified and analyzed.

As with the other Vital Signs packages, this package follows a general format. The first section is the theoretical background for the topics to be covered. This goes so far as to include measurement protocols. This section is organized into distinct lessons. Each one is self contained, and builds upon the previous lesson. At the end of each lesson is a series of questions which refer to the concepts of the lesson. Each lesson is also directly connected to one of the exercises to be found in the main body of the package.

The main body of the package are the measurement assignments. They are divided into three levels. The first level is experiential in nature, helping the student to get an intuitive grasp of the nature of these vital signs which are being monitored. The second level uses a range of equipment to measure a range of variables, in an instantaneous fashion. The third level introduces the concept of measurement over time, or extended measurement.

There are a glossary, an annotated bibliography, and the answers to the lesson quizzes in appendices. With the equipment available to you through the Vital Signs project, or similar equipment mentioned in the text, these exercises should prove interesting, challenging, and rewarding. Enjoy.

VITAL SIGNS

## ACKNOWLEDGMENTS

We wish to thank Cris Benton, Alison Kwok and Bill Burke for their guidance throughout the project, and for having had the excellent good sense to conceive of and organize it to begin with.

We wish to thank Pacific Gas and Electric, the Energy Foundation and all the others who have contributed funds to this project.

We wish to thank all of the reviewers for their excellent suggestions. Russ Leslie, Bruce Haglund, Mary Guzowski, John Kingman, David Scheatzle and Bill Burke provided additional experiences as well as constructive advice on the organization of the package.

# 1 THEORY

# LESSON ONE - BASIC PHYSIOLOGY

There are two aspects to perception. The first is the biophysical aspect, relating to the eye and how it functions. The second is the internal interpretation of the physical input, namely, how the mind translates the data sent to it by the eye. The first aspect is what we can measure with instruments. The second aspect requires a great deal of interpretation. We will begin with the first aspect, namely the physical aspects of light, and we will begin by defining terms and understanding how the eye perceives light. This is merely a quick review, so that we can proceed to a discussion of measuring devices with a solid understanding of specifically what each device measures.

## 1.1 PERCEPTION AND THE EYES

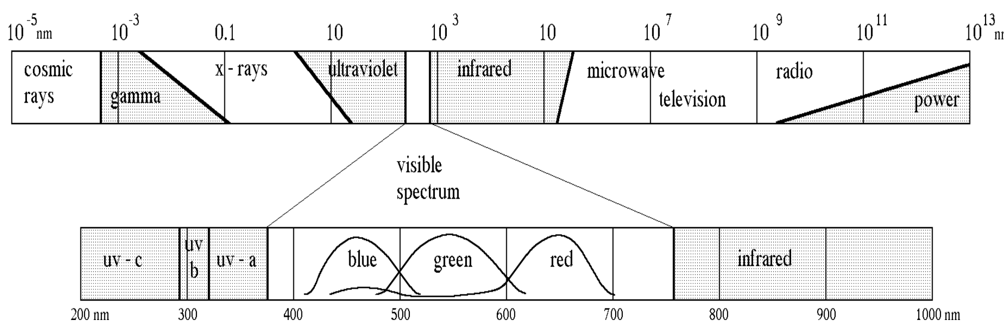



**Figure 1.1** The visible spectrum

We define light as that part of the electromagnetic radiation spectrum which can be perceived by the human eye. This ranges from blue light (at wavelengths around 475 nanometers or nm) through green, yellow, and orange light (at 525, 575 and 625 nm) to red light (at 675 nm) and into violet (at 725 nm.) White light is the combination of all of the wavelengths (Figure 1.1).

When we see a wall surface as blue, what really happens is that the white light shines on the wall, and all of the wavelengths except the blue are absorbed by the wall. The blue wavelength bounces back, and is sensed by the eye (Figure 1.2). Similarly, something which is a translucent blue absorbs the non-blue wavelengths, and transmits the blue. (In most cases, the translucent blue surface also reflects some blue wavelengths.)

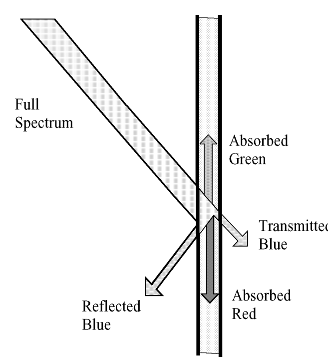



**Figure 1.2** Absorption, Reflection and Transmission

## 1.2 THE HUMAN EYE

The eye is composed of several critical pieces. There is a focusing device called the *lens*. There is a device which controls the amount of light admitted to the eye called the *iris*, and a sensing surface called the *retina*. The retina is composed of two types of nerve pickups, the *rods* which sense black and white (or simply the presence or absence of any light) and the cones which sense colors. The rods work efficiently at very low light levels, such as moonlight, or low levels of light within a building. The *cones* give much more relative information, but require more light. In a very dark room, you lose the sense of color, even if you can still see well enough to move without bumping into things. Color or cone based vision is called *photopic* vision, and monochromatic or rod based vision is called *scotopic* vision (Figure 1.3).

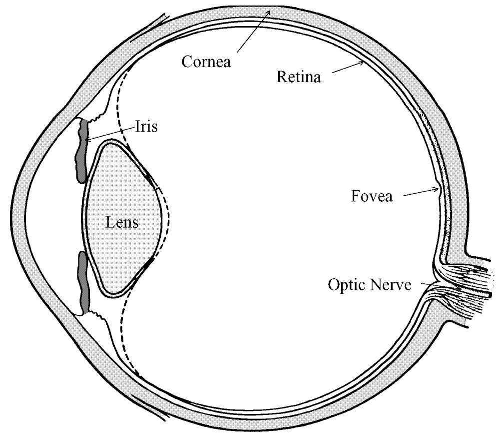



**Figure 1.3** A cross section of the human eye

Colors are literally perceived in relation to one another, rather than in an absolute sense. The cones sense red, green and blue spectra, and measure the different ratios of those spectra. This means that the colors are always perceived in relationship to the colors around them, and to the background. Blues are bluer in a red room. This is especially true of adjacent colors, which give the greatest immediate differential reading in terms of adjacent cones on the surface of the retina.

There are some colors which may disappear because of the absence of a certain wavelength of light in the source which is illuminating them. This is true primarily of artificial light sources. The cones cannot pick up the differential, and because one of the wavelengths is not available to be reflected and sensed. The subtleties of color theory are taken up in several books (ref. Iten, Albers, Munsell & CIE.)

The eye is astoundingly adaptive in range. It can adjust from levels below 1 footcandle, to levels over 10,000 footcandles in moments. It is only damaged when the change is too rapid, or most of the background is dark, but one spot is intensely bright. Such extreme contrasts are known as *glare*.

## 1.3 GLARE

There are two types of glare. One occurs when the eye has adapted to an environment and the environment changes. The other occurs when the eye has adapted to an environment and a source of light appears within that environment that is much brighter than anything else within the field of view.

The first case occurs when the iris is wide open because it has adapted to very low light levels, and then the environment changes. This is like leaving a movie theater and coming out onto a sunlit parking lot. The iris adjusts rapidly, but not without some discomfort during the adjustment. The eye will also adjust through the reverse procedure, but not as rapidly. It takes much longer to become adapted to the lower light level when moving from the brightly lit parking lot to the darkened theater, and it is wise to wait a moment before trying to find a seat. There is no discomfort, however, as long as one has sufficient patience. The general rule, then, is that glare, in the first case, may come from extreme light level increases in a brief period of time. Note that the same light level increase may cause no glare, if there is a sufficient adjustment period.

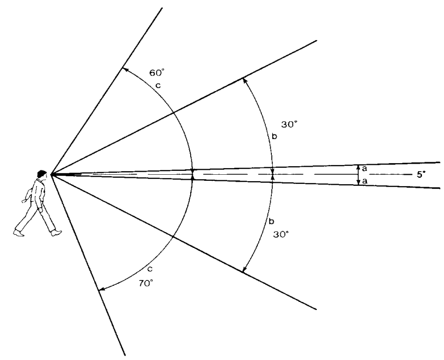



**Figure 1.4** Glare within field of View

The second form of glare occurs because the iris adjusts to the overall brightness within the *field of view* (Figure 1.4). This means that in a dark room, the iris will open wide. If there is just one point of light within the field of view, the average will still remain low, but that one point will be effectively burning a hole in the retina at the point at which it is focused. Fortunately, there is discomfort again, which prompts us to make an adjustment, which in turn protects the eye. We turn away, we squint, or we simply correct the environment. This adjustment can be overridden, such as squinting and looking directly at the sun, which is extremely detrimental to the retina, and can cause permanent damage. The rule of thumb is that glare in the second case comes from extreme contrast within a given field of view.

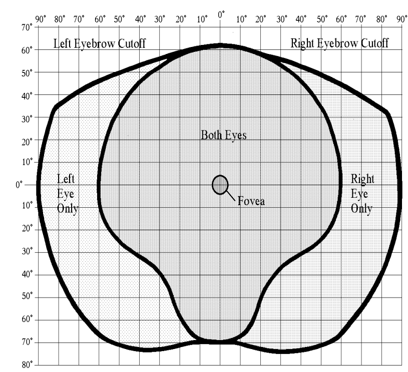



**Figure 1.5** The human horizontal field of view

Glare also occurs in a subset of this general case, which occurs when there is a reflection in the field of view, from a very bright source outside the field of view. The reflection causes discomfort, and often causes the additional annoyance of veiling or masking out the information which is being sought within that view (Figure 1.5).

Not all cones adjust evenly to lower light levels. Red is the first color to “disappear”. If an observer ranks different sheets of paper for “brightness” when the light level is extremely low, red colors are often perceived as being very dark, nearly black. When the lights are turned back up, the perceived brightness returns, and the same reds are ranked much higher.

## CONCLUSIONS

Exercise 1 is directly based on these concepts. It is intended to acquaint the user with their own eyes and the way they function. It requires no special equipment or preparation. You may choose to go to the exercise or continue with the basic principles.

## REVIEW QUESTIONS

1.1 What wavelengths of electromagnetic radiation can be perceived by the human eye?

1.2 Which receptors in the eye sense colors? They are found on what surface?

1.3 What is the focusing device of the eye? What is the exposure adjustment device of the eye?

1.4 Do large amounts of light (high illuminance levels) invariably cause glare? Do small amounts of light never cause glare? Think of some examples.

# LESSON TWO - CONCEPTS, TERMS AND BASIC PHYSICS

In discussing light, there are several terms which we use in day to day speech which must be defined more carefully if we are to deal with them in a quantitative manner, or even understand clearly the qualitative differences. The following section provides a basic understanding of the definition of light, its behavior, and qualitative and quantitative measurements. It is a review of those terms, and the more careful definitions which come from the IES (Illuminating Engineering Society.)

## 2.1 TRANSMISSION, REFLECTION, REFRACTION AND ABSORPTION

All light which strikes a surface is either transmitted, reflected, or absorbed. *Transmitted* light passes through the material (Figure 2.1). If the material does not completely change or lose the image, the material is called *transparent*. Material which is transparent may change the image in another way, such as the lens on a pair of glasses. This is called *refraction*, and occurs to some extent with nearly all transparent materials (Figure 2.2).

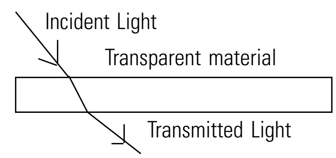



**Figure 2.1** Transmission

Refraction occurs when light is bent moving from one material to another, such as from air to glass or from air to water. When one looks at a fishing line in clear water, the line seems to bend sharply just below the surface. It is not the line that is bent, but the path of the light rays from the line through the water and air interface. This is part of the wave-like behavior of light. Note that light is within the range of electromagnetic radiation where it sometimes behaves like a wave, and sometimes behaves more like a particle. This is called wave/particle duality. When we use the particle model of light, the particles are called *photons*. This is used to model the fact that light generally travels in straight lines, and also exerts a faint pressure.

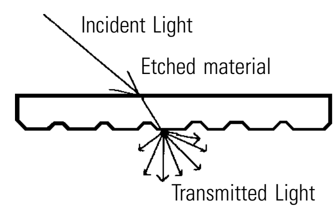



**Figure 2.2** Refraction

Materials have different indices (indexes) of refraction. Furthermore, different wavelengths refract at slightly different rates, which why a prism is able to break white light up into its constituent colors or wavelengths (Figure 2.3). Each color bends at a slightly different rate.

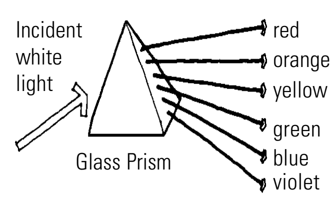



**Figure 2.3** The visible spectrum

Lenses are based on the principle of refraction. A flat material will bend light upon entry, and then bend it back again upon exit from the other side. If the two sides are not parallel, there may be a net divergence, or convergence. Light may be aimed and focused by such lenses. This is typical of eyeglasses, microscopes, telescopes, etc. It occurs occasionally in lighting.

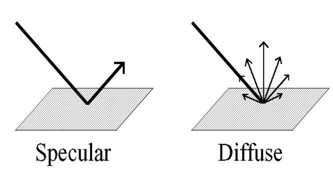



**Figure 2.4** Specular vs Diffuse reflection

If no image is transmitted, but there is still light passing through, the material is called *translucent* (frosted glass is an example). Translucent materials may actually transmit more light than some transparent materials. It depends on their *transmissivity* , often designated $\tau$

(tau). The transmissivity is the fraction of the light falling on one side of the surface which passes through the material and leaves the other surface. It is sometimes expressed as a percentage (Figure 2.5).

If the light is bounced off the material, the material is called *reflective*. If the reflected image is maintained (such as with a mirror) the surface is called *specular*. If the image is not maintained (such as a matte white finish) the surface is called *diffusing* (Figure 2.4).

Again, the *reflectance* , designated ρ (rho), is the fraction of light falling on the surface which returns from the surface, in this case, on the same side (Figure 2.6).

If absolutely no light passes through the material, it is called *opaque*. Materials that are transparent in one wavelength may be opaque in another. Glass is transparent in the visible spectrum, but nearly opaque in some of the infrared spectra (e.g. 2% transmittance.)

| MATERIAL | TRANSMISSIVITY (T) |
|---|---|
| OPTICAL GLASS | 95-98% |
| CLEAR FLOAT GLASS | 80-90% |
| CLEAR PRISMATIC PLASTIC | 70-92% |
| SANDBLASTED, ETCHED, FROSTED GLASS | 70-85% |
| WHITE DIFFUSING PLASTIC | 40-75% |
| FLASHED OPAL GLASS | 30-65% |
| ALABASTER (STONE) | 20-50% |
| SOLID OPAL GLASS | 15-40% |
| TINTED GLASS (SEE MANUFACTURERS) | 25%-75% |
| REFLECTIVE GLASS (SEE MANUFACTURERS) | 15-65% |

**Figure 2.5** Common Transmittances

| MATERIAL | REFLECTANCE (R) |
|---|---|
| GLASS MIRROR | 80-98% |
| CLEAR PLASTIC MIRROR | 75-95% |
| POLISHED ALUMINUM | 60-70% |
| POLISHED CHROME | 60-65% |
| POLISHED STAINLESS STEEL | 55-65% |
| WHITE PLASTER | 85-90% |
| WHITE PAINT | 75-95% |
| PORCELAIN ENAMEL | 65-90% |
| WHITE TERRA-COTTA | 65-80% |
| CLEAN LIMESTONE, MARBLE, GRANITE (WHITE SURFACES) | 35-65% |
| GRAVEL | 10-20% |
| GRASS (HEALTHY) | 6% |

**Figure 2.6** Common reflectances

## 2.2 DIRECT AND DIFFUSE LIGHT

Light is usually available to us in two forms. In an outdoor setting, *ambient*, *diffuse* light is the kind of light experienced on an overcast day. There are no distinct shadows, because the light is coming from all directions. In a building, this is analogous to a ceiling full of fluorescent lights, or a white ceiling lit by coves around the sides. The light is coming from all directions, and there are no sharp shadows. The idea is also to light the entire room or area, and is therefore referred to as *area* lighting (Figure 2.7).

*Direct* light is the kind of light which comes directly from the sun on a sunny day. There are very sharp shadows, and the light is very strong. There are also very distinct, directional reflections from shiny objects. Inside a building, direct light is analogous to the light from a projector, or more mildly, from a drafting lamp. It is most often useful when aimed at a task requiring special attention, and when so used is called *task* lighting (Figure 2.8).

Flat surfaces such as murals, paintings and papers or books are best viewed in diffuse light. There will be fewer *veiling reflections* or *reflected glare*. Strongly modeled objects, such as sculptures are

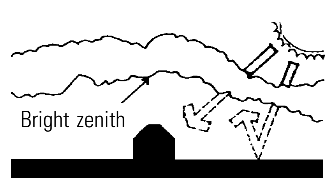



**Figure 2.7** Diffuse Light

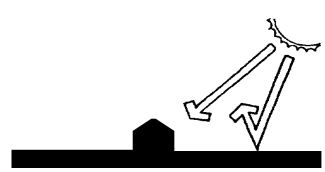


**Figure 2.8** Direct Light

more amenable to dramatic lighting, such as direct lighting, which casts sharp shadows, allowing us to understand the form.

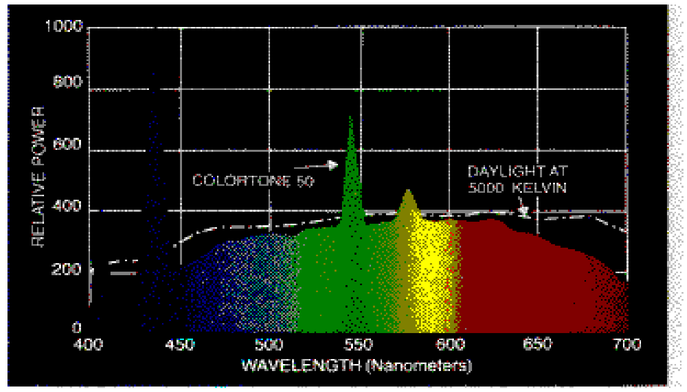



**Figure 2.9** Spectral Distribution of Colortone 50 vs Daylight at 5000 K. Courtesy: Philips Lighting

## 2.3 COLOR TEMPERATURE AND COLOR RENDITION

### INDEX

"Perfect" white light consists of a complete spectrum of wavelengths, with an even distribution. However, white light which has been transmitted through a translucent surface or reflected off a surface, is often shifted in color, or missing some part of the spectrum. Similarly, light which is created by lamps of various types will also often have parts of the spectrum missing, or have the distribution shifted one way or another. Even daylight, which begins with all of the spectrum present, may be shifted or filtered by the glazing through which it has passed.

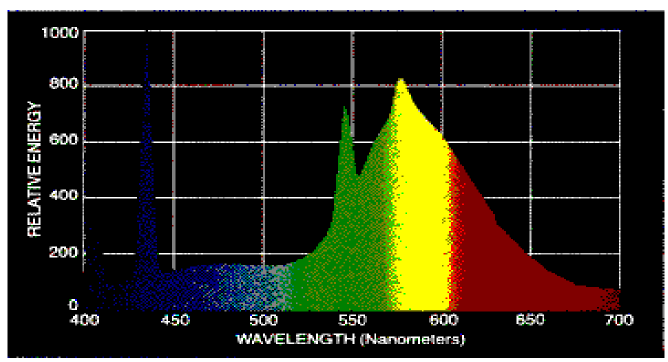



**Figure 2.10** Spectral distribution of White Lamps. Courtesy: Philips Lighting

One way of rating the tint of the light from a particular source is called the *Color Temperature*, which comes from the theoretical relationship between the temperature of an object and the color of the light. The wave-length is inversely proportional to the fourth power of the tempera-ture. For example, there is a temperature increase from a dull cherry glow to red hot to yellow hot to white hot followed by a big jump to daylight (the sun is at 6000 K) The filaments or phosphors are not necessarily at the temperature indicated by the color temperature, but the color of the light appears as if they were.

The Color Rendition Index (C.R.I.) is an attempt to measure whether all of the colors are properly rendered by the light from a given source, and whether certain colors may be missing. Eight reference colors are tested. Their color rendition is compared with the color rendered under a reference source which represents a full spectrum at the same color temperature as the source being tested. Below 5000°K, the reference source is an incandescent filament. Above 5000°K, the reference is daylight.

The best possible rating is 100, in which colors would be "true" and there would be no wavelengths or colors missing, or badly rendered. Fluorescent and H.I.D. (High Intensity Discharge) lamps often have some portion of the spectrum missing, not just the shifted peak which is approximated by their correlated color temperature (Figure 2.9, 2.10, 2.11 and 2.12). Thus, the CRI is often lower. It is difficult, however, to compare a CRI of 100 at a color temperature of 6000°K with a CRI of 100 at a color temperature of 2000°K. A particular color that we wish to look at may look better at one color temperature than another, even if the CRI is worse. Generally, the higher the CRI, the more complete the spectrum, and the better the rendition at a given color temperature. But, a *specific* color may be missing in a higher CRI, even though generally more wavelengths are present.

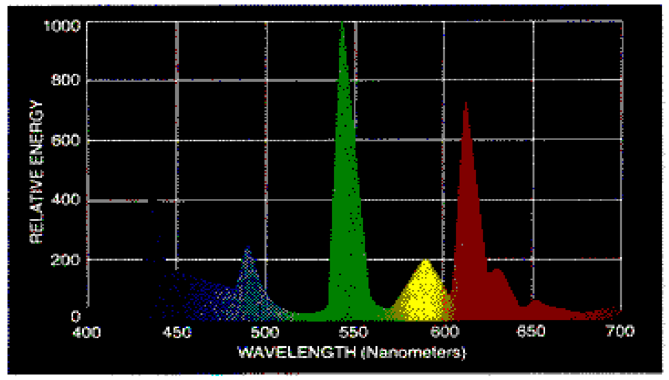



**Figure 2.11** Spectral Distribution of Ultralume 50. Courtesy: Philips Lighting

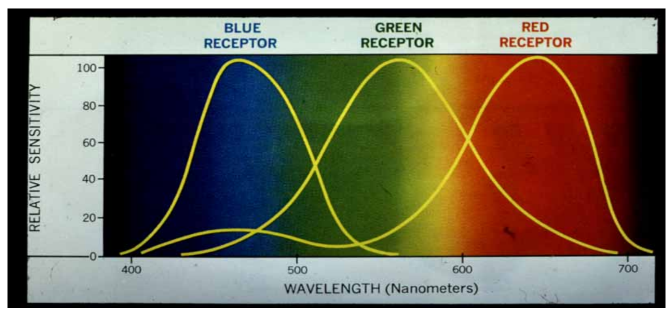



**Figure 2.12** Spectral response of the eye.

## 2.4 UNITS OF MEASURE

We have learned terms which allow us to speak of light with a more specific understanding of what we refer to. The next step is to carefully define the variables which allow us to calculate absolute and comparative numerical levels. Again, there are several distinctions we need to make. These are all usually lumped together in English, but must be carefully separated for the purposes of measurement.

### 2.4.1 Luminous Energy

To begin with, *luminous energy* (Q) is the amount of energy transmitted in the visual spectrum. It is measured in lumen-seconds (lm-sec). This unit is rarely used in calculations, but helps us to understand the physical phenomenon.

### 2.4.2 Solid Angle

A solid angle is the portion of space around a point described by a cone whose tip is exactly at the point source. For example, the beam of a flashlight is roughly a cone, whose tip is the flashlight. The unit of measure for a solid angle is a steradian (sr). If we drew a one foot square on the surface of an imaginary sphere with a radius of one foot, that surface area would define one *steradian* (Figure 2.13).

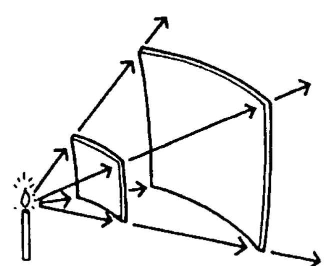


**Figure 2.13** A solid angle

**2.4.3 Luminous Flux**

If we defined some surface on that sphere (based on the solid angle), the amount of luminous energy, or light, flowing through that theoretical surface would be termed the *luminous flux* (f). Thus, it is a light-energy flow rate. The unit for measuring flow through a theoretical surface is the *lumen* (lm).

**2.4.4 Luminous Intensity**

The amount of light put out by a source *in a particular direction* is called the *luminous intensity* (I). The unit of measure is the *Candela*. A luminous intensity of one candela (measured in the direction of the steradian) results in a luminous flux of one lumen passing through that steradian.

**2.4.5 Illuminance**

The light energy arriving at a real surface is the *Illuminance* (E). The unit of measure is the lumen per square foot(l/sf).

If we were to place a source measured at one candela (in the direction of a blackboard) at a distance of one foot from the blackboard, there would be one lumen arriving on one square foot of blackboard surface, resulting in one lumen/square foot. (Figure 2.14). In the SI system the unit comparable to the footcandle is the *lux* (lx). Note that they are not the same resultant flux density, since one lumen arriving onto one square meter (= 1 lux) is spread much *thinner* than when it is arriving onto one square foot (= 1 l/sf). In fact, comparing the density of the two units, an illuminance of one footcandle is equal to an illuminance of 10.764 lux.

**2.4.6 Exitance and Luminance**

The term for the luminous flux density *leaving* a surface is the *exitance* (M). The unit of measure is the *lumen per square foot*. This is without regard to direction

The magnitude depends on the surface reflectivity (if the light is reflected) or the transmissivity (if the light is transmitted through from the other side).

The term for the luminous flux density leaving a projected surface *in a particular direction* is *luminance* (L). The unit of measure is the *candela/sq. ft.* or *candela/m*.

Another way to think of this is that a perfectly reflective surface receiving an illuminance of one footcandle would result in a

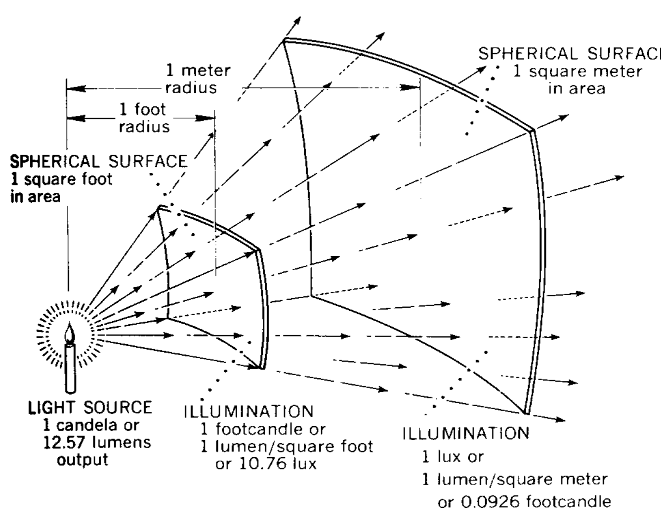



**Figure 2.14** Relation between Luminous flux, intensity and Illuminance

*exitance* of one lumen per square foot. If the surface lined up with the source and the viewpoint, and the illuminance were one footcandle, the *luminance* would be *one footLambert* (fL).

Luminance may also refer to the amount of light passing *through* a translucent surface. For example, a white surface with a reflectance of 0.65 and a white material with a transmittance of 0.65 will both have the same "brightness" if exposed to the same illumination. The translucent surface will simply have that brightness when seen from the far side, rather than the same side as the source.

**2.4.7 Contrast**

When we see a surface, we are sensing the luminance of that surface. It is useful to recognize that the way we see the surface, infer things about it, or read things from it is by the *variation* in the luminance.

For example, if a surface has words printed on it in black ink, then the luminance of that surface varies based on the variation in the reflectance of the surface and the black ink. This is called *contrast*. In the end, it may be that contrast is the most important thing. Glare may come from too much contrast, but information is conveyed by sufficient contrast, and sometimes most easily conveyed by a sharp, low level, contrast, such as a diffusely lit, matte surface, printed page.

Contrast may be calculated by comparing the luminance of the adjacent surfaces or the luminance of adjacent reflectances on a given surface.

**CONCLUSIONS**

Exercise two directly tests your understanding of these terms and concepts. You may choose to go to the exercise or continue with Level II, which deals with making measurements with simple instrumentation.

**REVIEW QUESTIONS**

2.1 Must a material be transparent in order to produce refraction?

2.2 Which is less likely to produce glare and veiling reflections, diffuse or direct light?

2.3 What is the difference between color temperature and color rendition index.

2.4 What is the unit of measure for a solid angle?

2.5 What is the unit of measure of illuminance? What is the unit of measure of luminance? What is the physical difference?

# LESSON THREE - ILLUMINANCE MEASUREMENTS

Now that we have a basic understanding of how the human eye works, and what it measures, we need to look at what quantitative levels correspond to the experiences which we have in our luminous environment. This allows us to understand how a building is performing, what corrections to make, if any, and most importantly, how to design and evaluate designs for new buildings. There are productivity issues, comfort issues, energy and environmental issues which are effected.

Measurements of performance data indicate a number of interesting relationships and certain behaviors in the lighting patterns of buildings. Data from these measurements can be used to assess the relationship between actual quantities of light and quality of light, and between controls and occupant interaction. Interestingly enough, because light remains in scale through the ranges we normally experience in buildings and models, it is also possible to use physical models to test issues which we find in buildings. The same equipment, and roughly the same techniques are applicable at both scales.

The study of an existing building poses some interesting technical challenges. Instrumentation must be installed with minimal disturbance to building occupants, certain calibrations need to be performed on site to provide accurate results and data should be recorded carefully following certain protocols for easier further evaluation.

This section deals with instantaneous measurements within an existing building, the equipment necessary to carry out these measurements along with the method and protocol to be followed while conducting a field investigation and gathering data. It is divided into two parts, the first section dealing with the measuring equipment and the second on the method of how to take and record measurements.

## 3.1 MEASURING EQUIPMENT

The most common approach is to measure illuminance levels on a horizontal work plane in footcandles or lux.

### 3.1.1 Illuminance Meters

Measurements of illumination levels are commonly made with portable footcandle meters or illumination photometers. Small handheld units are easy to use, but more accurate, stationary units provide more complete and reliable data.

**Configuration**

The simplest illuminance photometer consists of a photovoltaic sensor with a photopic correction filter, connected to an amplifier with a display. These can be enclosed in one single case or the sensor and filter can be in one module which is connected by a cable to a second module which contains the amplifier and display (Figure 3.1). Because the human eye is so adaptable, photometers typically detect light over a large range. Since the illuminance on a surface may come from anywhere "in front of" the surface, the sensors also typically cover a 180° angle, effectively the entire hemisphere which faces the sensor. There are several corrections necessary to give an appropriate reading.

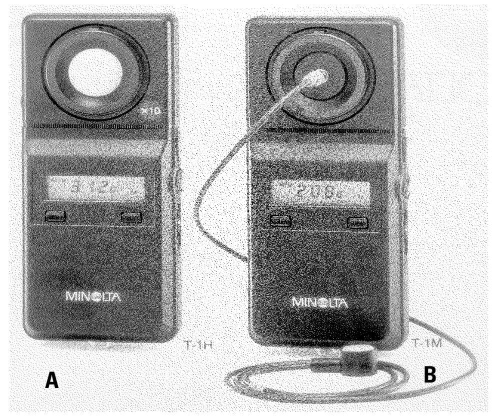



**Figure 3.1** Illuminance Meters, (A) Portable digital Illuminance Meter, (B) Digital meter with remote receptor. (Courtesy: Minolta )

**Corrections**

Color correction

The human eye is not equally sensitive to all the wavelengths i.e. colors. Therefore if a meter should be useful in terms of human eye response, its inherent response must be corrected to that of the eye. Most meters are currently corrected to mimic human eye sensitivity in the photopic range, since this includes both pattern recognition and color differentiation. Some meters follow the Purkinje shift, and are calibrated to the human eye's scotopic range. Such meters are rare, and will be specially labeled.

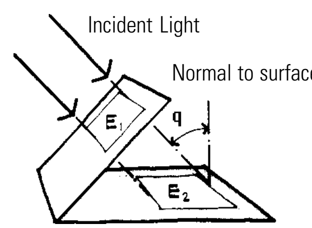



**Figure 3.2** The Cosine Law

Cosine Correction

The meters must also be corrected for light incident at oblique angles, and which does not reach the cell due to reflection from the surface of the sensor or housing. The Cosine Law states that light energy impinging on a surface at an angle q other than the normal is distributed over a greater area. For example, area $E_2$ is greater than area $E_1$ as shown in Figure 3.2. This requires that the surface of the meter receiving light be flat, which ensures that light reaching the meter from oblique angles is measured as contributing less illuminance than more direct light in accordance with the Cosine Law (Figure 3.3).

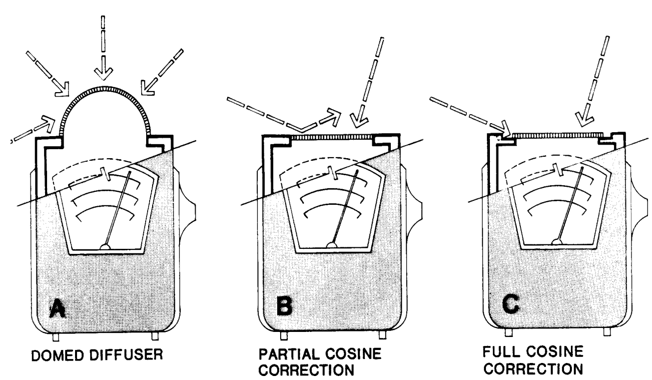



**Figure 3.3** Geometry of Cosine Correction: (A) Hemispheric meter is equally sensitive to light from all directions, (B) Simple flat diffuser approximates cosine-correction but reflects too much light at low angles, and (C) fully cosine corrected meter allows extra light to strike side of diffuser to compensate for higher diffuser reflectance at lower angle.

The Cosine Law states that $E_2 = E_1 \cos(q)$

where E = Illumination level in footcandles

and q = angle between the ray of light and the normal to the surface in degrees

Leveling

For accurate measurements, it is necessary to level the photometer, while measuring on uneven or sloping surfaces.

### 3.1.2 Multi-sensor systems

Multi-sensor systems are photometers which have the sensors on a cord, remote from the display. When available, these are a desirable alternative to the self contained meter in which the sensor and the display are in the same enclosure. The self contained meter is large enough to actually change the average reflectance within a model. Even when measuring full size buildings, the user, who is holding the self contained unit, is likely to block or otherwise interfere with the light which the sensor is reading. With remote sensors the display is positioned a few feet away from the sensor and as such both the user and the module cause less interference with the measurement (Figure 3.4).

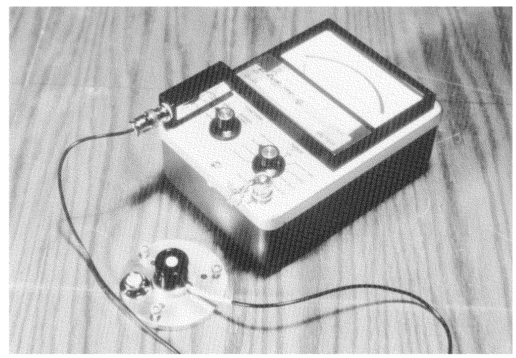


**Figure 3.4** Illuminance meter with remote sensor

Multiple sensor systems are several sensors connected to a single meter greatly facilitating the large number of measurements necessary for building evaluation. Once positioned these sensors are scanned rapidly from a remote location. The advantages of this system include reduced errors due to variation in sensor position, and relocation. An important calibration with multiple sensors is the calibration of sensors relative to one another to ensure that all sensors read the same under identical conditions (Figure 3.5).

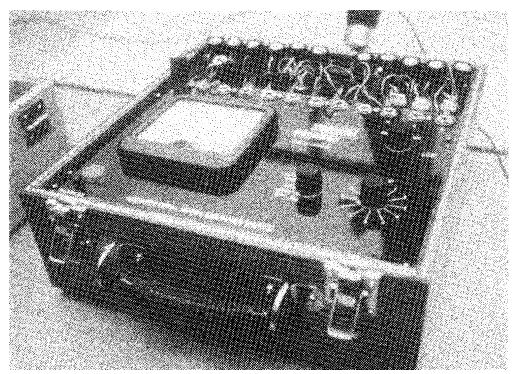


**Figure 3.5** "Megatron" multi-sensor system. Sensors are scanned manually using a rotary switching dial and read from a single anlaog meter dial. Readings are recorded manually.

### 3.1.3 Microcomputer sensing Devices

Micro computers have become suitable for automatic data acquisition. These systems conduct rapid scanning of sensors, automatic sensor calibration and printouts of data. They typically consist of 6-8 remote photometric sensors, on a battery operated system suitable for 3-8 hours of operation in the field, and an AC adapter for AC operation and battery recharging.

The analog signal from the sensor is converted to a digital signal, and the microcomputer recognizes the digital signal.

One example is the Fowlkes System. It has three ranges of illuminance levels. A trial measurement needs to be made to determine the correct range, and then the actual measurements are made using one of the three internal load resistors corresponding to the range. The software is in BASIC which controls the systems operation. It is menu driven and controls the scanning of sensors, automatic calibration and computes illuminance and daylight factors as percentages of exterior illuminance. It is also capable of calibrating the sensors on the field.

Another example is the SAM system with Datalit Software from UCLA. A third example is a Lawson Labs Model 201, 24 bit A/D data acquisition, which can be connected to any laptop.

Systems which use a computer are usually used for measurements which continue over an extended period of time. For more information, see Lesson 6 - Long Term Illuminance Measurements.

## 3.2 PROCEDURE FOR MEASUREMENT

### 3.2.1. Preparation

**Preparing a Hypothesis**

Any effective investigation requires careful advance preparation. It is a good practice to write down a hypothesis or statement of exactly what you intend to measure and list out all the variable factors which affect the particular behavior you are intent on measuring. You might choose to measure the quantity of light at some critical point in a room, for example, where you expect it to be a minimum. You might intend to plot the distribution of light across the room in the form of graphs of contours. You may wish to check user productivity or comfort at various workstations. Prepare a definition or statement of your objective. Visit the site and estimate spacing, equipment, and possible obstacles. Observe the occupants and try to predict what surfaces would result in interference between their activities and your equipment placement.

**Laying out the Grid**

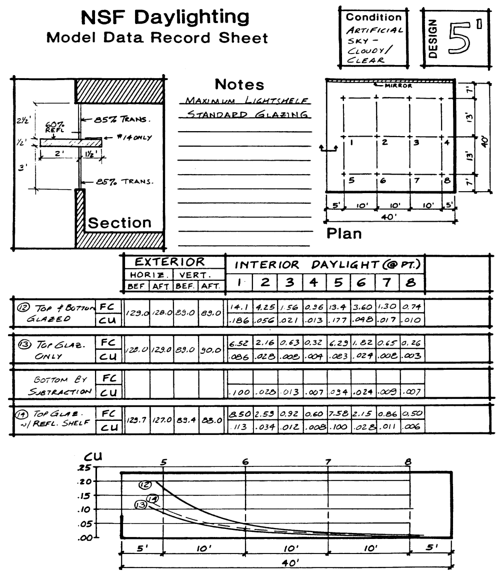
Your next step would be to draw out a plan of the space you are measuring and mark the points identified for measurement. It is often useful to make the grid correspond to the physical grid in the space, for example drop the ceiling grid, lighting grid or follow the floor tile grid. Make a number of copies of this, to record measurements made at various times, and in different situations, e.g. with and without the artificial lights turned on, at 9 a.m. or 5 p.m. etc. The number of points to measure depends on the accuracy required. If testing natural light, the changing sky conditions need to be noted over the period of time taken to measure all the points, including the exterior point.

**Equipment**

Make a list of equipment necessary to carry out the measurements, depending on the type of measurement to be undertaken. Standard hand held meters (e.g. GE meters) or multi-sensor systems can be used, and placed corresponding to the grid which has been laid out for the particular space.

**Recording Data**

It is important that a recording of every measurement conducted is made. A log sheet showing the plan of the building with the points at which measurements are to be made, should be used to record every measurement. The time, date, sky conditions (if natural light is being tested) along with the measured values of illuminance, reflectance or luminance should be recorded on this sheet (Figure 3.6).




| | | EXTERIOR HORIZ. BEF | EXTERIOR HORIZ. AFT | EXTERIOR VERT. BEF. | EXTERIOR VERT. AFT. | INTERIOR DAYLIGHT (@ PT.) 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (12) TOP & BOTTOM GLAZED | FC | 129.0 | 128.0 | 89.0 | 89.0 | 14.1 | 4.25 | 1.56 | 0.36 | 13.4 | 3.60 | 1.30 | 0.74 |
| | CU | | | | | .186 | .056 | .021 | .013 | .177 | .048 | .017 | .010 |
| (13) TOP GLAZ. ONLY | FC | 128.0 | 129.0 | 89.0 | 90.0 | 6.52 | 2.16 | 0.63 | 0.32 | 6.29 | 1.82 | 0.65 | 0.26 |
| | CU | | | | | .086 | .028 | .008 | .004 | .083 | .024 | .008 | .003 |
| BOTTOM BY SUBTRACTION | FC | | | | | | | | | | | | |
| | CU | | | | | .100 | .028 | .013 | .007 | .094 | .024 | .009 | .007 |
| (14) TOP GLAZ. w/ REFL. SHELF | FC | 129.7 | 127.0 | 89.4 | 88.0 | 8.50 | 2.59 | 0.92 | 0.60 | 7.58 | 2.15 | 0.86 | 0.50 |
| | CU | | | | | .113 | .034 | .012 | .008 | .100 | .028 | .011 | .006 |

**Figure 3.6** Example of Data Record Sheet

### 3.2.2. Measurements

**Calibration**

Handheld meters rarely agree exactly. A variance of 10% is not uncommon. It is necessary to take simultaneous readings at several levels, comparing the values and determining a coefficient for each meter, to normalize observations.

In fact, when using more than one sensor, or a multi-sensor system, it is necessary to calibrate the sensors against each other, so that all of them are corrected to read the same, under the same conditions. This is done by placing all the sensors together and noting down the light levels of all the sensors. Any relative difference in each sensor is noted and should be adjusted for in each measurement taken. Some computer systems do an automatic relative calibration at the start, in that an initial reading of all the sensors placed together under diffuse conditions should be made. This assumes a linear difference, which is not always the case, but is the best calibration short of sending all of the units back to the manufacturer.

The manual calibration is simply:

$C_x = E_{ave} / E_x$

where: $C_x$ is the multiplier for the reading from the current sensor

$E_{ave}$ is the average of all the sensor readings

$E_x$ is the reading from the current sensor

The standard GE photometer (handheld meter) has a range of 1 to 10,000 footcandles. To cover this wide range, a perforated cap is provided for the sensor, which allows only a fixed 10% of light to penetrate to the sensor. Thus while reading off the meter, it is necessary to multiply the reading by a factor (of 10), to know the exact footcandle level. Care should be taken while using handheld meters, as to when the cap was placed on the sensor and that reading should be multiplied with the corresponding multiplication factor and recorded simultaneously in the record sheet. This happens particularly when you move from indoors to outdoors and the light levels change considerably. Other meters have ranges set elsewhere on the display, and some are auto ranging, which means they reset themselves.

**Making Measurements**

Illumination Level

To determine room illumination, a number of footcandle readings are taken at regular intervals, and the average is computed. Hold the meter's light cell parallel to the plane of interest, usually the work surface. Do not cast shadows on the meter or hold it close to your body where clothing could add reflected light to the reading (Figure 3.7).

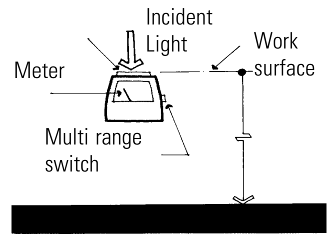



**Figure 3.7** Illumination Measurement

Brightness

To measure brightness (i.e. the luminance), position the meter's light cell against the surface being measured and slowly retract the meter to a position 2 to 4 inches away until a constant reading is obtained. Luminance in footLamberts is equal to the meter reading in foot-candles (Figure 3.8).

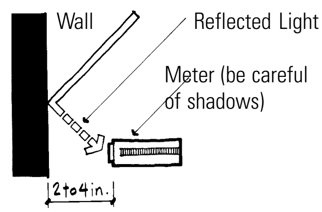



**Figure 3.8** Brightness Measurement

Reflectance

Reflectance of a surface is measured as the ratio of the reflected light to the incident light on a surface. Measure the reflected and incident light as discussed above (Figure 3.9). Find the reflectance of the surface.

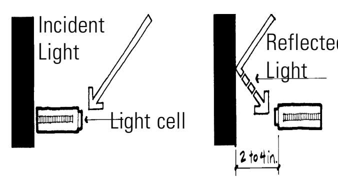



**Figure 3.9** Reflectance Measurement

Daylight Factor

The daylight factor is loosely defined as the amount of light available inside as a result of natural lighting. It is technically defined as the ratio of the internal illuminance at the horizontal workplane to the *diffuse* exterior illuminance available on the ground. This presents some problems, because the interior illuminance might actually have a direct beam component, or even a reflection of the direct beam component. On the other hand, throwing away the direct beam component when measuring clear sky conditions has always seemed like a silly idea, especially in climates such as Southern California or Arizona. A definition which is appropriate for London or Boston is not necessarily useful the world over. It is suggested that direct beam be included in both your measurements, but you should recognize that the technical definition excludes the direct beam from the exterior measurement.

DF at a point is defined as

$$DF = \frac{\mathbf{E}(\text{incident illumination at point})}{\mathbf{E}(\text{exterior horizontal})}$$

Obviously, the daylight factor is defined only when the interior electrical illumination sources are turned off. It is useful because even though the absolute level of light available outside might change drastically, the daylight factor for a given time of day and sky condition remains fairly constant. Indeed, in overcast skies, the time of day does not seem to be a factor. The only variable is the actual exterior illuminance, and the interior illuminance remains a fairly constant fraction.

**Protocols**

1. Make a trial measurement at the start of any investigation to establish illuminance ranges.

2. Calibrate the sensors (refer section 3.2.2).

3. While placing photocells, either indoors or outdoors, make sure that the plane of the photocells is parallel to the plane of the surface you are testing. If they cannot be held in that relationship, then try to mount them on a surface which can be placed in that relationship. Some Licor and Eppley sensors come with small self leveling podiums.

4. Read all measurements on the appropriate scale. If the measurement is at the end of one range, use both of the overlapping ranges, and record the fact. If possible, use the values from the same range on all of the internal measurements. If not, make certain that there is a record of which range produced which measurement.

5. When making any interior measurements which include daylight, repeat the measurement, shutting off the lights, and taking a simultaneous measurement of the exterior light levels, to help determine daylight factors, sky luminances etc. This is done by placing 2 of the 8 sensors outside, one measuring the direct and diffuse component of sunlight (by placing it in direct sunlight), the other measuring just the diffuse component (by shading it from direct beam sunlight without reducing diffuse radiation). If you are using only one sensor, take the outside measurements at the beginning of the sequence of measurements, proceed through the series as rapidly as possible, and take an outside measurement again at the end. If there is greater than 10% variance, repeat the series. If there is less than 10%, use an average of the first and last measurements as the outside value.

## CONCLUSIONS

Instantaneous illuminance measurements are necessary not only for predicting the quantity of light available at the point for performing the task, but can also to allow an evaluation of the comparative distribution of light levels within the space. You have learned how to make instantaneous illuminance measurements. You may be astounded by the amount of data you can collect by just making one run of measurements. In Exercise 3 you may experience how to record and more importantly, how to analyze the resultant data to obtain useful information from your measurements.

## REVIEW QUESTIONS

3.1 Sensors are usually color corrected. What do they match when the color correction is complete?

3.2 Why is the daylight factor a useful calculation? (Where and why might it be less useful?)

3.3 Why is it necessary to normalize (or cross calibrate) sensors if you are using more than one?

3.4 What formula would you use to calibrate manually?

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# LESSON FOUR - LUMINANCE MEASUREMENTS

Now that we have understood illuminance, and illuminance measurement techniques, it is time to realize that what we see is not the illuminance of a surface, but the luminance. Vision is about luminances, contrasts and brightness of surfaces in the field of view. What we perceive is not the illuminance on a surface, but the light that is leaving that surface or the luminance of the surface. To be able to accurately evaluate the visual environment, it is necessary to understand this distinction. A good lighting environment is not just one which has adequate levels of light (illumination) to complete the task, but also which has no excessive contrasts, and bright areas in the field of view. Furthermore, any creative design done with lighting, is really done with the luminance of the surfaces.

When light falls on a surface, the luminous flux is spread over the surface. This is *illuminance*. This, however, does not yet cause a visual response. The light has to be reflected back to the eye, where the retina receives it and compares the light received from all the surfaces, to generate a visual response. This is called the *luminance* of the surface. It is a physical, measurable quantity, and depends on the illumination on the surface and the material property of the surface. Brightness is one more term used while describing a visual environment. It is often confused with luminance, but their difference needs to be understood. It is a nonphysical quantity and is defined as the subjective or comparative appraisal of the luminance at a given adaptation level. An automobile headlight is considered very bright at night, when the background luminances are very low. The same headlight has the same luminance during the day, but it is not considered very bright, because the eye has adjusted to the background luminances of daylight, which are much higher.

When we evaluate the visual environment in terms of comfort, excessive brightness, glare etc. we are talking of our perception of the luminances in the field of view. Hence to be able to quantify glare and contrasts in the field of view and the overall visual comfort within the space, it is necessary to measure the luminances within the space and also to comprehend how we respond perceptually to these luminous distributions.

This section deals with luminance measurements and protocols for making measurements as well as a discussion of visual comfort, glare and glare evaluators.

## 4.1 LUMINANCE METERS

### 4.1.1 Configuration

Luminance photometers consist essentially of the same elements as that of the illuminance photometers except with the addition of suitable optics to image an object onto a sensor. A means of viewing the object is usually provided, so that the user is able to see the area that is being measured as well as the surrounding field. Often the actual luminance being sampled is represented as a dot in the middle of the image. The measured field is usually a degree or less, while the viewed image is usually 5-10 degrees.

### 4.1.2 Corrections

**Surrounding Field Response:** Luminance meters are designed to measure light within a specified acceptance angle. No optics system however are perfect, so the stray light or flare outside the acceptance angle may not be completely eliminated. The method of determining this error (how much stray light splashes into the acceptance area) involves a measurement with and without a gloss trap (opaque, diffuse black material) in front of a uniform luminance source, 10 times larger than the acceptance.

**Detector or sensor response:** This is another factor to be considered before measurements. This describes the uniformity of response of the sensor, some areas of the sensor may be more or less sensitive than the whole. This should be calibrated at the factory. Many manufacturers will periodically recalibrate sensors, for a slight fee.

Luminance meters are equipped with a hooded cell arranged to block oblique light and calibrated in units of luminance. In newer meters this is candelas/$m^2$ or candelas/$ft^2$, whereas in older meters this is footLamberts or Lamberts. The difference is really in the definition, and is moot as far as the instrument is concerned. Old and new meters are both really measuring candelas/$m^2$ or candelas/$ft^2$.

### 4.1.3 Types

There are several types of Luminance meters

1. Comparator type: This Luminance meter requires a brightness judgement to be made by the user. The brightness of the scene is compared to a calibrated bright spot in the field of view.

2. Spot Meters: These are direct reading, narrow angle luminance meters, for example the Minolta Luminance Meter which displays the luminance of the central one degree angle of view in an overall 9 degree scene. It is calibrated in footLamberts and has a range of 0 to 100,000 fL. It is easily portable (Figure 4.1).

The Minolta Luminance Meters LS-100 and LS-110 are perfect for spot metering of light sources or surface brightness. It combines a flare free optical design with a highly sensitive silicon photocell for accurate readings. The viewing is through the lens and the center spot indicates exactly what is being measured. There is an LCD panel on the side of the meter and with one inside the viewfinder to allow readings to be taken while viewing the object. It has a wide measuring range, with two modes of measurement available, cd/sq.m. or in footLamberts and in percentages to compare the luminance of two light sources. Peak measurement can also be displayed. It has a one degree acceptance angle within a nine degree field of view. One of the most important considerations in the construction fo the spot luminance meter is in the reduction of the influence from light outside the photocell's angle of acceptance. The object lens focusses the light entering the meter precisely so that only the light within the center spot is measured (Figure 4.2).


**Figure 4.1** The Minolta Luminance Meter

3. Laboratory Unit: This is a more sophisticated unit, which reads both luminance and contrast. It is useful in determining the effect of veiling reflections and contrast reduction, luminance ratios etc. It is a very accurate instrument and measures in the range of 0 to 56,400 footLamberts.

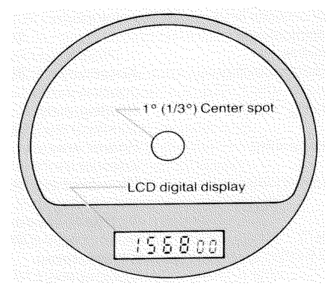



**Figure 4.2** The Viewfinder - Minolta Luminance meter

## 4.2 GLARE AND VISUAL COMFORT

Visual comfort is taken to mean the absence of a sensation of physiological pain, irritation or distraction. Visual Comfort within a space depends on the contrast levels and luminance variations across the space. Glare is the chief cause of visual discomfort and can result in the occupant interacting with the lighting system. Occupant interaction with lighting and lighting control systems can significantly impact the energy use patterns of spaces. If issues of glare and visual discomfort are understood during the initial design process, they could be designed for and hence affect the predicted energy requirements of a space.

## 4.3 DEFINITIONS

### 4.3.1 Luminance

The light energy leaving a surface in a particular direction is called luminance. It is described physically as the portion of the illuminance of the surface which is reflected or transmitted.

$L = E \times \rho$, or $L = E \times \tau$

where $\rho$ = reflectivity of surface and $\tau$ = transmissivity of surface

It is an absolute value, and its technical definition is

$$L = \frac{d^2\phi}{d\omega dA\theta}$$

where $A\theta$ = area viewed from angle q and

$\omega$ = solid angle taken in the direction of the viewer

and $\phi$ = the luminous flux

### 4.3.2 Brightness

When light falls on a surface, spreading luminous flux over it, and when this luminous flux is reflected back to the eye, by virtue of the reflecting power of the surface, the luminous sensation which we receive is called the BRIGHTNESS of the surface. It is the mental appraisal of the luminance in the field of view, at a given adaptation level.

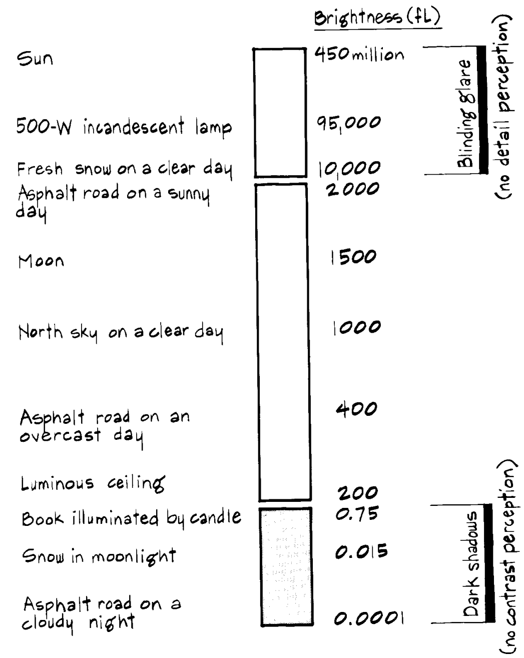



**Figure 4.3** Range of Brightness perceived by the human eye.

Courtesy: Egan, David (1983)

### 4.3.3 Adaptation

Adaptation is the ability of the human visual system to adjust the sensitivity of the system, to the average level of light existing in a space. The eye is astoundingly adaptive, it can adapt from 1 fc to 10,000 fc in less than a minute. It can detect brightness over a range of 1012 to 1 fL. At any one instant however the eye can perceive within a range of 1000 to 1 fL (Figure 4.3).

### 4.3.4 Contrast

Contrast is the sensation of luminance difference between two visual proximate things. (e.g. between paper and ink, tabletop and book etc.). It is the brightness difference between the object being viewed and the immediate surroundings. It is a luminance ratio expressed as a single number derived from the equation

$$C = \frac{L_b - L_o}{L_b}$$

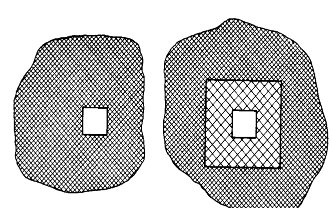
where $L_b$ = Luminance of background of task (luminance of this paper)

and $L_o$ = Luminance of object, or target (luminance of the black writing on this paper.

Contrast is a vital element in visual perception. Visual performance increases with contrast depending on the eye adaptation.

### 4.3.5 Contrast grading

The surrounds to a source have a significant effect on the quality of the light within a space. Areas around a window always appear darker because of the simultaneous contrast with the sky. High levels of surrounding brightness in the field of view causes eyes to adjust by reducing amount of light entering eye and hence sensitivity to contrast is lost. Unfavorable contrast of this kind makes the room look gloomy or glary. A grading of brightness between the source and surrounds is called contrast grading, and should be incorporated into any design, to reduce glare (Figure 4.4).



Source alone Source with surround

**Figure 4.4** Contrast grading

## 4.4 GLARE

Good lighting demands not just adequate amounts of illumination but also a uniform light distribution within the space. Glare is the result of unwanted light in the visual field, and is caused by the presence of one or more sources of bright light in the field of view. The eye functions well only when the object upon which attention should be concentrated is the brightest in the visual field and is worst when extraneous objects are much brighter than the visual task.

For optimum comfort, the brightness of the task should be graded into that of the general environment, through a local area of intermediate brightness. Visual comfort limits for glare depend on the relationship of brightness and size of the source, position of the object in the visual field and the eye adaptation of the viewer.

## 4.5 TYPES OF GLARE

### 4.5.1 Disability Glare

This is glare which results in a direct reduction in the person's ability to see objects in the field of view. Brilliant light sources, like car headlamps at night, or the view of the sun from a window at the end of a corridor are examples of this sort of discomfort.

### 4.5.2 Discomfort Glare

Glare in which there is no significant reduction in the ability to see, although discomfort still persists, due to the bright sources in the field of view is called discomfort glare. e.g. the view of an excessively bright sky near the line of sight of the worker. It might be necessary for the occupant to shade one's eyes with a hand to reduce discomfort (Figure 4.5).

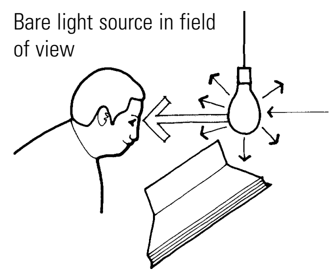



**Figure 4.5** Direct Glare

### 4.5.3 Veiling Reflections

Veiling Reflections are caused when the reflected image of a source of light is brighter than the luminance of the task, e.g. the image of a window or luminaire off the surface of the VDT screen. Pencil handwriting where the graphite acts as a mirror is more susceptible to veiling reflections than other types of ink (Figure 4.6).

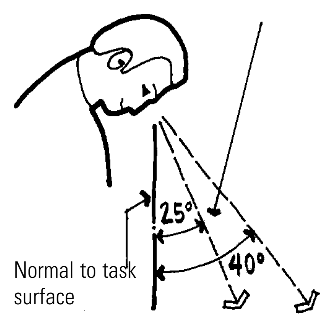



**Figure 4.6** Veiling Reflections

### 4.5.4 Reflected glare

When light from a light source is reflected off specular surfaces into the eye or field of view, it is called reflected glare. An example would be the discomfort produced by the sun's reflection from a swimming pool (Figure 4.7).

In order to determine on a scientific basis, the necessary standards of lighting in a building, it is necessary to break down the characteristics of visual comfort, visual acuity and task, and express this relationship in terms of brightness, contrast ratios and adaptation levels. These have been the basis of methods of glare evaluation to date.

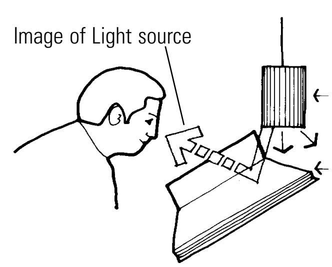



**Figure 4.7** Reflected Glare

## 4.6 GLARE EVALUATORS

### 4.6.1 Visual Comfort Probability (VCP)

This is a rating that expresses the discomfort glare produced by an interior lighting system in terms of the percentage of occupants who do not find the system uncomfortable.

VCP is a function of

1. The luminaire's average luminance

2. The solid angle subtended by luminaire at observer's position

3. The position of the luminaire with respect to the observer's line of sight.

4. The average luminance of the field of view

5. The number of luminaires in field of view.

The discomfort produced by each luminaire in the field of view, is summed up, to give the total index of sensation, and using nomograms, the actual visual comfort probability for that particular lighting system can be read off.

VCP does not rate the overall acceptance of the visual environment. e.g. a room with a lighting system having a high VCP can be dull and uninteresting or a room with a low VCP may have chandeliers or accent lighting to add sparkle and drama and interest.

**4.6.2 Glare Index**

This method not only takes into account the luminance of the sky and the surroundings, but also makes allowance for the fact that glare is less when the direction of the glare source is removed from the field of view of the observer. It assesses discomfort on the basis of

1. Luminance of the light source ($B_s$)

2. Size of the light source (Q)

3. General level of adaptation ($B_b$)

4. Position of the sources and field of view ($\theta$)

5. Luminance of the surrounds to the source ($B_i$)

and G (discomfort rating) is given by $$G = \frac{f(B_s)f(Q)}{f(B_b)f(B_i)f(\theta)}$$

Visual comfort is influenced not just by the luminance of the sources of light, but also by the general luminance of the environment and that of the local surrounds. Hence the area and luminance of the field of view play an important role. This method takes into account the adaptation and surround luminance levels in the calculation of glare.

**4.6.3 Relative Visual Performance**

Relative Visual Performance is defined to be the speed and accuracy of performing a visual task. Visual task performance generally involves detection. Performance is defined in terms of time and errors at a reading-writing task and is affected by the luminous contrasts between the white paper and the ink.

Contrast measurements of the ink calibration squares is calculated by

$$C_v = \frac{L_b - L_t}{L_b}$$

where $L_t$ is the luminance of the calibration square

$L_b$ is the luminance of the paper adjacent to the calibration square.

The relationship between each performance measure and contrast at a given adaptation level and 'S', the time taken to complete a task, is used to evaluate conditions of visual comfort within a space.

**4.7 LUMINANCE MEASUREMENTS**

It may be necessary not only to know the individual luminances of small areas of an interior, but also the average luminance of a larger area. To evaluate the visual environment and visual comfort within it, it is necessary to be able to see the entire view, and measure a sort of average luminance of the view. This can be done with the help of the visual luminance photometer. The advantage of this is that the particular area whose luminance is being measured can be seen at the time of measurement. This becomes extremely important when trying to evaluate comfort at specific task locations.

To determine the Glare Index for any building, it is necessary to take measurements of the luminances of the glary sources, e.g. a window or a lamp, using the luminance photometer and also the general background luminance or what can be called the adaptation level. The adaptation level can be measured with the same photometers, after deciding which parts of the view should be included in the background to constitute the field of view.

Luminance meters give average luminances for surfaces. There is very little or almost no calibration involved. The number of sampling points is limited to the number of meters which are available. These measurements are instantaneous and need to be recorded separately to measure over a period of time.

**CONCLUSIONS**

Luminance is that which we actually see. It is strongly related to illuminance and reflectance. Brightness is a sensation related to the comparative luminances of object and background, and not to absolute illuminance and luminance. Understanding the difference between illuminance and luminance is critical to an understanding of the visual environment. Handheld luminance meters can provide a sense of the ranges in luminance which are experienced in different environments. It is especially important to understand the relationship between contrast, brightness and glare.

## REVIEW QUESTIONS

4.1 What is the difference between illuminance and luminance? Which is measured by aiming a device at a workspace, as opposed to placing the device within the workspace?

4.2 Do all reflections cause glare?

4.3 Why is adaptation so important in determining glare? How is it taken into account in the Glare Index?

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# LESSON FIVE - PHYSICAL MODELS

Physical models can be used to test measurement techniques and ideas. Building physical models and measuring within them has been a method which has been actively recognized over the past few years. Scale models can be used for a variety of tasks, from actual quantitative measurements to providing a visual and photographic record of the space. They can also be used to test various daylighting options early in the design stage and how each affects the quantity of light and perception of the space. It offers a way to evaluate light levels in an area where design with numbers alone does not ensure a fine building.

**Figure 5.1** Model of a space

The principal reason why daylighting models are being used to test lighting strategies is because of their accuracy in predicting light behavior and distribution within a space. Light waves (electromagnetic waves) have extremely small wavelengths (380-750 nm) compared to the size of a model or that of a real space. Therefore they behave in the same way within a model as they would in an actual space (Figure 5.1). If the actual space is modeled accurately, all surfaces, furniture, fixtures and textures scaled exactly, the model's lighting characteristics will be exactly similar to that of the actual space (Figure 5.2).

**Figure 5.2** The actual space

Perhaps the most important benefit is that models can be used to answer questions about various aspects of the building design. Various design options can be quickly and accurately studied in the small period of time taken to change the model to reflect the design. Quantitative data about light determines its adequacy for meeting visual needs. With this information projections about electric lighting and conditioning can be proposed. It provides information about visual comfort, glare and contrasts within a space. It provides a clear picture of how the daylighting system will provide light in the building and how different materials, furniture layouts, colors etc. will affect this distribution of light within the space.

This section describes in short how to make models and decide upon the scale of the model, test the model under artificial or natural sky as well as develop guidelines to follow while photographing or recording within the space.

## 5.1 QUANTITATIVE EVALUATION

Before starting to model and measure light within the space a few decisions need to be made. This will reduce unnecessary changes and modifications later in the measurement stages.

### 5.1.1 What to measure?

This will decide the scale of your model as well as all the variables you wish to investigate.

### 5.1.2 Scale of Model

Models can range from simple massing models ( to study shade and shadow patterns) to full scale mockups of rooms (to evaluate furniture patterns, colors and textures and their effect on the lighting). Depending on what you intend to test, the scale and type of models should be decided upon. An important consideration to be made while deciding the scale of the model is the kind of direct, visual observation that will be employed to evaluate the model, e.g. a view port for photographing the interior. The level of data needed and evaluation techniques used also affect the scale of the model. Simple questions about two or three skylight alternatives can often be done at 1/2" = 1"-0". Qualitative models, for photographing interiors, are 1" = 1'-0" or larger.

### 5.1.3 What to model

It is necessary to duplicate the geometry of the building as well as the reflective and transmissive properties of all surface materials as accurately as possible. Also, a decision has to be made as to what needs to be modeled. For example, in considering what details to include outside of the model, it must be determined which objects each aperture views and whether or not it is critical to daylight penetration and distribution within the model. The models should be placed on the same site as the actual building, whenever possible. For exact photography, it is even useful if the model is placed at eye height, compared to the surroundings. Thus the view outside the window of the model mimics exactly the view outside of the room being modeled.

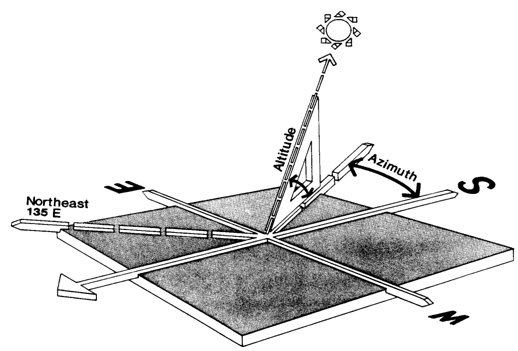


**Figure 5.3** Solar Geometry

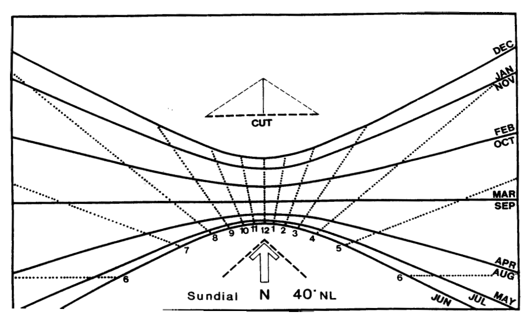


**Figure 5.4** Sun dial or Solar Gnomon

### 5.1.4 Testing the Model

Real sky or outdoor testing is cheaper and easier than artificial sky testing. Outdoor testing can be conducted on any model. It is advantageous to test the model on both a clear as well as a cloudy day to ascertain the building's full scope and range of performance. When modeling different times of year in a single session, the site chosen for testing should be relatively unobstructed. This is because it will be necessary to rotate the model to different virtual azimuths and altitudes (Figure 5.3). This means that obstructions will not remain constant with regards to the model.

For an overcast sky, the time of the day is not important, however for a clear sky the time of day and solar location are crucial to the test. Clear sky measurements are still extremely useful when gauging the overall energy performance of a building. It is best to make several measurements throughout the day and for various seasons of the year to evaluate for change in available illuminance. This can be done by using a solar gnomon or sun chart stuck to the model (Figure 5.4). The model can be rotated on a tripod to simulate nearly every situation.

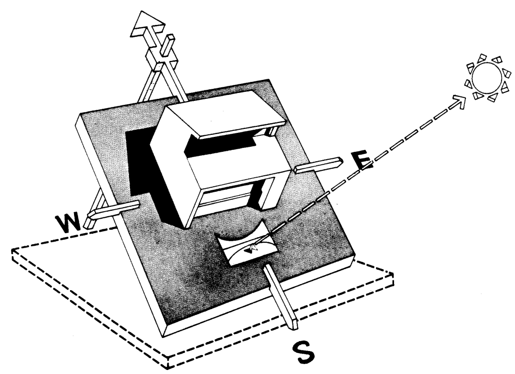


**Figure 5.5** Model studies using the sundial attached to the model and a tripod to move the model to the desired azimuth and altitude.

While rotating the model it is much easier if the azimuth is first fixed by rotating the model in the horizontal plane and then setting the altitude (Figure 5.5). Care should also be taken that when the model is tilted, it does not see an excessively large view of the ground plane as this effects the photometric evaluation of the space. It is easier on a summer day to model South facing fenestration, since winter angles can be modelled by lifting the southern facade up until the effective altitude angle represented is lowered to the winter value. It is very difficult to use a winter day to get high summer sun angles. The facade ends up facing the ground (Figure 5.6).

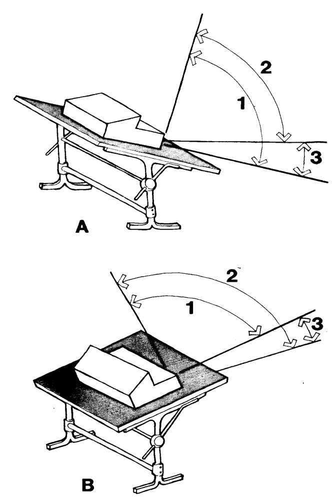


**Figure 5.6** Errors introduced by tilting models. These are insignificant where direct and reflected sunlight is the major daylight component. (1) sky seen by the real building, (2) sky seen by the model and (3) sky error associated with the model for (A) summer simulation and (B) winter simulation.

Artificial sky tests are better where weather does not permit real sky testing or there are a large number of tests to be conducted, and uniform exterior horizontal illuminances are important. This also depends on the availability of a mirror sky, heliodon, or sky vault. These are difficult to build and expensive to maintain (Figure 5.7).

A mirror sky is capable of producing consistent levels of diffuse sky values, so that a test done on the second day is the same as a test done on the first day, the third day and so forth. It cannot provide direct beam or clear sky conditions, because the source would be mirrored causing a "multiple suns" effect, which is valuable only in science fiction novels. A heliodon provides only direct beam simulation, and in fact, has no diffuse component. It is really useful only for measuring shadow locations, or for measurement of radiant gain for thermal purposes (which coincides primarily with direct beam irradiation, or insolation.) Only the sky vault or hemisphere is capable, in some cases, of producing a clear sky environment which includes both the direct beam and the diffuse component. This is even difficult, because the "sun" is never infinitely far away, and thus the rays are never exactly parallel. It is also difficult to get the direct beam component high enough to model the correct relationship between diffuse and direct values. However, with care, these factors can be modelled in a repeatable fashion, eliminating the tilting and viewed horizon problems which are found with outdoor simulations, as well as the variation in exterior illuminances from one day to another.

### 5.1.5 Measuring the Results

Photometric evaluation of a daylighting model is the measurement of absolute illuminance within the space. It can be done by handheld light meters or ones in which the probe is separate from the meter. It is necessary to take both interior and exterior illumination readings to be able to compare DF factors.

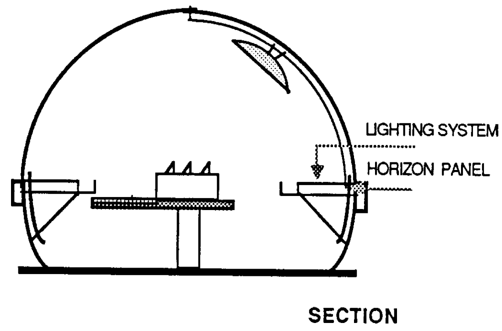


**Figure 5.7** Schematic section of sky simulator

Establish a pattern of measurement in the model. The single point, line or grid measurements can be performed with single or multiple probes (Figure 5.8). If only one probe is available, it should be moved around systematically within the model to cover all the points and the exterior value should be measured at the beginning and the end of the sequence. They should be placed at the height of the plane being studied, in scale (Figure 5.9).

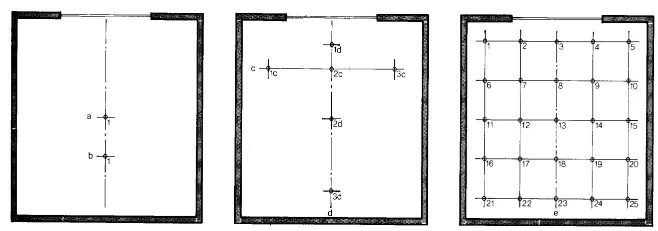

**Figure 5.8** Single point, line or grid measurements

Since the illuminance of the source of light in an artificial sky does not match that of the sun, absolute measurements of illuminance are not possible. However simultaneous exterior and interior illuminance measurements will establish the DF which can then be used to determine performance under overcast or minimum sky conditions.

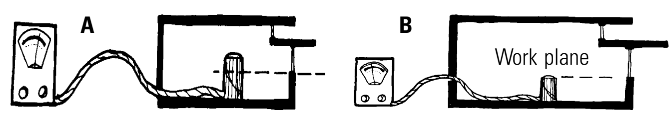


**Figure 5.9** (A) Improper match of sensor at workplane, (B) matching model scale to sensor.

### 5.1.6 Recording Data

Documenting the results is extremely valuable for later analysis. Since outdoor testing may take several hours or days and needs to be conducted on both clear and overcast days, it is helpful to keep a record of observed sky conditions as well as the illuminance data. Observed information about reflectivity of ground surface, and other test conditions should be recorded.

Since the exterior illuminance changes with solar location on a clear day, an accurate record of the sun position should be maintained. It is also a good idea to measure diffuse light as well as total exterior illumination. This can be done by shading the probe and taking a reading. On overcast days exterior illuminance readings should be checked periodically since changes in cloud density alter the amount of available light. The record sheet should be a fairly organized record of the various tests and will prove useful for evaluating different lighting strategies.

## 5.2 VISUAL AND PHOTOGRAPHIC EVALUATION

Visual and photographic evaluation also provide some clues as to the quantity of light in the space as well as the quality. In fact, visual observation is crucial in establishing the quality of light in a daylighting model as no instrument can adequately measure or duplicate the response of the human eye to the light in the space. Viewing ports large enough to allow both visual and photographic inspection should be made in the model (Figure 5.10). They should be placed in the model in such a way that the model can be viewed at a scaled eye level. View ports should be placed on as many surfaces as possible, since the orientation and direction of view is important to get a full understanding of the quality, penetration and distribution of light in the model. Viewports should coincide with doors, paintings, shelves, or other internal discontinuities in the wall surface. Thus, the viewport becomes invisible when it is replaced, which is important for the photographs taken from the other viewports. Use a hood to block light entering the model through the view ports while making observations. While taking photographs a separate record of the photographs including camera setting, date time etc., should be preferably made.

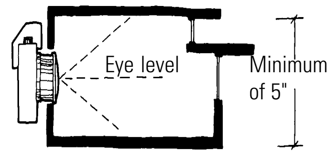


**Figure 5.10** Position of camera inside model

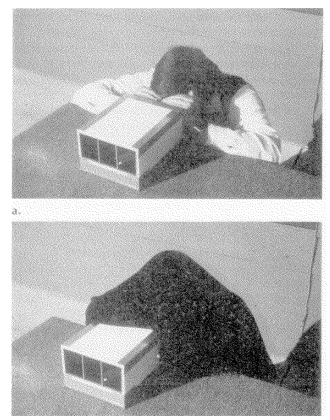


**Figure 5.11** Use of hood to block light from observation point

To make identification easier at later stages, a card with the simulated date and time for which the model is being tested can be introduced into the model itself, and incorporated into the photograph. Conversely, include the proper time on a clock within the scene, and some other factor which identifies date. Visual observations are probably the designer's best feedback tool and should not be curtailed for quantitative performance. A well designed daylighting system performs best when both the quantity and quality of light in the space have been carefully balanced (Figure 5.11). Model testing makes it possible to evaluate this balance simultaneously as it combines both visual as well as photometric measurements.

## CONCLUSIONS

Many situations can be studied in a model as well as at full scale. In fact, it is often useful to look at possible changes that could be made to the building, by constructing a model, and making the design changes in the model. If the model has been calibrated to the building by getting the same measurements in both, then any changes made will be measured extremely accurately.

## REVIEW QUESTIONS

5.1 Why is there usually no difference between a model of the space and the space itself?

5.2 Given that you wish to photograph a model. Why is it important to include the simulated date and time on something which is visible inside the model?

5.3 What scale is an effective minimum size for photographing interiors?

5.4 What is the biggest problem with an oversized sensor in placing it inside a model? Can you think of another problem?

# LESSON SIX - EXTENDED ILLUMINANCE MEASUREMENTS

Having developed a reasonable understanding of how to take measurements and what measurements to take, the question of dynamic change arises. We might know how a space is illuminated at a particular moment in time, but we also know that it changes over time. To make any assessment of the effect of lighting on energy usage, it is necessary to know how the lighting changes over the entire period of time in question, or at least a reasonably representative period.

The protocols and the equipment for extended measurement are similar to the equipment for instantaneous measurement, with the addition of a few key factors. The most significant is the way in which the data from multiple sensors is recorded. In the 70's and 80's there was a significant shift from analog recording devices such as paper and magnetic tape to digital devices such as magnetic tape of digital data, direct serial connections to personal computers, phone connections to remote computers, and extended time storage in local RAM, to be downloaded onto computer. Most recently there has been the development of unitary sensors/ storage devices which may be individually placed and later collected and downloaded.

## 6.1 DATALOGGERS

The most common method of sampling data over time is to connect one or more sensors to a digital datalogging device. These devices are typically capable of simple mathematical functions, such as averaging a series of samples at varying time intervals, and then recording the average. They may be programmed to various ranges in sensitivity, and also to do data processing such as the sampling of a difference between two values, the multiplication of one of the sampled values by one of the other values, or a ratio of samples, such as one sample of temperature followed by ten samples of illuminance. They are capable of recording induced current to detect when lights are on, while also recording the illuminance levels produced. It is even possible to record the temperature of the luminaires, as a proxy for their on/off state, since most luminaires get quite hot when they are turned on. Measure the temperature of a luminaire which has been on for a minute, and whenever the temperature exceeds that value, assume that the fixture is "on". The manipulated data is stored for an extended period of time, depending on available RAM, sample rate, and battery life. It can be regularly downloaded by modem or direct connection to a computer (Figure 6.1).

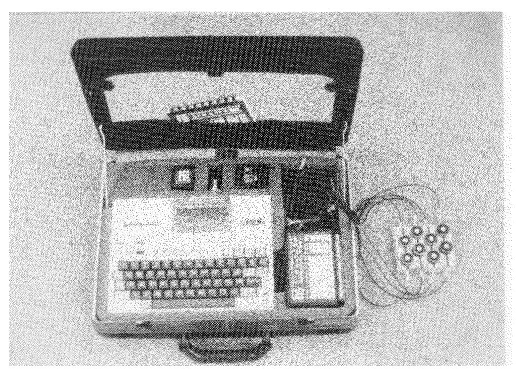

**Figure 6.1** Daylighting Data Acquisition System (Courtesy: Fowlkes Engineering).

Dataloggers are extremely powerful. Early versions required that the user learn the language of the particular datalogger, which consisted solely of numbers representing certain functions, numbers representing certain data locations in memory and other arcane conventions established by the equipment manufacturer. Indeed, many dataloggers required that the program be manually loaded by loading a series of numbers. In some instances, such equipment is more readily available, and is worth the effort of learning the language, or calling someone who has used that particular type of datalogger, and has the programs already written.

Most dataloggers now come with software which allows the program to be written separately on a computer in a more user friendly language, or most recently in graphic formats, and then the program itself may be downloaded onto the datalogger.

The remaining consideration with dataloggers is the compatibility of the devices and the loggers. For example, Licor sensors produce *current* in the microampere range. Campbell dataloggers sense *voltage* in the milliampere range. In order to log data from Licors using an Campbell datalogger, it is necessary to include a bridging resistor in the circuit. The resistor closes the circuit of the Licor (connects the two ends of the wires from the Licor) and then the voltage drop across the resistor is measured by connecting that to the Campbell.

It is possible, of course, to use Licors with a Licor datalogger, but that would be too simple. In point of fact, manufacturers sometimes make excellent sensors, and mediocre and overpriced dataloggers, and vice versa. In any case, it is necessary to provide a wiring harness to collect the input from all of the sensors, convert it if necessary, and make the connection to the data logger.

### 6.1.1 Licor Dataloggers

The LI-1000 has 6 channels for current or voltage sensors, and a wide variety of sensors can be used with this datalogger. It operates on a menu driven software which can be configured to suit any application. The LI-1000 datalogger has auto-ranging capability, which provides a wide range of measurements and eliminates the need for switch selection. Data can be collected as integrated, averaged or point values over logging periods ranging from 1 minute to 24 hours. Each datum is stored with a time stamp. It is also capable of collecting, maximum and minimum values etc. The LI-1000 datalogger has 32 K RAM and can store data covering 6000 points. Data stored in the memory is output to a computer or printer using a RS-232C serial port (Figure 6.2).

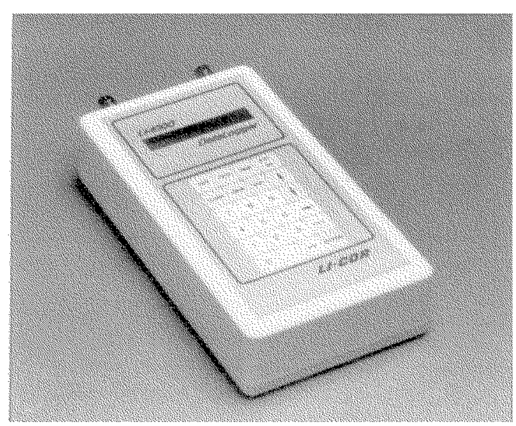


**Figure 6.2** LI-1000 Datalogger (Courtesy: LI-COR)

## 6.2 DOWNLOADING DATA

Subsequent downloading of data is done onto a computer or a cassette tape. Most datalogger software now allows downloading to computer without reprogramming the datalogger. Some datalogger programs will even make regular phone calls from the datalogger to a remote computer location, or answer remote phone calls from a computer, establish a connection and download data.

Again, it is necessary to be certain that the communications protocol between datalogger and computer matches. For example, if using a phone line connection, normal modem settings must be considered. Be certain that the number of bits, even or odd parity and data transfer rates are equal. Using a serial port on site is usually less complex, and allows for regular inspection of the sensing equipment, but there are times when this is not practical.

## 6.3 UNITARY DEVICES

Most recently, independent sensing devices have become available. These devices contain a sensor, a small battery and a small amount of RAM. There is a very simple port which connects to a docking station, embedded as a card in the computer, or directly to a serial port. The sensor is “launched” by connecting it to the computer and programming the sample rate from the computer host. After sampling is complete, the sensor is again connected to the computer host to download data, and typical programs then convert data into graphic format. Several of the programs will also dump information in spreadsheet format, and all will dump in ASCII. One such example is the HOBO, which is available to sense illuminance (and in other versions to sense other "vital signs.")

### 6.3.1 Hobo

Hobo dataloggers are miniature remote recorders, with BoxCar as its companion software for DOS, Windows and the Macintosh, providing the HOBO with a graphical interface useful for launching, reading and plotting data. The HOBO runs on a single lithium battery which can power the logger for 2 years. The HOBO is capable of storing 1800 measurements with launch time, and interval measurements. It can be deployed to measure for as long as 360 days, and can operate at a temperature range of -40 degree Celsius to 75 degree Celsius. Some Hobo’s have the extended features of delayed start, and external start. They have multiple sampling, it can sample average, minimum or maximum values. Data is read out by connecting the HOBO back to the computer with the readout cable and running the BoxCar software (Figure 6.3).


**Figure 6.3** Hobo Light Intensity Logger

The illuminance sensor on the illuminance HOBO is a diode, which is apparently more sensitive to infrared than to ultraviolet, which means that the contribution of fluorescent lights is underestimated. This may be corrected at a future date. Since the Hobo’s are so easy to use, they seem to be the instrument of choice for learning the process.

The spectral sensitivity of a sensor is always a concern. The Hobo's faults will become more significant if the IES shifts to a measure of scotopic instead of photopic curves, since the scotopic curve is generally shorter wavelengths (shifted toward the UV.)

## 6.4 PROTOCOLS

### Choosing the time

There are two chronological aspects to extended sensing. The first question is the number of samples and the time *interval* between samples. The second is the overall *duration* of the experiment.

### Interval

If there are momentary surges in the value of the sample, then frequent samples averaged over a period of time are most useful. This submerges the surge in the data, with little change. It also allows extended sampling periods without the penalty of excessive data storage. However, if the surges are other than momentary, the data can be significantly disturbed, and it is preferable to actually note the anomaly in the original sample. It is better to find the cause and throw out the one pathological observation (carefully!) than it is to estimate the shift in the averaged data created by the anomalous observation. In addition, with step functions (on/off, etc.) it is better to know the state of the device, which can be smudged if the average extends over a period of time. It may be most critical to know exactly when a particular device turned or was turned on. Averaging data can lose that information.

Many sensing devices themselves have a finite response time, and the time interval between samples should always be longer than the response time of the sensor, unless it is the sensor itself which is being tested.

### Duration

For the extended measurements to be useful, it is necessary that a sufficient period of time be covered, and furthermore, that representative times be considered. If the illuminance measurements are to include occupant interaction, normal working hours must be covered, off hours, and weekend or holiday times need not be included. It is useful to include at least a week's worth of data, since many patterns change depending on the day of the week.

If natural lighting is a factor (and it should be) then the seasonal variations must also be considered. The prototypical solution is to include a week around each solstice and at least one equinox. Given the confusion during the Christmas holiday season, several weeks might be in order, especially in academic institutions where this coincides with a semester or quarter break.

**CONCLUSIONS**

Extended data sampling is necessary for most applications of illuminance data and occupant interaction. The primary difficulty is in the connection between the datalogger and the equipment, and in downloading digital data. Recent developments in technology and software have made the problems comparatively insignificant, and allow creative correlation between varying factors which indicate behavior. It is up to the designer of the experiment to use the principles of scientific investigation, and a little creativity, to record the variables which should be considered together.

**REVIEW QUESTIONS**

6.1 What is a resistor bridge and what is its purpose?

6.2 What is the minimum interval between samples in extended sampling?

# LESSON SEVEN - EXTENDED LUMINANCE MEASUREMENTS

While evaluating glare and visual comfort, it may be necessary to know, not only the individual luminances of small areas of an interior, but also the average luminance of a larger area and measure a sort of average luminance of the view. Typical luminance measurements do not describe the visual phenomenon, rather luminance meters either average the visual field at some angle of view to provide a single number value or measure the detail within the visual field to describe some specifically interesting value e.g. a maximum or minimum luminance value. With these measurements, calculations for Direct Glare ratio etc., could be performed. Unfortunately, these results are only roughly proportional to the complex visual environment. To evaluate the complex behavior of adaptation levels, field of view and source luminances, it is necessary to make use of video photometry, whereby the luminance of an entire view, (general background level) and individual surface luminances can be measured simultaneously.

## 7.1 VIDEO PHOTOMETRY

Video photometry offers the capability to map and characterize the visual environment. This process uses video cameras incorporating CCD's (charge-coupled devices). The system typically consists of a camera, an image acquisition board (IAB) and a microcomputer. On instruction from the software, the IAB freezes and digitizes the luminance pattern viewed by the camera. The analog signal is converted to digitized signal by the converter, and consists of many thousands of individual bit values corresponding to each pixel of the camera's CCD array. By suitable calibration, the bit values are processed by the microcomputer to provide the luminance values at the corresponding points in the field of view. Typical video cameras scan 250-500 horizontal lines with analog information in each horizontal line roughly equal to 500 points. This is equivalent to 125,000 individual luminance meters distributed over the area of view (Figure 7.1).

Video photometry is fast and convenient, especially where it is necessary to obtain a large number of luminance values. One such system is 'CapCalc', called the Capture/Calculate system, which was developed by Dr. Mark Rea at the National Research Council of Canada. It provides photometry by the following five step procedure

1. Capture a video image on the camera.

2. Scan the image for digitization.

3. Calibrate the image based on the zoom and aperture settings.

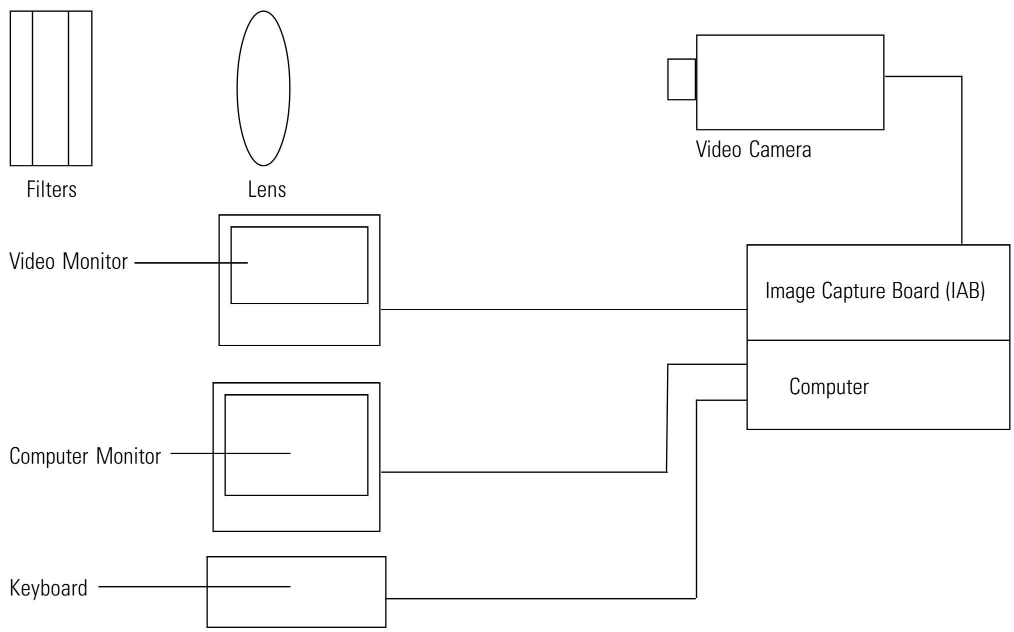


**Figure 7.1** Components of Video Photometry

4. Develop the photometric values of the 250,000 or so luminance points on the digitized image.

5. Call up and analyze the video image.

A major disadvantage of this system is the extensive calibration required to offset all camera gains, settings and spectral responsivity etc. The effect of temperature also needs to be considered. The resultant system is accurate, but expensive.

CapCalc also includes analysis software to give the average luminance within any designated area or the relative visual performance (RVP), expressing the probability that an observer can see a task. This allows a direct comparison of task performance under different lighting schemes.

**7.2 LUMINANCE DISTRIBUTION METHOD**

The Luminance Distribution method is one step further in video photometry. It offers a solution to the prevalent drawbacks in video photometry like recording f-stop, range etc. Video cameras are not exactly linear in their response. Each sample point results in an analog reading which can be digitized on a relative scale of 0-255. Any scale could be chosen, but the sensitivity and scanning response of most cameras does not justify a greater spread. The brightest point (say 1000 cd/ft$^2$) would turn up as 255 in intensity and the 0 cd/ft$^2$ area would turn up as 0 in intensity. The middle value (125) would be approximately 500 cd/ft$^2$. The nonlinearity, however, means that the value might be slightly above or below that. Most cameras are least linear at the upper end of their sampling range, or at both ends of the range.

Furthermore, cameras cannot handle a full range of intensities without an irising mechanism like that of an eye. The f-stop determines the amount of light being let into the camera, which is sampled or recorded. Video cameras automatically adjust the aperture to provide the optimum amount of light for the pickup surface. This means that the 0-255 range could be either 0-1000 cd/ft$^2$ or 0-5000 cd/ft$^2$, depending on the f-stop during the recording.

The Luminance Distribution Method is based on the idea that rather than recording the f-stop and the non linearity of the pickup for each recording, a known luminance box can be introduced into the image acting as a self calibration scale. This ensures that the known luminance will always be in the pickup range of the camera, either at the high intensity end, the low intensity end or somewhere in between. Since one portion of the image is now certain in absolute value, other portions of the image can be determined in relation to this known absolute value.

## 7.3 PROTOCOLS FOR VIDEO PHOTOMETRY USING THE LUMINANCE DISTRIBUTION METHOD

### 7.3.1. Designing the experiment

The design of the experiment depends on what you are intent on studying. For example, if the study is a post occupancy analysis, then you may need to record continuously within the space over time, or you could be interested in measuring just the luminance ratios within a room at a particular day or time. You will have to lay out your experiment based on what you intend to study (Figure 7.2). Design the experiment and make note of all the protocols, corrections etc. you need to carry out with your equipment before you proceed with the actual recording. If you are intending to survey occupants along with your recording, keep the questionnaire ready to hand out to the occupants. Follow the same sequence in changing variables if you are testing many different options. This will facilitate data gathering and analysis at later stages.


**Figure 7.2** The test cell at the Collins Center.

### 7.3.2. Setting up the experiment

**1. Location of the camera:** Depending on your experiment, locate your camera so that it is least obtrusive within the space. Try to position the camera such that it best mimics the typical occupant's location within the space (Figure 7.3).


**Figure 7.3** The test cell at the University of Southern California

**2. Location of the box:** The luminance box should be placed so that there is minimum effect on it from other light sources in the room. They should be placed below the eye level and away from any window so that no exterior sunlight and direct artificial light hits the luminance box (Figure 7.3).

**3. View of the camera:** The view seen by the camera can be adjusted to accommodate only those surfaces and areas that need to be studied.

### 7.3.3. Equipment

1. Whatever camera is chosen, it must have time exposure capability, and it is preferable if it can be operated remotely. (We have used a JVC GR-M7 Camera Recorder with reasonable effectiveness.) The camera is equipped with a nickel cadmium battery which is connected to the AC outlet through an AC power Adapter/Battery Charger AA-V10U. Please note that any other type of camera-recorder, or camcorder could also be used, but you will have to check the compatibility of different types of video format and input connections between your PC and camera for later downloading and analysis, for example NTSC, PAL, VHS, Super-VHS, Beta and 8mm formats, and composite and serial port connections.

2 The known luminance box uses long life fluorescent lamps and opal glass diffusers to provide a known luminance of 250 cd/ft$^2$. The luminance should be checked immediately prior to installation, since there is some deterioration with lamp lumen depreciation. Use a luminance meter similar to the Minolta in the previous exercise, and record the luminance for the center of the luminous panel, and for each corner. Each box also has an absorptive surface of approximately 0 cd/ft$^2$ providing 2 surfaces within the image, one at 0 cd/ft$^2$ and the other at 250 cd/ft$^2$, to provide the range of pickup (Figure 7.4). If you do not have access to a known luminance box, you must use a hand held luminance meter to measure the luminance of the same surface consistently in all your recordings.

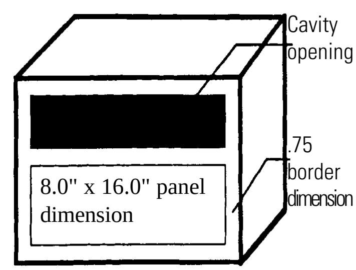


**Figure 7.4** Luminance Box

3 Compact VHS-C tapes

The easiest format is a compact format, such as VHS-C cassette tapes to record using your camera recorder. Check for the types of tapes your camera is compatible with.

**7.3.4. Recording**

Record the space within which you wanted to measure the luminances. Mount the camera on a tripod or suspend it from the ceiling or a duct, so that it is stationary, and does not obstruct normal movement and activity within the space. Remember to keep the date-time function on, when setting up the camera so that you have a record of the time and date of the observation.

**7.3.5 Capturing the recorded images**

Once you have the recorded observations on tape, you would need to capture and digitize these images.

1. Capturing and digitizing can be done in two ways. For option one, you will need a video digitizer board within your PC, as well as software such as Video for Windows, which will allow you to replay your cassette and capture the scenes while digitizing them. The other alternative is the Snappy digitizer, which is a piece of battery operated hardware which acts as the video digitizer. It is plugged into your computer on its parallel port, i.e. the port on which most printers are connected to. If such a port is not feasible, you could connect it to a parallel switch box. Check Snappy manuals for further details, they are pretty self explanatory. A cable is connected from the Snappy or the video digitizer board to the video camera. Replay your cassette. It is preferable to use the preview mode on the snappy software, and then snap when you have the exact frame on the screen, which you want captured. You will observe that some images are clearer and more stable than others. After capturing, you need to save the image. You can use any of the formats offered by Snappy which include .BMP, .PCX etc. We suggest the .PCX format.

2. Your next step would be to obtain the luminance distributions within the space, both in relative scale as well as in absolute scale. You will need to convert the .PCX file into a .PPM format which is acceptable by the software VIDEO1[1], which runs the .PPM file and in the process generates an .XLS file which gives the intensity of each pixel within a range of 1-225. This conversion (i.e. from .PCX to .PPM) is done by using software packages like COREL, ImagePRO, Photoshop, or other small utilities often available from bulletin boards. The particular one for this conversion is called 'pcxtoppm'. The .XLS file allows detailed examination of the data using EXCEL or a similar spreadsheet program.

Another option would be to use Photoshop, a program which makes instantaneous histograms of the image. However there is a disadvantage here: Photoshop makes histograms of the images, but it is not possible to save the data or export it. For initial experimentation these could be used to understand the distribution of intensities within the

1 VIDEO1 was developed at California Polytechnic Institute at Pomona under funding by Southern California Edison.

space, but you need to remember that they are relative and there is no way to find out which pixel in the image is at which intensity.

3. There is an additional utility offered by the VIDEO1 software. It works out a color coded image which shows each pixel in a particular color depending on its intensity. With this color coded image, the histograms generated from the .XLS files and the actual .PCX (image files), it is possible to make observations about luminance distributions within the space.

### 7.3.6 Analysis

The analysis can be carried out in terms of

1. Histograms of the intensity distributions within the space both in terms of distribution and numerical analysis.

2. Color coded images showing the intensity of each pixel.

3. Recorded images of the space

**Analysis of histograms**

The histogram of a scanned video image is analyzed in terms of its distribution and absolute range of intensities (Figure 7.5). Most images include a bell curve, and sometimes a spike or two outside of the bell curve. The relation between the bell curve and a spike presents a way to find out the relationship between the background adaptation level and various intensities within the space.

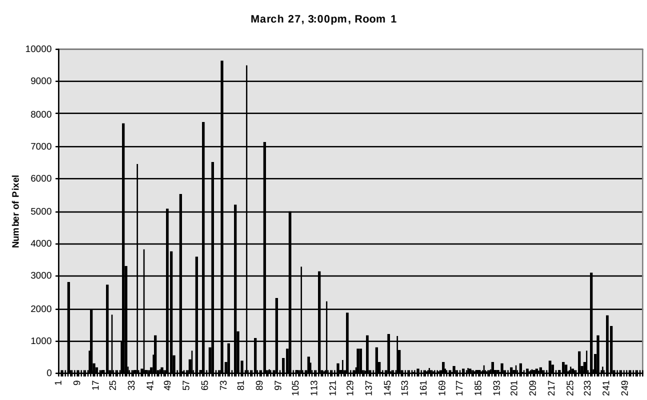


**Figure 7.5** Histogram of intensity distribution

**1. Shape and distribution of bell curve:** There is a distinct bell curve observed in the histograms of images. This bell curve can be assumed to be representative of the background level. The shape of the bell curve is also sensitive to the luminance distributions within the space. A wider bell curve implies a more uniform distribution of light intensities over the space. A narrow bell curve implies that most of the background is at a smaller range of intensities.

**2. Field of View:** From the histograms it is possible to evaluate the number of pixels within that field of view. For a given field of view, there is a linear relationship between the number of pixels in an image and the actual steradians of the field of view. Hence by evaluating the number of pixels at the background intensity or at the high intensity level, and comparing them to the total number of pixels in the image, the percentage of the field of view which either the background or the glare source occupies can be established. Since there can be a relation established between number of pixels and steradians in field of view, the histogram can provide critical information about the percentage of field of view.

**3. Relative Range of Intensities:** The histograms also provide a relative range of light intensities which are present in the space. These are then correlated with the color coded images of the space to get the absolute values of the intensities. However, just their relative range of intensities provides useful information. There are ratios of 1:200 to 1:250 between the highest intensity and lowest intensity levels within the image. Not all of them produce discomfort. The ratio of intensities between the background level and the highest intensity is more critical to glare analysis, which can be established from the histograms. This is especially true if the background is composed of the lower intensities.

**4. The spike:** The spike indicates a significant area at some intensity outside the background level of the image. The position of the spike on the histogram and its relation to the bell curve determines the visual comfort within the room. A spike at the low intensity indicates that there is a significant area at a lower intensity. This is typically not a problem, since large contrasts below the adaptation level are not problematic. The problem arises when there is a spike at the high intensity end on the histogram. This spike could be a potential high intensity glare source like the window, or table top or wall surface, or the known luminance box itself. The source can be determined exactly by examining the color coded images, and can be reasonably ascertained even using the unprocessed image. The relation between the spike at the high end and the bell curve establishes the contrast between the background levels and potential high intensity glare source, which is consistent with the conclusion that it is the ratio between the background level and the high end source which defines glare or no glare situations. The percentage of field of view which the high intensity occupies is also determined from the histograms.

**Numerical Analysis**

1. Median Pixel Intensity: This is the relative intensity of the median pixel in the bell curve distribution (Figure 7.6).

2. Weighted average Intensity: This is the average of the product of each intensity level and the number of pixels at that intensity. This gives equal importance to each pixel and its intensity.

3. Number of Background Pixels: The total number of pixels which constitute the background or correspond to the bell curve portion of the histogram.

4. Total number of Pixels: This is the total number of pixels in the image.

| NAME | MEDIAN | WEIGHTED | NO.OF | TOTAL | % VIEW | MAX INT | RATIO | RATIO | NO. OF | % VIEW | GLARE ANALYSIS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | PIXEL INT | AV. INT. | B.PIXELS | PIXELS | | | | | MAX.INT | | |
| | Imp | Iw | | | | Im | Im/Imp | Im/Iw | PIXELS | | |
| 03273PM1 | 67 | 67.73 | 134218 | 151040 | 88.90% | 235 | 3.51 | 3.47 | 10260 | 6.80% | NO GLARE |
| 03273PM2 | 64 | 56.98 | 129508 | 151040 | 85.70% | 226 | 3.53 | 3.97 | 7326 | 4.90% | INTERNAL GLARE |
| 03275PM1 | 63 | 60.01 | 131292 | 151040 | 86.90% | 238 | 3.78 | 3.97 | 4397 | 2.90% | NO GLARE |
| 03275PM2 | 65 | 58.4 | 123316 | 151040 | 81.60% | 247 | 3.8 | 4.23 | 666 | 0.40% | NO GLARE |

**Figure 7.6** Numerical analysis of Histograms

5. Percentage of view: This is the percentage of the entire field of view which the background pixels occupy.

6. Maximum Intensity: This corresponds to the intensity of the median pixel of the possible glare source.

7. Ratio: This is the contrast between the intensity of the median pixel of the glare source and the median pixel of the background level.

8. Percentage of View: This is the percentage of the field of view the possible glare source or any surface at the highest intensity occupies.

### Analysis of recorded images

The absolute values of luminances are available from the images. The images are color coded, each color corresponding to a specific range of intensities. With this code, the luminances of various surfaces, within the room and specifically in the field of view of the occupant can be identified. The color of the known luminance box gives us the relative scale needed to establish the absolute values of other surfaces in the field of view. The image is then analyzed to find out which surface corresponds to the highest intensity, which could either be the window, or a patch of light on the wall above the monitor or a patch of sunlight on the floor. By identifying the surface which is at the highest intensity, we can then evaluate its importance in the field of view of the occupant, and whether it could be a potential glare source.

The image also shows us the occupant's interaction with the visual environment. The position of blinds, and obvious change of task location or any other occupant response can also be studied from these images.

The images can be analyzed in terms of overall luminance, luminance distribution, contour maps or histograms, individual luminance, contrasts, luminance ratios etc. Apart from these it is also possible to record the view outside the window, position of the blinds, solar position and resulting shadows and sunspots and the resulting occupant behavior in the space. The luminance readings from the digitized images can be correlated with the simultaneous recording of illuminance and occupant behavior within the space. The ability to make recordings over time, and to be able to record user interaction with controls, lighting systems etc. within the space are the advantages of this system along with the capacity of the system to give absolute values of luminances rather than just a range of intensities. This method is still under development at the University of Southern California, and any questions regarding file conversion etc. could be directed to them.

## CONCLUSIONS

Understanding the difference between illuminance and luminance is critical to an understanding of the visual environment. Handheld luminance meters can provide a sense of the ranges in luminance which are experienced in different environments. It is especially important to understand the relationship between contrast, brightness and glare

A photometer instantaneously measures luminances and provides a representative number, whereas video photometry takes a few seconds to capture, digitize and calibrate the image. It takes a significant amount of time to analyze. Thus, if a single number is needed, it might be advisable to use a photometer. But if more complex and statistical information is required, the photometer is less capable. The photometer is of high precision whereas the video is of high definition and can measure over time.

The important decision here to be made is what are we trying to analyze. If the measurements are needed over time or for later analysis, video photometry becomes more useful than conventional photometry. If necessary, the camera can measure and analyze a smaller area than any hand held luminance meter, or it can zoom out and handle an entire room. Most importantly, it allows specific and simultaneous measurement of source, middle background, overall environment luminance levels, and occupant interaction.

## REVIEW QUESTIONS

7.1 What is the essential difference between handheld luminance meters and video based systems? Which gives more data? Which gives single summary numbers instantaneously?

7.2 Why is it necessary (or advisable) to include a known luminance in any video image?

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# LESSON EIGHT - DATA ANALYSIS AND PRESENTATION

Technological developments have made increasing amounts of data available to the user. The rude awakening occurs when the user realizes that there is now far more data available than can be usefully digested. The question becomes one of organizing and analyzing the data into useful forms, and of distilling principles from those analyses. The organization and analysis of data really begins before the experiment begins. Designing the experiment to learn as much as possible requires determining what measurements are necessary, in advance.

## 8.1 DESIGN OF THE PROCEDURE

The scientific method simply states that observation and repeatability are most important in the determination of true statements. Philosophy and logic may be useful, but what cannot be observed, documented or predicted, is not useful. The entire notion of measuring the behavior of light in buildings takes the scientific method for granted.

The entire point of measuring building vital signs is to track certain behaviors, and explore relationships between those behaviors and find possible causal relationships. As these relationships are observed, further tests are derived, based on the notion that if the observation repeats itself in specific ways, a relationship has been determined, and predictions may be made. The ultimate test, then of a supposed relationship is to make predictions and then see if they are verified and whether we can improve this environment and design better ones using this information.

The Hegelian dialectic is the notion that a hypothesis may be stated from observations. Tests of the hypothesis are proposed, or tests of the antithesis (opposite) are proposed. It is possible, from the results of such tests, to confirm or deny aspects of the hypothesis. From these observations there is a synthesis of information, resulting in a "true" statement about the universe. The entire discussion, testing and resolution is, in fact, a thesis, whence we get the term for much academic research.

This is an extremely useful way to design an experiment or a series of observations. On the very first pass, if we have no idea what is happening, we use the empiricist approach. We look for relationships to consider. Normally, we already have a proposed relationship between two variables. In that case we design the experiment to be certain to test those two variables, and either eliminate, or test for any extraneous variables which might influence those two. It is most useful to design the samples to be taken in terms of a specific question. Thus, it is most useful for the user to prepare a clear hypothetical statement, resultant tests for that statement, a list of variables to be tested, and then choose the appropriate devices and time period to make the tests. The entire process may not always be possible, but it is a useful paradigm to consider.

It is often very useful to create, or find, a control or base case for every variable tested. This means that if we wish to test light shelves, we learn most about them by instrumenting two rooms at the same time, one with a light shelf and one without. The data then will not simply be an observation of a room with a light shelf, but rather the comparison of a room with a light shelf to a room without a light shelf, with weather data variables now neutralized. If we can test two bays of the same room and eliminate scheduling or other differences, it is even better. Typically the simpler case is the base case against which we compare other variations. A control case is technically any case in which we have not varied anything, which in terms of buildings is similar to a base case, or the case against which we are testing.

If we cannot establish a specific control or base case, the second most useful strategy is to increase the number of situations sampled, so that there is an increase in the likelihood that the observations hold for more than just one specific case.

## 8.2 ANALYSIS OF DATA

After the experiment has run its course, there are several ways of considering the data. Since humans are capable of absorbing more data graphically than in any other way, graphic presentation is most important. The questions revolve around what variables to plot against one another, and what format and interval to use for the data. The most common plot is chronological, tracking a particular variable or pair of variables across a single day, or through representative days across a single year. The second most common plot is a spatial plot, either of a two dimensional cross section, a two dimensional floor plan, or of a three dimensional space. It is useful to categorize such plots and consider looking at the data in more than one version, at least once.

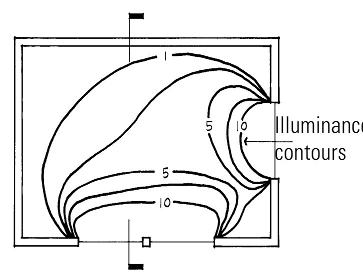



**Figure 8.1** Plan of space showing illuminance contours

### 8.2.1 Two dimensional plots

The simplest plot is the grid of values as measured in the plan of the space (Figure 8.1). If this is a line of sensors from the window, it is best shown as a cross sectional plot of values (Figure 8.2). If this is a more complex grid, it is best shown as an isolux plot. An isolux plot is a "contour map" of illuminance levels, showing all the lines of constant illuminance values (Figure 8.3).

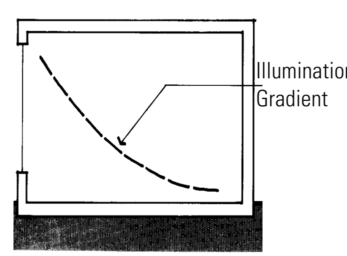



**Figure 8.2** Illumination gradient, graph of DF plotted against distance from window.

An isolux plot is created by finding the integral values at regular intervals on a line connecting two measured values on the grid. The distances may be prorated to match the spacing of the measured values. For example, if two grid points are measured at 46.2 fc (462 lux) and 54.4 fc (544 lux) respectively, then there will be eight isolux lines between them, at 47, 48, 49, 50, 51, 52, 53 and 54 fc. If such crossing points are noted between all of the measured grid points, the crossing points may be connected to form the isolux plot lines. Some smoothing may be appropriate, since the actual illuminance distribution rarely contains points or corners.

However, when comparing solutions it is often useful to plot different situations on the same graph, allowing direct comparison. If there was a control case, the simplest is to overlap the control case and the variations on a simple cross section of the space. It might also be useful to plot a single point in the space, over a period of time, overlapping the control case and the variations to consider the behavior in a chronological sense.

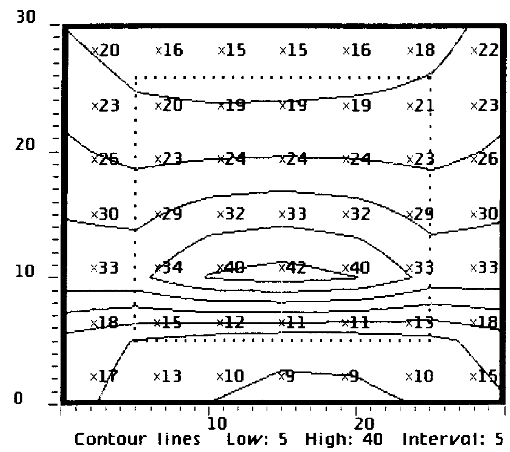



**Figure 8.3** An isolux plot

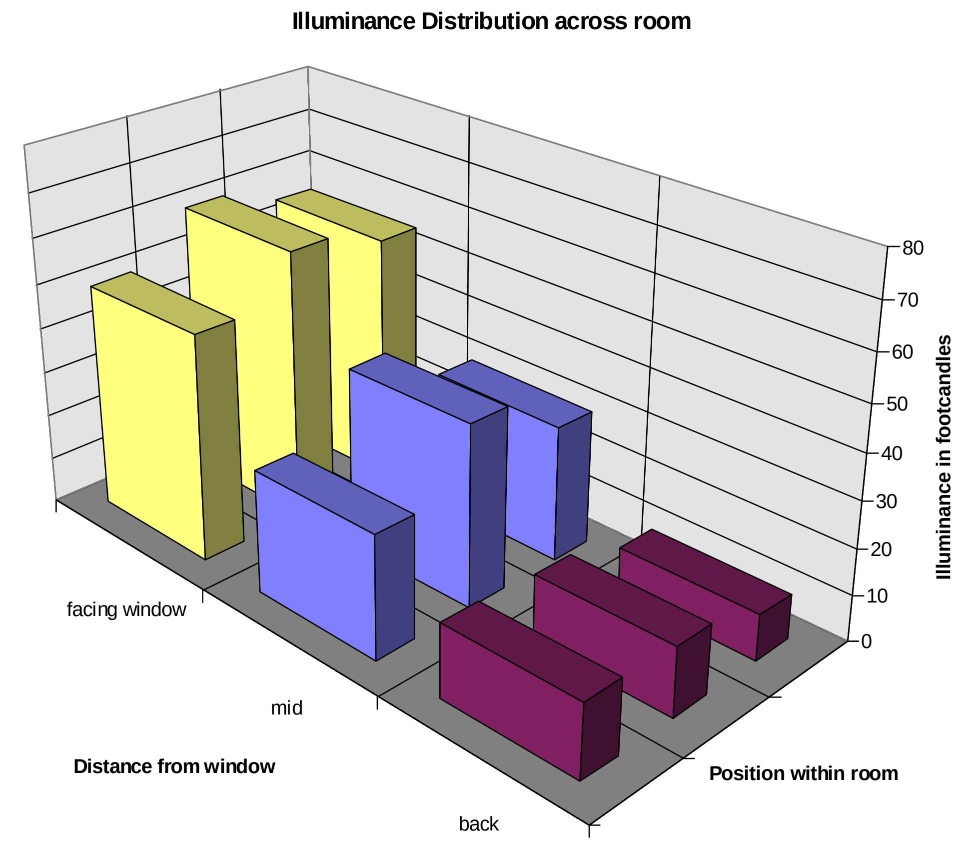
Parallel variables, or variables in which we expect to see a relationship may also be plotted the same way. The relationship may be causal (one causes the other), or several variables may be simultaneously tracking an external variable. Finding similarities in behavior do not necessarily prove that one is driving the other. Cause and effect variables, or trigger and responding variables, should always be tracked over a period of time. The case for cause and effect becomes strongest when one variable slightly precedes the other in its behavior, but even then, it might simply be the more responsive of the two variables to some external factor.

### 8.2.2 Three dimensional plots

It is possible to plot all the values of a variable in an entire three dimensional space at a particular point in time. This results in a landscape of the illuminance levels, for example, which is similar to the isolux plot (Figure 8.4). It is conversely possible to plot a single point in space over an extended period of time. This results in a chronological map which shows at what point in time the highest level is achieved for that spot, and often yields a great deal of information about shading and other events which might not be visible on any one given instantaneous plot. Either plot is three dimensional.

It is also sometimes useful to mathematically subtract the values of one variable from the other, resulting in a plot of the *difference* between the two variables. When plotting a base case and a variant, the user can immediately see the difference resulting from the variation, instead of visually trying to find the detailed difference between two complex three dimensional plots.

An extremely useful variation has been introduced by Murray Milne at UCLA (Figure 8.5). A contour plot of one variable is color coded at key




levels. This results in a banded contour plot. This banding is then mapped onto the contour plot of the next variable, allowing the superposition of two three dimensional maps on top of one another. This can prove extremely useful.

**Figure 8.4** Output from Microsoft Excel Spreadsheet program: A three dimensional plot showing distribution of illuminance levels across space.

If the equipment is available, it is possible to record successive instantaneous three dimensional plots to create a video of the behavior of a variable over time in a three dimensional space. This looks like a room with wave behavior as the sun moves around the space, or as occupants turn lights on and off. Again, it is possible to identify behavior patterns that are not apparent from any single sampling. It is also possible to color code the contour levels so that it is immediately apparent when a particular level is exceeded. A classic version of such an illuminance plot video was produced by Sumption et al at University of Idaho.

## 8.3 PROPRIETARY PROGRAMS

There are several useful spreadsheet and presentation programs available on the market. (Excel, QuattroPro, Lotus) These programs

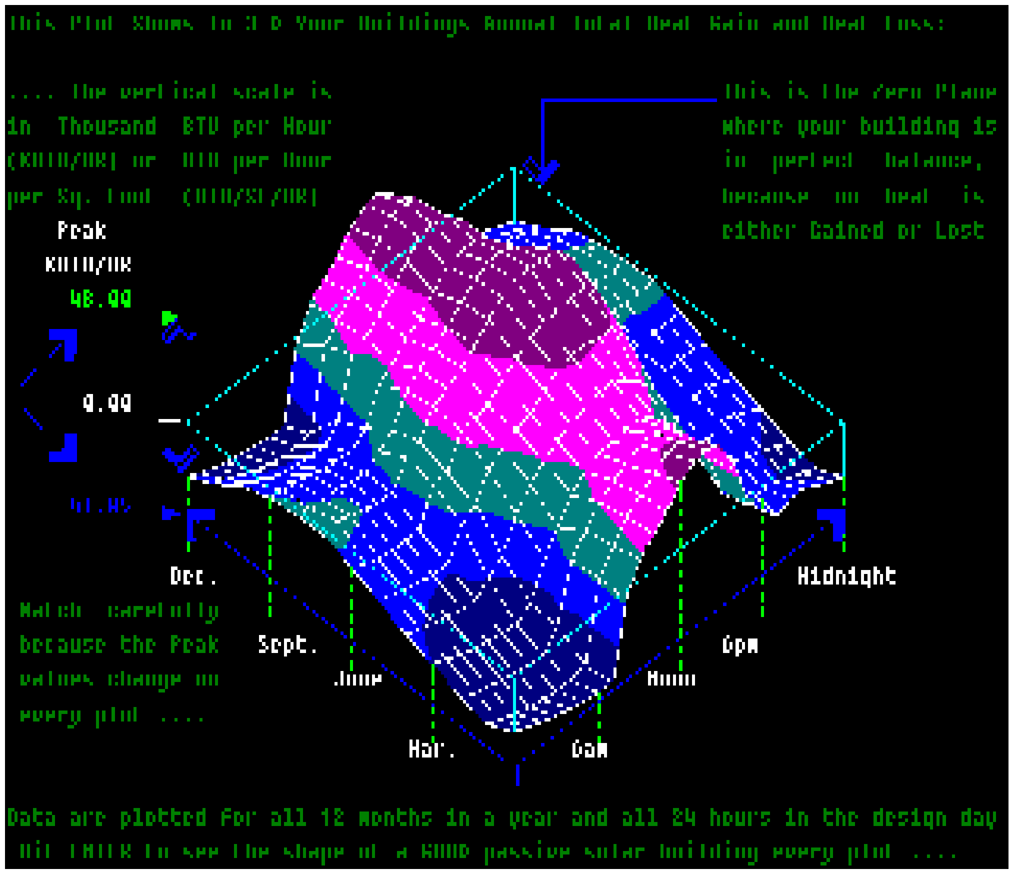



**Figure 8.5** Output from Solar53, with ability to plot contours of different variables simultaneously overtime.

provide the ability to load ASCII data, or files which have been created by other users in the same program. They are capable of manipulating the data to find averages, sums, differences, unit conversions, and various programmed extensions of the data. This allows the user to project cost data from illuminance data, for example, or anything else which the user's creativity can correlate.

At the same time, different data may be plotted against one another. The programs are particularly capable of plotting two dimensional graphs. Superimposed line graphs are the most useful and common, but scatter plots are available, and in some instances, curve fitting is possible. Unfortunately, three dimensional plots are still typically primitive, usually limited to rather blocky bar graphs, in which the number of points is limited, and bars at the front obscure information at the rear. Three dimensional mesh and contour graphs are available in some of the more obscure programs, and should eventually become more common. These will be useful, especially when employed to find three dimensional plots of differences, as described above.

**CONCLUSIONS**

Extended data sampling is necessary for nearly all useful applications of illuminance data and occupant interaction. The primary difficulty is in the connection between the datalogger and the equipment, and in downloading digital data. Recent developments in technology and software have made the problems comparatively insignificant, and allow creative correlation between varying factors which indicate behavior. It is up to the designer of the experiment to use the principles of scientific investigation, and a little creativity, to record the variables which should be considered together.

**REVIEW QUESTIONS**

8.1 What is an isolux plot, and how is it created from a grid of data points?

8.2 What is a control case? What is a base case?

8.3 What is a thesis? Give an example which is in relation to building diagnosis.

# LESSON NINE - CONTROLS

To understand the interaction of controls and light, it is necessary to have a better understanding of the range of control devices and how they function. There are two general categories of controls. There are controls of incoming natural light, which are typically a manipulation of the building's skin. There are controls of the electric lighting sources, which may be manual or automatic.

## 9.1 PLACEMENT AND ORIENTATION

The simplest and most often used strategies are really quite simple. Critical tasks requiring high light levels and reflected light, are usually placed near the fenestration. We are all familiar with the wonderful Vermeer paintings showing the women of the period working at critical tasks close to windows.

When there was too much glare, people simply moved the task away from the windows. Reflective surfaces were oriented away from the window, or conversely, the observer tried to stay between the window and the specular surface, or to the side of the surface.

With the advent of luminous screens, such as television monitors and computer display terminals, the issue became considerably more complex. They are specularly reflective, which makes veiling reflections likely, and they are also luminous, but at low levels. This means that they cannot be between the viewer and the fenestration, because the background field of view (discussed earlier) is too bright, and the information on the screen is lost. It is not a direct form of glare, it is merely a loss of information, or signal-to-noise ratio. Conversely, luminous display terminals cannot be oriented directly away from luminous surfaces, because the reflection of surface from the screen again obscures information at best, and causes outright glare, at worst.

Placement at angles to the fenestration or at a distance is usually the best, and other controls e.g. glare screens must often be employed.

## 9.2 BLINDS AND SHADES

The second "layer" of physical controls are the modifications to the building skin. These may be external modifications of a static nature, such as louvers, overhangs, fins, or light shelves (Figure 9.1 and 9.2). These are discussed in many excellent references on daylighting in buildings.[1] [2] Venetian blinds, vertical blinds and rolling shades are far more common.

Rolling blinds are actually effective only if they are completely opaque. Translucent blinds are probably the greatest source of glare whenever they are employed. They reduce the level of light within the

1. Daylighting" in *Passive Solar Commercial and Institutional Buildings: A Sourcebook of Examples and Design Insights*, edited by Robert Hastings, John Wiley & Sons, Ltd. , Chichester, UK, January 1994.

2. *Simplified Design of Building Lighting*; John Wiley and Sons, August 1993, New York.

space, but in the process become a tremendously bright glowing light source, in themselves. Since they are almost always in the field of view, this is a major mistake. Opaque blinds with tiny holes are an improvement. The light coming through the holes is rarely perceived as a very bright surface, depending on what material is in view behind the blinds, outside the window. Such blinds reduce the light level within the space, as well as reflecting some heat, to mitigate heat gain.

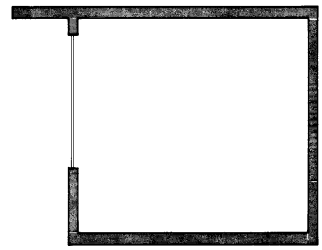


**Figure 9.1** Overhang

Venetian blinds are the best of the internal skin controls, because they are able to redirect some light to the ceiling, are able to tilted in such a manner that the inside of the space sees only the comparatively dark underside of the reflectors, and transmissivity may be continuously adjusted from 100% to nearly zero, uniformly across the window (Figure 9.3). Horizontal venetian blinds are by far the best for southern exposures and vertical blinds are slightly preferred for East, West and North exposures.

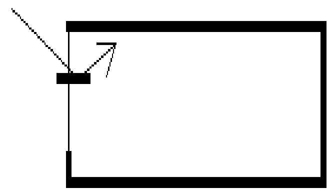


**Figure 9.2** Light shelves

All of the above devices may be controlled manually, or by sensors, computer input or other building programming.

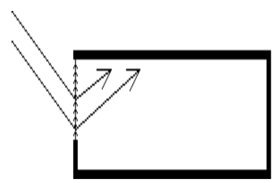


**Figure 9.3** Venetian blinds

## 9.3 DISCRETE CONTROLS

Most electrical controls are simple on/off switches. They are manually controlled by the occupants. Good switching allows portions of the room to be dark while other portions are lit, and allows the portions of the room lit with natural light to be switched off while other portions remain on.

## 9.4 SCHEDULERS

Many larger buildings have lights on automatic controls controlled by a central schedule. At a preselected time of day, the entire building is shut down. Some lights are left on for security, but anyone still working in the building has to contact the building maintenance superintendent, or dial into the controller itself, to override the shut down order. This must be done repeatedly at regular intervals.

## 9.5 OCCUPANCY SENSORS

Perhaps the most effective development has been the development of occupancy sensing devices, which are capable of recognizing movement, and keeping the lights on as long as there is movement. These sensing devices typically measure a change in the infrared distribution in front of the device, or send out high frequency sonar waves, and recognize a change in the reflection pattern. All occupancy sensors are on/off devices, and can be used in conjunction with any of the other devices. For example, an occupancy sensor will turn on the lights when the room is occupied, but a daylight sensor will dim the lights appropriately (or in some cases, override the occupancy sensor and not turn on the lights at all.)

One variation is *manual on*/auto off motion sensors, which require a manual touch to turn them on, but switch off after a period of no motion. They are good for daylight spaces so the lights don't come on unless the occupant switches them on, (i.e. hopefully not when daylight is present) but they will turn off automatically.

Occupancy sensors have varying detection patterns, and may be mounted in the ceiling or on the wall. They also have varying sensitivities, in some instances recognizing very small movements, and in other instances requiring occupants to make major movements at regular intervals. The "time-out" period is defined by how long the device will wait without detecting movement, before it shuts off the circuit. There is a delicate balance between sensitivity and time-out period, and between saving energy and irritating the user. There are several classic stories associated with occupant sensors.

Electrical contractors are still unfamiliar with their installation. One installation was filled with disgruntled employees. Subsequent inspection found that the wall mounted sensors were installed upside down. The ceiling was being scanned for movement, but no one in a sitting position could have any effect on the sensor. The employees had to stand up and wave to turn the lights back on. Similarly, the restroom in an office building was equipped with a wall mounted infrared occupancy sensor. As soon as some one sat down in a stall, they disappeared from the sensor's view. Before long, the lights would go out, and nothing the occupant could do from within the stall would change the absolute darkness. The building superintendent had no idea what to do about the problem.

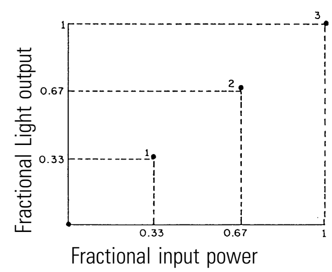



**Figure 9.4** Light output vs input power for a stepped lighting control system with three control steps.

## 9.6 PHOTOSENSORS

The most recent development has been the addition of photosensing devices which are capable of detecting the light level within a space. These separate into two categories. The most basic response is to simply shut the lights off when there is enough natural light. The photosensor is set to recognize double the necessary level of light (the "design" level) and shut the lights off when that level is achieved. Variations of this method allow half of the lights to be shut off, or even one third of the lights, in properly circuited three lamp fixtures. This is called "stepped dimming" (Figure 9.4).

Advanced electronic ballasts are capable of partially dimming fluorescent fixtures. This is not a variation in the line power, but rather an electronic control. This allows photosensors to send a low voltage signal to the ballast, which in turn can dim the lamp to almost any desired percentage of full output. Some ballasts have a minimum level, others are able to dim to 1%. There is, however, usually a residual current draw, on the order of 15%, depending on the system. This process is called "continuous dimming" (Figure 9.5).

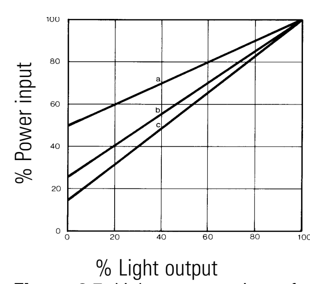



**Figure 9.5** Light output vs input for continous dimming systems.

One weakness of stepped dimming is that there is usually excess light, since the light level rarely matches exactly what is needed. On the other hand, the recommended illuminances can be exceeded by

50% without detrimental effect, anyway. An additional annoyance, however, is the discontinuous jump which occurs when one of the set levels is passed. However, there is no residual electrical draw when the lights are completely off, and the systems are typically cheaper. In a room where there is ample light for most of the time, the continuous dimming is a moot point. Under such circumstances, the residual current draw is an excessive penalty and the stepped systems are more efficient.

The most significant factor in favor of continuous dimming is actually the psychological one. The occupants do not notice the gradual dimming of the system, and are not annoyed. They are particularly annoyed if the stepped system shuts on and off, even with a time delay.

The biggest challenge in employing the photosensors is to coordinate what the sensor sees in its field of view (luminance) and what is the actual illuminance on the task areas.

**9.7 MEASUREMENT**

There are several ways to determine whether the sensing devices are functioning, depending on what resolution is required. The simplest measure is to put a time summing device on the same circuit as stepped fixtures. This will simply record how long the fixtures are in use. There are several variations on this, including induction coils which sense the current, without being in the circuit. These are minuscule electromagnetic devices attached to the circuit without breaking the insulation, and they sense the change in the field caused by the current passage.

Dimming sensors are more difficult to meter. These can be metered by measuring the level of current in the circuit (much more difficult than the on/off measurement) or by connecting a device to the low voltage signal wire from the sensor to the ballast.

The most inclusive measurement of the on/off sensors is video recording. It is possible to see from the image whether or not the lights are on. Unfortunately, it then requires the observer to enter the data manually. The benefit of the video recording is that the reasons that the lights are on or off are simultaneously recorded. Again, this is much more difficult for the continuous dimming systems, since determining the percentage dimming form the video requires analyzing the surface luminance of the fixture.

**CONCLUSIONS**

Controls represent a great opportunity for saving energy, both in occupancy sensing and in daylight harvesting. The optimum interactions depend on the occupants, their function, their level of control over the system, and other factors as yet not fully explored.

**REVIEW QUESTIONS**

9.1 Why are vertical louvers better for East, West or North exposures?

9.2 For an on/off system, why do we shut off the lights when there is twice as much light in the space as is necessary?

9.3 What are some variations on occupancy sensors?

9.4 What is the benefit of a stepped photosensing system? What are the primary liabilities?

# LESSON TEN - OCCUPANT SURVEY

The primary purpose of an occupant survey is to analyze and understand how to design optimum environments for people by evaluating existing buildings. This need may develop in response to complaints from building occupants or in reaction to some unexpected incident in the building performance. A lighting evaluation study finds and analyses ways in which the luminous environment does or does not meet user needs and satisfaction. It also establishes criteria for better lighting designs which are responsive to human needs and comforts, and for formulating future standards and building lighting codes.

## 10.1 A BUILDING LIGHTING EVALUATION

It is the systematic evaluation of a building to acquire knowledge and data on how the luminous environment affects people's behavior. There are quite a few reasons why we need to evaluate buildings.

1. To gather information for a particular problem which needs to be solved for example occupants complaining about bad headaches due to bad lighting.

2. To gather generic data and information about the relationship between people and the building.

3. To make the design process more of a feedback mechanism whereby evaluative data is included in the design making process.

There are many ways of going about conducting a building evaluation. Some of the methods apply analytic approaches, others take a more dynamic stand viewing people and buildings as interactive and mutually dependent. There are some models which simply elicit information on how best to respond to user's complaints and recommend building improvements for those problems, without incorporating the technical aspects of building performance.

## 10.2 SURVEY METHODS

The traditional way of conducting a building evaluation(and what we have been doing till this stage) has been to go and measure every measurable quantity. It is an onslaught of tests on a building to analyze and assess the quality of its performance. However the major limitations of conventional approaches to building performance measurement are

1. That it is based on laboratory research, which when applied to field studies of human comfort and performance, do not serve as accurate indicators of comfort.

2. That a conventional lighting performance analysis cannot measure and account for the "occupants interaction" with the lighting controls or environment. This can be evaluated through a survey by posing questions about manipulation, frequency, and cause of interaction with controls.

One such assessment is the building-in-use assessment which was carried out by the team at the Architectural and Building Sciences, Public Works Canada, Ottawa. The basis of this assessment was to compare buildings or parts of buildings to one another. A database of baseline ratings was prepared to which all buildings were compared. Users were typically asked to assign a rating of 1 (uncomfortable) through 5 (comfortable) for various interior environmental conditions that pertain to lighting, acoustical and thermal comfort, air quality etc. Users were asked to rate these conditions for their individual workstations, workgroups or on their floors. Ratings were then averaged across floors, or certain areas. Once the baseline of scores had been made, scores of individual buildings could be compared to them to ascertain deviation. This sort of assessment can help pinpoint buildings and buildings areas which need urgent attention, develop goals and objectives for long term planning and resource allocation, assess and monitor quality in any part of the building.

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| **Electric lighting:** | 1 | 2 | 3 | 4 | 5 | (0.67)* |
| | "Bad" | | | "Good" | | |
| **Glare from Lights:** | 1 | 2 | 3 | 4 | 5 | (0.66) |
| | "High Glare" | | | "No Glare" | | |
| **Brightness of the Electric Light:** | 1 | 2 | 3 | 4 | 5 | (0.55) |
| | "Too Much Light" | | | "Does Not Get Too Bright" | | |
| **Colors:** | 1 | 2 | 3 | 4 | 5 | (0.47) |
| | "Unpleasant" | | | "Pleasant" | | |
| **Daylight:** | 1 | 2 | 3 | 4 | 5 | (0.38) |
| | "Bad" | | | "Good" | | |

**Figure 10.1** Lighting Ratings

Courtesy: Vischer, Jacqueline C., Environmental Quality in offices.

## 10.3 SURVEY

Conditions which are investigated in an occupant survey fall into regular categories or disciplines for which instrumentation and techniques of measurement are available e.g. lighting, thermal and acoustical comfort, air quality etc. Many of these measurements have a bundle of measurable physical attributes, which can be related to these surveys, to make them meaningful in terms of human experience. A valid and reliable set of rating scales for occupants subjective assessments will need to be developed. If parallels need to be drawn between performance of various buildings, then the rating scale should be kept consistent.

**CONCLUSIONS**

One might wonder why we need to go into such an extensive evaluation. An occupant survey simultaneously measures the quality of the environment as experienced by the users and the actual physical dimensions of the environment (measurement). It yields an understanding of the quality of the space. The ratings are based on how people judge the interior work environment and how these psychological dimensions assess environmental quality within the space. Lighting rating questions as part of a building lighting evaluation are included as an example (Figure 10.1). You could also refer the generic questionnaire presented as an appendix in "Environmental quality in offices" by Jacqueline C. Vischer, Pg. 230.

The most useful building evaluation model is that which incorporates user-building interaction. It attributes a psychological component to the environmental quality. The building is studied through the eyes of those using it. It uses occupant judgment to focus on the evaluation of the building rather than on the user and uses norms or standards derived from existing buildings.

**REVIEW QUESTIONS**

10.1 Why are post occupancy surveys important?

10.2 Why are test cell surveys important?

10.3 Do surveys sample the experience of a moment or the overall experiences in a spatial environment?

VITAL SIGNS

# 2 FIELD EXERCISES

# ASSIGNMENT ONE - VISION

**OBJECTIVE**

To understand the basic concepts of vision, by performing a few simple experiments with yourself as the subject.

**DISCUSSION**

These exercises create an awareness of the importance of the visual process in the evaluation of a building design, and introduces the concepts of adaptation, parallax, depth perception, acuity, glare, reflections and color sensitivity.

**EQUIPMENT**

There is absolutely no equipment necessary for this exercise except this exercise sheet and two pencils!

## 1. ACCOMMODATION

The self-adjustment of the lens of one eye for focusing on objects at different distances.) Find or create a brightly lit environment. Touch the left edge of this sheet (nearest the "A") to your cheek just below one eye. Hold the sheet horizontal with the row of letters pointing in front of you.

A B C D E F G H I J K L M N O P Q R S T U V W X Y Z

Circle the closest letter you can focus on. While still keeping that letter in focus, circle the farthest letter that is also in focus. As you know, the range between these two letters is called the depth of field. As your eye looked backwards down the list, your lens is changing shape (by the action of the ciliary body and the myeloid muscle attached to the lens.) Repeat the process for your other eye.

If you wear glasses, try the same thing without them on. Are you near sighted or far sighted?

Now, shut off most of the lights (or find a dimly lit environment.) You should just be able to see the letters after a period of adjustment. Repeat the experiment. Do you have a greater or shorter depth of field?

**Depth of field is effected by age and irregularities such as cataracts. The lens begins to stiffen and it is more difficult to focus it exactly. When there is plenty of light, the iris closes and the eye uses only the middle of the lens, which allows a greater depth of field, and is more forgiving of irregularities. This is why brightly lit environments become important to visual acuity, especially for older eyes.**

### 2. CONVERGENCE

(The act of aiming both eyes at the same point.) This is the mechanism by which we perceive depth stereoscopically. Hold up two pencils vertically; A at arms length and B half way between A and your nose. Focus on A with both eyes; you should see two out-of-focus images of B. Draw what you see below. Close your left eye and label the remaining image of B as BR. Close your right eye and label BL.

Now focus with both eyes on B; you should see two out-of- focus images of A. Close your left eye and label the remaining image of A as AR. Close your right eye and label AL.

Compare the location of the left and right images in the two drawings above.

**This effect is called parallax. It is not effected by light level, because it is not dependent on the iris at all. It comes from the fact that the eyes are separated. This is where our sense of depth perception comes from. Our minds process the eye aiming angle at which the images coincide, which gives us the approximate distance to the object.**

### 3. ACUITY

(The resolving power of the eye.) Acuity is a measure of our ability to see very small details, for instance you should be able to see a fine line that subtends a visual angle as small as 0.01 minutes (with a very bright background.) To demonstrate this, find the greatest distance at which you can see a single human hair; you will have to experiment to find the best lighting and background (contrast) conditions. Record the distance and the lighting conditions below. (You might also try this with different color hairs, or with a textured material to see when it reads as a solid.)

DISTANCE FT.

DESCRIBE OR SKETCH.

**Contrast is a useful factor here, since the greater the contrast, the easier it is to see the hair. Most people cannot see something that fine from a distance greater than 60 feet, however, since the image falls between the spacing of the internal receptors of the eye. Sneaky students can use a blond (fairly translucent) hair and shine a bright light at it, and get some diffusion, which lets the hair be seen at up to 120 feet. It isn't really the hair you see, but rather something like a lens flare in a camera.**

### 4. PUPILLARY ADAPTATION

Adaptation is the ability of the eye to adjust to light of various intensities. There are two mechanisms of adaptation: retinal and pupillary. The latter is accomplished by a sphincter muscle in the front of the eye called the iris. It is capable of responding very rapidly to up to a seventeen fold change in illumination levels. The pupil is able to dilate from 2 mm to 8 mm in diameter. You can demonstrate this as follows: set up a small very bright light (against a dark background), close or cover one eye, with a small hand mirror watch how the other pupil changes as you cover and uncover the light source with the mirror. In the margin to the left, draw your best estimate of the actual size of the pupil at the smallest and largest diameters you can observe. How much time does each size change take? How does this affect the way things "look"? Can you explain why it is more difficult to see the large diameter case? (It is interesting to look for this reflex in someone else's eye).

While still facing the light source, open the other eye but shade it with the mirror and observe the pupil of the other eye while you alternately shade and unshade the other eye. What happens? (This is called the conscentual reflex).

**Understanding the response time of pupillary adaptation will give you the basis for understanding many of the causes of glare in architectural spaces. The eye requires time for adaptation, since it must cover such a broad range of light levels.**

### 5. RETINAL ADAPTATION

The second kind of adaptation is called retinal adaptation. Unfortunately, you can't watch how it operates but you can experience its results. The response time of retinal adaptation is much slower (on the order of 20 minutes) but it is capable of adapting to a fantastic range of energy levels (one hundred million fold). To experience this (and also to answer question 6) you will need a watch and five or six objects which are the same shape but different colors (pieces of paper, pencils, or box of pastels). Go into a dark room that has only a tiny sliver of light entering. Note the time before you enter the darkness and record the elapsed time before you can see the objects if it takes less than two minutes, find a darker room). After 20 minutes, arrange the objects in your hand from lightest to darkest and record the results. Can you detect any color or color differences? (BRING THE OBJECTS TO CLASS). You will find it most interesting if you take along objects which are yellow, yellow-orange, yellow-green, red, blue, and gray.

TIME: MIN. COLOR DETECTED? (YES) (NO).

ORDER OF COLOR SAMPLES:

**This is called scotopic vision; at low levels you see using primarily the rods in your eye**.

### 6. COLOR SENSITIVITY

After you come out of the dark room with your color samples and record their order, arrange them again and in room light from lightest to darkest and record the results. As you have probably realized by now, your visual color sensitivity shifts as a function of light level. The change in color sensitivity is called the Purkinje Shift and is due to the differential sensitivity of the rods vs. the cones in the retina.

DARK ADAPTED ORDER (ROD VISION):

LIGHT ADAPTED ORDER (CONE VISION):

**Color differentiation occurs only at higher light levels, when the cones can function. This is called the photopic range. Not only is the order of brightness different, but the ability to tell yellow grays from blue grays, or color patterns, or analyze skin tones for diagnosis, all occur only at the higher light levels.**

### 7. AFTER IMAGES

In situations of extreme glare (i.e. luminance in the visual field that is too great for the retina and the ability of the iris to constrict sufficiently) the receptors in the retina are temporarily fatigued. In this situation you “see” an image that does not exist! Set up a seeing task in the most glare-producing situation you can think of which produces an after image, such as looking at a bright overhead light bulb. To get an after image, keep your gaze steady on the bright image until you begin to experience discomfort, then turn your head and look at a plain, medium value surface (wall?) and blink your eyes rapidly. Draw a sketch of the task set-up and describe (sketch) what you see; what color is it? Is it positive or negative?

How does your perception of the after image change when you tip your head from side to side?  Don't think, just look.

**(Now think.)  The pattern remains constant because the sensors which were affected remain in the same spot on the retina.  The cones detect color by sensing difference.  They are not absolute sensors, so when they are fatigued in a certain color, a neutral color is perceived as shifted.  The rods become fatigued as well, resulting in the dark/light displacement.**

## 8. COLOR CONSTANCY

Find a space or work station where you can instantly switch from fluorescent to incandescent lighting with approximately the same illumination level from each on a reading task (black ink on white paper).  Spend about ten minutes under one source, then instantly switch to the other. Look at the white paper.  After 10 to 20 minutes more, switch back to the original source.

WHAT WAS THE FIRST SOURCE?  THE SECOND?

WHAT DID THE WHITE PAPER LOOK LIKE AFTER YOU SWITCHED?

HOW LONG DID IT LAST?

WHAT DID THE WHITE PAPER LOOK LIKE WHEN YOU SWITCHED BACK?

IS THERE A COLOR NAME OR COLOR TEMPERATURE ON EITHER SOURCE?

**There are colors present in differing amounts from differing sources. This is especially apparent when you shift between them. Color temperature and Color Rendering Index are important issues in light quality and lighting design.**

### 9. VEILING REFLECTIONS

The most insidious problem lighting designers face are caused by bright sources located behind the observer that reflect off shiny surfaces of the task, for example off a glossy magazine or the surface of a VDT (Visual Display Terminal.) Place a piece of clear plastic (glass, acetate) over this page, and move it around in your environment until you see the reflection of a fairly bright source. Compare this reflected glare with direct glare as "seen" in experiments. Draw a sketch

**Fortunately, your mind can filter out some of the "noise" of this reflection. (Does accommodation and/or convergence help or hinder?) It does cause fatigue and occasional errors, and sometimes simply cannot be filtered. Reflected glare is particularly important in work areas.**

# ASSIGNMENT TWO - SELF GUIDED LIGHTING TOUR

**OBJECTIVES**

To establish a direct encounter with the lighting environment of a building and various light sources within it. To create an awareness of the issues in a lighted space, i.e. illumination (amount of light), luminances (brightness), glare, luminaire design, layout and suitability for each space and task.

**DISCUSSION**

In this exercise you will note the physical characteristics of the lighting system, and other features of the space, for example materials, surfaces etc. that might be related to the luminous performance of the space. There are several basic questions which underlie all your experiences in buildings:

· is the amount of light available sufficient for the task, e.g. reading, socializing, display?

· are there excessively bright surfaces causing discomfort?

· is there any direct glare through the windows?

· are there any lamps directly visible to the eye causing extreme discomfort?

· or are there any reflections which veil important information?

When you observe the specific spaces and tasks, look for clues in the surfaces and features of the room, window location and luminaire location. Feel free to note down suggestions as to how to improve the negatives in the design when you rate it negatively and how you feel the design has succeeded in creating a positive luminous environment.

**EQUIPMENT**

Bring along a glossy surface, such as a magazine. Keep extra sheets of paper to make sketches and notes. In fact, many lighting designers and architects keep sketchbooks to record observations for future reference. You may bring a camera, if you wish to make a more comprehensive visual report. Use a 400 ASA film, or faster. Slides often show lighting better than prints, but this depends on the final presentation medium.

**METHOD**

Pick four spaces which have significantly different lighting environments. For example, a large daylit lobby space, a small student bedroom, a classroom and a computer room. Stand or sit at a typical occupant's task location. Evaluate the total lighting system design and each aspect on a 10-point scale as shown below.

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Scale A: | | Awful | | Bad | | So-So | | Good | | Superb | |
| Scale B: | | None | | Low | | Okay | | High | | Way too much | |

Use 0 or 10 only in truly rare cases

**PROCEDURES**

To evaluate *direct* glare, place your hand between your eyes and the offending source. Compare this with what you would see in your normal field of view without any shading. (use Scale A);

To evaluate *reflected* glare take along a "glossy" magazine or a sheet of clear plastic. (use Scale A);

To evaluate brightness ratios, try to sense the slight time lags caused by pupillary dilation as you scan around the room and then look back at your task. Try to separate out the effect of daylight (i.e. by turning lights on and off, or by visiting the same room at night). (Use Scale B);

To evaluate light level (overall amount of light) decide if it is too dark or too light to do the task. (use Scale B);

To evaluate luminaire design and layout consider the aesthetics of forms, shapes, and patterns. (use Scale A);

To evaluate overall visual comfort consider the totality of the luminous environment. (Use Scale A);

Add any brief comments or add a footnote number here and attach a separate sheet with longer comments. (Use Scale A).

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**ROOMS AND TASKS**

**Room One - Large Lobby Space**

1. Is the illuminance level higher outside or inside?

2. Is the luminance level higher outside or inside?

3. Is there any diffusing glass in windows or skylights, and does it have a high luminance?

4. How are the luminances from exterior to interior graded? Note surface materials, colors and window treatment.

5. Is there any direct glare from outside?

DIRECT GLARE

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SCALE A: | | AWFUL | | BAD | | SO-SO | | GOOD | | SUPERB | |

6. Is there any direct glare from light luminaires?

DIRECT GLARE

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SCALE A: | | AWFUL | | BAD | | SO-SO | | GOOD | | SUPERB | |

7. Is there any reflected glare off any surface?

REFLECTED GLARE

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SCALE A: | | AWFUL | | BAD | | SO-SO | | GOOD | | SUPERB | |

8. Identify and evaluate possible sources of veiling reflections. Note the sources and the orientation of surfaces on which there would be glare.

9. Evaluate overall visual comfort within the space. (make notes as well.)

OVERALL VISUAL COMFORT

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SCALE A: | | AWFUL | | BAD | | SO-SO | | GOOD | | SUPERB | |

---

**Room Two - Student Bedroom**

1. Is there task lighting for studying and reading?

2. Can it be controlled so that the lamp is not seen?

3. How would you rate the luminaire design and location?

LUMINAIRE DESIGN & LAYOUT

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SCALE A: | | AWFUL | | BAD | | SO-SO | | GOOD | | SUPERB | |

4. Is the luminance of the luminaire higher than the luminance of the surface being illuminated? (This is especially critical if they are both in the field of view when you are in the task position.)

5. At what angles does a glossy magazine have veiling reflections from the lamp?

6. What is the color of light? How do the color of surfaces in room change?

7. What is the illuminance at the task surface?

LIGHT LEVEL (AMOUNT OF LIGHT)

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| SCALE B: | | NONE | | LOW | | OKAY | | HIGH | | WAY TO MUCH | |

8. Evaluate overall comfort within the space.

OVERALL VISUAL COMFORT

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| SCALE A: | | AWFUL | | BAD | | SO-SO | | GOOD | | SUPERB | |

---

**Room Three - Classroom**

1. Is the room evenly and diffusely lit? Are there any shadows thrown by the lighting system?

2. Are the illuminances pretty even on all of the note taking surfaces?

LIGHT LEVEL (AMOUNT OF LIGHT)

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| SCALE B: | | NONE | | LOW | | OKAY | | HIGH | | WAY TOO MUCH | |

3. Is the blackboard strongly illuminated?

LIGHT LEVEL (AMOUNT OF LIGHT)

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| SCALE B: | | NONE | | LOW | | OKAY | | HIGH | | WAY TOO MUCH | |

4. What is the *luminance* of the blackboard compared to the wall around it? (This is considered a trick question by some. Be careful.)

LUMINANCE RATIO (CONTRAST)

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| SCALE B: | | NONE | | LOW | | OKAY | | HIGH | | WAY TOO MUCH | |

5. What are the luminances of the chalk compared to the board? (In some cases, this might be the luminances of the marker compared to the board.) If there are slides shown, what is the luminance of the slide compared to the surrounding background?

LUMINANCE RATIO (CONTRAST)

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| SCALE B: | | NONE | | LOW | | OKAY | | HIGH | | WAY TOO MUCH | |

6. Are there any windows or skylights in the room? Is there any diffusing glass on them? What is its luminance compared to the rest of the room?

LUMINANCE RATIO (CONTRAST)

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SCALE B: | | NONE | | LOW | | OKAY | | HIGH | | MAXED OUT | |

7. What are the surfaces, sills around the window? How are they colored and what are their material properties?

8. Is there any gradation (transition) in brightness between the window itself and the wall in which it is set, or from the wall to the interior surfaces of the space?

9. What is the position of blinds or curtains on the windows, if any? Try changing window blind and curtain position and note any change at task location.

OVERALL VISUAL COMFORT

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SCALE A: | | AWFUL | | BAD | | SO-SO | | GOOD | | SUPERB | |

---

**Room Four - Computer Room**

1. Is the room evenly and diffusely lit?

2. Is the light level (illuminance) sufficient on desktop for reading?

LIGHT LEVEL (AMOUNT OF LIGHT)

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SCALE B: | | NONE | | LOW | | OKAY | | HIGH | | WAY TOO MUCH | |

3. What is the luminance of the screen compared to the typing on screen?

LUMINANCE RATIO (CONTRAST)

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SCALE B: | | NONE | | LOW | | OKAY | | HIGH | | WAY TOO MUCH | |

4. What is the luminance of the screen compared to the rest of the room?

LUMINANCE RATIO (CONTRAST)

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SCALE B: | | NONE | | LOW | | OKAY | | HIGH | | WAY TOO MUCH | |

5. What is the position of the lighting luminaires?

LUMINAIRE DESIGN & LAYOUT

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SCALE A: | | AWFUL | | BAD | | SO-SO | | GOOD | | SUPERB | |

6. Sitting at any one workstation, are there luminaires within the field of view?

LUMINAIRE DESIGN & LAYOUT

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SCALE A: | | AWFUL | | BAD | | SO-SO | | GOOD | | SUPERB | |

7. Is there any discomfort caused due to the presence of luminaires.(too bright and too much glare)?

DIRECT GLARE

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SCALE A: | | AWFUL | | BAD | | SO-SO | | GOOD | | SUPERB | |

8. Now look at the screen, is there any discomfort? What is the source? What sort of discomfort glare is it?

9. Move the contrast button on the monitor back and forth. When is the discomfort greatest?

10. Moving your head sideways or up or down, at what position relative to the screen is there the least glare. What is the angle to the screen? What is the angle from screen to luminaire?

11. Does the room have any windows? If yes, what is the position, with respect to field of view at the same location?

12. What is the position of blinds and curtains on windows? Try changing window blind and curtain position and note any change on screens.

OVERALL VISUAL COMFORT

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SCALE A: | | AWFUL | | BAD | | SO-SO | | GOOD | | SUPERB | |

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**There are several cardinal rules which you might develop from your observations.**
**· Unless there are other high luminance surfaces surrounding it, the lamp or light source should never be in the direct field of view, or it should be aimed or shielded in such a way that it cannot be seen.**
**· It is always brighter than the surface which it is illuminating, which is usually the work plane.**
**· Diffusing glass which can be struck by direct sunlight should rarely be in the field of view, unless there is shielding, or there are surfaces of transitional luminances.**
**The evaluation of the environment consists of finding direct glare, and finding likely instances of reflected glare. Sketching or photographing these situations is an excellent way to document your analysis of a building. These are qualitative evaluations which coincide with quantitative predictors that we will learn to measure in the next exercises.**

# ASSIGNMENT THREE - INSTANTANEOUS ILLUMINANCE MEASUREMENTS

**OBJECTIVE**

To be able to make illuminance measurements. To learn to record the important observations and data. To learn about calculated and derived measurements, such as daylight factors.

**DISCUSSION**

Illuminance is light arriving at a surface and is a measure of how much light is available to perform a task. The most common illuminance measurements involve measuring light arriving at a horizontal work surface. It is easy to take data. It is unfortunately not easy to make certain that you have all the critical data, especially when measuring daylight, since the available light and weather conditions are also important. Being unfamiliar with the equipment and methods can cause problems. A lack of experience in recording trivial but critical events, conditions and setup may result in leaving out the most important piece. It is also possible to corrupt the data in the process of measuring it. The observer often blocks incoming light with their body, or the metering equipment itself. If you stand next to the metering device, you occupy a large portion of the field of view of the device.

This exercise deals not only with making instantaneous illuminance measurements but also with learning how to record and gather data. You will measure whatever light is available in the space, but you must measure the space during daylight hours, and turn off the internal lights. This allows you to learn about daylight factor and other calculated derivatives of the actual data. (Refer to Lesson 3, for details on measuring equipment, method and protocols to be followed.)

**EQUIPMENT**

You should use either hand held GE meters or similar meters to make these measurements, along with field data sheets to record data.

**METHOD**

Choose any two of the spaces you surveyed in your lighting tour, (Refer to Assignment 2). Fill in the top of the data record sheet to record your observations, beforehand. (Refer Figure 3.6 in Lesson Three for an example of a record data sheet.) At the beginning and end of each test measure the total sky illuminance, the diffuse sky component (with direct sun beam blocked.) Record illumination at 2 foot intervals measured perpendicular from the window. In a skylit space, measure across the room perpendicular to the primary axis of the skylight. Hold the meter 30 inches from the floor, with the sensor looking straight up. Be very careful to keep your body below the plane of the sensor. If you are looking down on the sensor, you are corrupting the reading. When you change scales on the meter make a reading on both scales without changing the location of the photo cell. Repeat the procedure for the second space.

Later, working with your data, first correct for any differences in your meter's scales by multiplying all lower readings by the difference ratio, if any. Next calculate the Daylight Factor (DF) by dividing footcandles (or the measured readings) at each point by the average of the diffuse sky readings. Note that the advantage of the daylight factor is that even if the outdoor illumination changes greatly, two different designs can be compared equally. Many design rules-of-thumb give daylight factors. If you try to associate your visual experience in the space with the numbers you are recording, this experimental data will translate directly back to your designs.

**EVALUATION**

1. Write a report which includes the method of testing and setting up the experiment, the time of day, observations about sky conditions, weather conditions, window location, surrounding obstacles, if any, and anything else which might later prove to be of importance. (When measuring "artificial" light, you must record the type or manufacturer and model of the light sources, since meters sometimes vary in their spectral sensitivity.)

2. Draw sections through your space (1/8" = 1'0") with the window to the left, and plot the actual measured illumination levels and corrected daylight factors. Repeat this for readings made in the second space.

3. Compare the graphs of the two spaces, and note the change in the daylight factors. Evaluate it in terms of difference in window orientation, size, sill height, window area, internal room reflectances, and internal shading devices such as blinds, etc. Attach your field data sheets.

4. Include your observations about:
whether light levels are lower than recommended levels,
their relation to sky condition, solar position, window area and location, and visual comfort within the space and speculations as to what could be done to improve the improve them if necessary.

5. Attach a data sheet with
   a. fc (both raw and corrected)
   b. DF (show calculations)

# ASSIGNMENT FOUR - LUMINANCE MEASUREMENTS

**OBJECTIVE**

To measure luminances and compare with illuminance measurements and to make simple glare measurements.

**DISCUSSION**

Defined simply, illuminance is light arriving at a surface and luminance is light leaving a surface. Illuminance measurements provide information about light levels and their adequacy for performing tasks. However luminance measurements provide information about contrasts, brightness, reflectance and glare within a space. In this exercise you will learn how to make luminance measurements and compare them to the illuminance measurements.

**EQUIPMENT**

GE meter, Minolta meter and sketch paper to draw views and sketches of the space.

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**METHOD**

Choose any one of the spaces in which you made instantaneous illuminance measurements. Identify any five surfaces within view from a typical task location in that space and measure the illuminance (using GE meter or similar) arriving at those surfaces. Measure the reflected illuminance on a theoretical surface a small distance from each of the surfaces. The reflectance of the surface is theoretically the ratio of the two illuminances. Then return to the reference point and measure the luminance of the surface as seen from that point. Again, the reflectance should be the ratio of the luminance to the illuminance of the surface. Then also measure the luminance of the glaring source and background luminance to determine glare within the space. For detailed procedures refer lesson 3, (3.2.2).

1. To determine illuminance, using a light meter, hold the meter's light cell parallel to the plane of the surface you are interested in measuring. Usually this means placing the base of sensor flat on the surface to be measured. Remember, do not bring bright objects close to the meter or do not cast shadows on it.

2. Measure the illuminance of a theoretical surface in front of the surface. Hold the light meter's cell close to the surface of interest and then draw it back 2 to 4 inches until the reading remains a constant. Aim the sensor at the surface you just measured. Ideally, the meter should be seeing nothing but the reflecting surface, and yet be far enough away so as not to shade the surface. The luminance is equal to the meter reading in foot-candles. Try to shade the surface as little as possible with your body.

3. Calculate the reflectance of the surface. The ratio of the second illuminance to the first illuminance is the reflectance of the surface. Calculate the reflectance of the surface as a percentage. (Note that this is approximate, since the meter itself is blocking some light, you are blocking some light, and the meter sees more than just the reflecting surface.)

4. Now, turn off the lights, or let down the blinds, to make the room comparatively darker than the previous set up. Repeat the entire procedure. Note that you might have to change the ranges on your light meter. Recalculate the reflectances. They should be approximately the same. Average the two reflectances calculated for each surface.

5. Now turn the lights back on, or raise the blinds again. Using a Minolta meter, measure the luminances of the surfaces. Point the Luminance meter towards the surface whose luminance you want to measure, to make sure that it is in the field of view. Note the reading on the LCD display, and the range of the reading.

6. Compare these values with those originally measured with the illuminance meter. How do these readings compare? Calculate the reflectance of each surface based on the ratio of the luminance divided by the illuminance. Compare these calculated reflectances with the reflectances calculated in step 4. If they are pretty close, you have made accurate measurements and your spot meter is pretty accurate! In fact, if they are within 10% of each other, you are doing well.

7. Now with the luminance meter measure the luminance of the glaring source of light. Also the background or environmental luminance needs to be measured. Try to average it out by measuring luminances across the space, or if a meter with a wider acceptance angle is available, this averaging is not necessary. Measure the luminances of surfaces near the source of glare. For example the wall near the window, or wall surrounding the blackboard in the classroom.

**EVALUATION**

1. The measured values of illuminance, luminance and reflectance for all the surfaces identified within the room for each situation (lights on and lights off.)

2. Rank the five surfaces in terms of highest to lowest brightness for each background condition. Remember brightness is the perceived luminance of the space. It is your subjective response.

3. What was the effect of the change in lighting on the illuminance, luminance and reflectances of the surfaces.

4. Your observations about

Ratio of luminance of glare source and background.

Comparison of the luminance of the source, surround and background for each view considered. Also sketch this view and show contrast grading. Did you feel that the level of contrast was uncomfortable in either case?

5. Would you go so far as to say there is glare in the space? If so, describe the cause.

# ASSIGNMENT FIVE - MODEL TESTING

**OBJECTIVE**

To design and build a scale model of an interior space which will be tested outdoors with a light meter. The criterion is to compare various design strategies to bring as much comfortable daylight indoors and to achieve comfortable lighting within the space.

**DISCUSSION**

The goals of designing good comfortable visual environments apply as directly to daylit spaces as to artificially lit spaces.

First: The absolute levels of illumination sufficient for seeing tasks should be provided as deeply as possible into the interior.

Second: Brightness ratios in the visual field should be kept within comfort limits just as with artificial lights (i.e., 1:3, 1:10, 1:20, 1:40 depending on location in the visual field). Because sky brightness is usually part of the visual environment of the occupants, the control of surface reflectances is even more critical than in artificially lit spaces. Patches of direct sunlight reaching a work-surface would be devastating. (See the IES recommended levels, and previous lessons.)[1]

Third: Location of fenestration in the visual field in daylit spaces has a profound impact, because the source can be very bright, and may have moved from the ceiling to one wall and its brightness level is many times higher. This means also that dynamic reflections are very difficult to anticipate and eliminate.

Fourth: Apparent size or visual angle of the source of daylight is much bigger than anything normally encountered in artificially lit spaces, however, its visual content (image) is far more interesting, which can be turned to the designer's advantage.

**EQUIPMENT**

The model you build should be fairly robust. If you try different alternatives, then it will be modified several times. It should be designed so that the exposed facade can be easily removed and modified. The scale should be 1/2"= 1'-0" or 1" = 1'-0". The material must be opaque, easily cut, and rigid (foam board must be covered with opaque black paper or aluminum foil). You will also need to bring along to class other materials like tape, glue, sheets of colored paper and possibly vellum, aluminum foil, and tinted acetates. Design exterior sun controls to be removable. Cut an access port large enough for your sensor, from which you can move the sensor around. It should also accommodate your camera lens. You may choose to cut several viewports, but do so carefully.

1. IESNA, *Handbook of Lighting Fundamentals*, 1994, IESNA, New York

Bring a model-testing sundial for your latitude if you have one, or photocopy one from *Simulating Daylight with Architectural Models*.[2] You may wish to record the actual process, photographing a view as seen through the "double doors", and also a photo of your facade with the sundial showing time and orientation.

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**METHOD**

Choose any one of the spaces you measured in the exercise on Instantaneous Illuminance Measurements (Assignment Three). Build a model of the space. Based on your observations from that exercise, propose an alternative design scheme for the space which you feel would be more successful in achieving a comfortable lighting environment within the space. First build the model to match the space, and adjust it until readings from the model match readings from the space. (Use DF if the weather is different from your original observations.) Keep the modifications and alterations to your model ready before starting to measure so that you can test both options successively.

Fill in the top of the data record sheet beforehand. At the beginning and end of each test, measure sky total, sky diffuse (with sun beam blocked) and so forth, exactly as you did for the Illuminance Measurements exercise. Record illumination every inch from the window. When you change scales on the meter make a reading on both scales without changing the location of the photo cell.

Later, working with your data, first correct for any differences in your meter's scales by multiplying all lower readings by the difference ratio, if any. Next calculate the Daylight Factor (DF) by dividing footcandles at each point by the average of the diffuse sky readings. Note that the advantage of the daylight factor is that even if the outdoor illumination changes greatly, two different designs can be compared equally.

Glare evaluation of your design can also be done, if there is time, using the luminance meter. Before beginning to measure, make a one-point perspective line drawing sketch of the interior space from the viewports. After you have made the illumination readings (above), use the spot meter to read the luminance of a dozen of the brighter and darker surfaces or area.

**EVALUATION**

1. Write a report which includes the scale of the model, drawings of the space showing your design alternatives, observations about sky conditions, weather conditions, window location and points at which measurements were taken.

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2. Schiler, et al; *Simulating Daylight with Architectural Models*, DNNA/USC, Los Angeles CA.

2. Draw sections through your building (1/8" = 1'0") and plot the actual measured illumination levels, corrected daylight factor, just as you did with the real building.

3. Compare the graphs of your two design options, in terms of available daylight factors using different colors or symbols. You also might want to indicate on the section drawing how the two facades or design schemes differed. Attach your field data sheet.

4. On your one-point perspective sketch, show brightness, the highest contrast ratio, plus your notes and observations about visual comfort in both spaces, and which you feel is more suitable and why.

5. Examine which option would you prefer for the space and explain why, both qualitatively and quantitatively.

# ASSIGNMENT SIX - MEASURING ILLUMINANCE OVER TIME

**OBJECTIVE**

To collect data over time. The general criterion is to evaluate and compare the lighting environment in spaces with different design features. Collecting data over time allows analysis under a variety of conditions which the space will experience.

**DISCUSSION**

It is necessary to measure data over an extended period of time, if any useful information in terms of lighting levels, energy considerations and occupant interaction is to be obtained. It is particularly useful if you wish to make predictions over a period of time, e.g. seasonal energy usage. Make any necessary observations about lighting controls, window blind positions etc. over the course of these measurements. This may be done with or without electric lights.

**EQUIPMENT**

Hobo recording sensors along with the accompanying BoxCar software, access to a PC or Mac where the BoxCar software can be installed, and tape to fix the Hobo's at their locations. It must be noted that the Hobo's are not very sensitive to shorter wavelengths, and there will be some inaccuracy, notably an underestimation of the luminance contributed by fluorescent sources. As a note, the alternative setup consists of a set of Licor sensors and a Licor or Campbell datalogger, or similar. These are more accurate, but much more difficult to program. The design of the experiment is the same.

**METHOD**

1. Draw a rough sketch of the place you wish to investigate. Decide the positions within the room where you want to place your Hobos. Remember, however, that you need to place one Hobo outside to measure the exterior illuminance. Hence depending on the number of Hobos available, decide on the positions within the space.

2. Launching the Hobo: To use the Hobos you have to install the BoxCar software available with the sensors onto your computer. The package comes along with a cable, whose one end is connected to your computer serial port and the other end to each individual Hobo successively. Once you have connected the cable, choose the Launch option from under the Hobo menu.

(You might have some trouble here about your computer not recognizing the port correctly. The software will prompt you to choose your port again.)

3. Setting duration and Interval: Hobos are capable of taking up to 1800 measurements. When you launch a Hobo you will be given a choice to enter the duration of your test. In our case it is going to be for a week. The Hobo will automatically set the sensing interval for this duration, with the total number of readings amounting to 1800.

Repeat this launching procedure for each Hobo.

Once each Hobo is launched, a flashing red light appears on the Hobo. This means that it is recording data.

4. The BoxCar software also gives you an option for a delayed start for some types of Hobo's. Once you enter the date and time you want to start making measurements, it will start measuring from that instant onwards. This is useful if there is no portable computer to take with you to the site of measurement.

5. Place these Hobos in the predetermined positions. Place one outside for measuring exterior illuminance. Remember to note the Hobo numbers for each position. The outside Hobo should be placed in a position where there is little obstruction of the sky, for example, on the roof parapet of the building being measured. If you really want to do accurate DF measurements, it is necessary to make a sunshading strip which blocks the sun's path and nothing else, for the dates being measured. For the purposes of this experiment, you may skip that.

Note: While carrying the Hobos to the place of measurement, make sure to keep them away from direct sunlight, as this will affect the scale of the output at a later stage.

6. Retrieving data: After the test is completed, connect each Hobo back to the computer and choose the readout option under the Hobo menu. The software gives you options as to how you want to read the data. For now the intensity or L/sf would be suitable. It also allows you to export your data to other formats like Microsoft Excel etc., which can be used to plot graphs, charts etc.

**ASSIGNMENT**

Pick any one of the following behaviors you wish to investigate. (Please note that these are just examples. You may wish to test your own hypothesis).

1. The effect of light shelves on the light levels within a space. Choose one space with a light shelf and compare it to another space without a light shelf. However, try to keep the window orientation and location similar to make it possible to draw conclusions.

2. The effect of vegetation on light levels within a space. Choose a space which is shaded by a tree or vegetation and one which has no such obstruction.

3. The effect of an atrium or an open court on a space adjacent to it. Pick a space adjacent to an atrium and a similar space which is entirely embedded. The perfect comparison (but hard to find) is a space which is adjacent to an outside wall on one side, and then a similar space which is adjacent to an outside wall on one side and an atrium wall on the other.

**EVALUATION**

1. A report including method of testing and setting up the experiment, time of day, observations about the environment, room occupants etc.

2. Sections of your spaces at three different points in time, with absolute illuminance values at each point. If the there is a version of the space with the lights off, then calculate the DF based on the ratio of the interior illuminance to the exterior illuminance at each given moment in time. Note that this is more universally comparable than a plot of the absolute values would be, although both are important pieces of information.

3. Sections of the spaces showing positions where lighting levels within the space fall below IES recommended levels[1] along with the time and date.

4 The graphs obtained from the BoxCar software showing the change in available illumination over the one week period.

5. Your observations about

When light levels are lower than recommended levels and their relation to sky condition, solar position and location.

When light levels within the space seem to be excessive, and if there is any relation with solar location.

Discussion of method, and behavior of light within the space over time.

Conclusions as to whether or not your hypothesis is supported by the data.

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**Obviously, planning becomes most important when doing extended measurements, since a great deal of time can be wasted. Furthermore, we tend to measure critical periods such as the two weeks around the winter solstice. Since this comes only once a year, it is worth doing a dry run as described in this exercise.**

1. IESNA, Lighting Handbook, IESNA, New York, 1994. p 460-475.

# ASSIGNMENT SEVEN - GLARE EVALUATION

**OBJECTIVE**

To measure and evaluate glare and visual comfort within interior spaces, in terms of sufficient light for efficient visual performance and a comfortable and pleasing environment. This exercise also introduces the method of video photometry and advanced video capturing and data processing.

**DISCUSSION**

Glare is a subjective phenomenon and is an expression of a form of visual sensation. This sensation cannot be measured. However the physical factors which determine this sensation can be measured. This is not the same thing as measuring the sensation itself, however with the aid of a statistically significant relation between the objective measurement of physical factors and the subjective estimates of the magnitude of the corresponding sensation, a method of evaluation of glare can be followed. This exercise is about the measurement of the physical factors, which should be reinforced with your subjective evaluations of the space (from Assignment Four) to determine comfort within the space.

**EQUIPMENT**

Video camera, digitizer board or "Snappy" digitizer, Photoshop or translator program, Excel or similar spreadsheet. Use a Minolta luminance meter in lieu of a known luminance box (or build a box, if you have the time.)

**METHOD**

1. You can continue studying one of the spaces you measured in Assignment Four. Sit at a typical task location, and look at the task surface. Now look around the space, and find a view with glare in it. This is again subjective, and some will find very glary views, and others will find that the space is well designed, and there is little or no glare. Set up the experiment to simulate a typical task location.

2. We will take a single exposure of the view, and digitize this information, but the procedure can be extrapolated for measurement over time. The protocols and method of recording, capturing and processing data remain the same except that here we would have one single image to analyze, and while conducting the experiment over time you would have many more images.

3. Record, capture and digitize the image. Please refer to Lesson Seven for protocols.

4. From the data obtained, find out the absolute luminance of the glare source, the background or environmental luminance as well

as the luminance of the surround to the glare source for example, the wall near the window. Refer Lesson Seven.

5. Prepare a matrix of observations showing intensity of source, background, percentage of view occupied by the source and background, as well as the contrast between the high intensity and background and any other interesting relationships you can think of.

**EVALUATIONS**

1. A Matrix of observations.

2. A report of the subjective evaluation. This will include the sketch of the view as well as the rendering of the brightnesses as seen by you.

3. A report explaining visual comfort in each situation carefully, in terms of measured luminances and contrast ratios between source and background levels, angle of view, distance from source (solid angle), contrast grading around probable glare source, illumination levels at task etc. This will be based on your measured as well as subjective conclusions. Also explain why you thought that discomfort was felt or could be experienced. (For example, high contrasts within field of view, low background luminance, time of the day, position of sun, materials used etc.)

# ASSIGNMENT EIGHT - DATA PRESENTATION

**OBJECTIVE**

Presentation of complex data in several different formats.

**DISCUSSION**

Producing data is of surprisingly little value. It is necessary to organize data, and to present it, in order to understand it and convey this understanding to others. What variables should be plotted against what, and what format should they be in? In order to understand the strength of different presentation formats it is useful to look at data in several different formats.

**EQUIPMENT**

Access to a computer (either a PC or a MAC), with some statistical software like Quattropro, Excel etc. Also software like DAYLIT, SUPERLITE, or Lumen Micro are optional. If available it would be a good idea to look them through.

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**METHOD**

**State a hypothesis:** What is the idea that you are testing? For example, you expect the distribution to be more even if there is a light shelf, or you expect the light levels at the rear of the space to be higher. These both can be proven or disproven with rather simple plots.

**Choose a base case:** It is usually useful to state which condition is the base case. For example, in the hypotheses above, the base case would be a room without a light shelf. The secondary cases are cases with light shelves. To be certain that the hypothesis is proven true, or disproven, you might have to try several different variations. Finding one case which matches the hypothesis and other cases which don't leaves you with a modified hypothesis, namely, "light shelves *may* improve the distribution (or absolute level) of light within a space." Finding the hypothesis to be wrong in all cases is just as valuable as finding it to be right in all cases. It is the middle ground which gets messy, and requires a lot more study. If some cases are improved, and some are worse, then you must determine the behavior of all of the variables.

You have manually drawn a cross section in an earlier exercise. This time the idea is to use the data stream output from the BOXCAR or similar software, or from a datalogger, as input for a data processing software, such as the common spreadsheets EXCEL or Quattropro.

**Load the data file into the spreadsheet:** You will note that there are several possibilities for loading the data. The files are typically positional. This means that the data is in the order in which it was recorded. Often there are positional records, as well. For example, position one is recorded as position one. You may delete this column, since it will plot as an extraneous and linearly increasing variable. (Position 1 has a value of 1, position 2 has a value of 2 ...)

The simplest plots are the bar chart plots and the line graphs. With the data from a single point, the line graph is the clearest. (Hobo data comes in four columns; highlight only the illuminance column when making the plot.) With the data from a second point, it is possible to compare the readings over time for two different points. You may add a third, fourth and fifth point. Most programs (Excel, for example) allow you to open two or three files at once. It is fairly straightforward to copy one column from one file an paste it into a new file, which will collate and present the new graph, when all the columns have been pasted in. It is much easier, however, to use the same chronological starting point *when cutting the data from the source files* (i.e. prior to pasting it into the new file) since matching dates is quite annoying if the columns have different start points.

However, something becomes apparent. You are able to compare different points over time, but that is not what you want. You wish to see different points in the room at the same point in time. This requires an exchange between row and column information. This can be done be retyping, for a small number of values, but for automated files, such as a Hobo file ( which may contain up to 1088 values) this is prohibitive. In some instances the program will allow a reversal such that all the rows become columns and all the columns become rows.

Finally, if you placed a three dimensional grid in the room, such as that which provides an isolux plot, you would want to show a three dimensional plot. The x and y values of the plot would be the position of the points in the plane of the floor, and the z value would be the daylight factor or the absolute illuminance. These are difficult, but possible in most spreadsheets, although typically they are shown as a three dimensional collection of bar charts. It is also possible to do successive cross sectional graphs, if the x dimension corresponds to the cross sectional measurement and the y direction corresponds to the position parallel to the window.

There are more complex plots, which plot a point over a period of time. These must be generated by specialized software, such as DAYLIT (Milne, et al, UCLA) or LIGHTSCAPES (Haglund and Sumption, U of Idaho.)

**EVALUATION**

1. Create a simple plot of a single point over a period of time. Show the values in at least two versions such as line plot and bar chart. Experiment with legends, axis labels and a title for the entire plot. Learn the variations in the labeling on these, the simplest cases. In some programs, you can display a range of samples for a single point, if you took more than one, and they were different. (Some will display the average value, and the range of values, for example.)

2. Create a plot of three different points over a period of time. Input the data for the point nearest the window first, then the middle point, and then the point furthest from the window. Then do the same for the next point in time. Show the data as bar charts and then as plots. Notice that the bar charts allow an interpretation as if we were standing at the window and looking at cross sections, from the end of each cross section.

3. Manipulate the data to show a three dimensional grid of points at a specific moment in time. This requires bar charts in most spreadsheets, but some will allow other three dimensional plots.

4. (Optional) Use DAYLIT to model your space. Plot a series of cross sections through the space at different times. First plot noon for each month. Then plot all daylit hours for a single day, such as December 21.

5. (Optional) Plot a three dimensional graph of the illuminance from daylight at the midpoint of the space over an entire year. Plot the illuminance from electric lighting sources for the same point. Notice that the one plot is the negative of the other, but clipped off at the ends. Why is that?

6. (Really optional) Write a piece of software in Visual Basic or Visual C++ which plots the data from Hobo's or a datalogger in the three dimensional form that DAYLIT plots the calculated data.

# ASSIGNMENT NINE - CONTROLS

**OBJECTIVE**

To be able to correlate position and manipulation of lighting controls to illuminance levels and occupant behavior within the space.

**DISCUSSION**

The goal of this exercise is to combine an understanding of the concepts of lighting controls, illuminance levels and occupant interaction. You will be measuring and recording:

1. The illuminance levels within a space.
2. Position and manipulation of lighting controls.
3. Occupant interaction with controls as well as artificial light.

**EQUIPMENT**

A JVC camera or any other camera recorder with time exposure capability along with the Snappy Digitizer, light intensity Hobos as well as temperature Hobos along with their accompanying Boxcar software. Please refer to Assignment 6 and 7 for further details on equipment and accessories.

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**METHOD**

1. Choose a space which has some form of operable lighting controls, for example, venetian blinds or rolling shades. Draw a sketch of the room and decide on Hobo positions as well as camera position.

2. Set up the camera within the space, so that it can record window position, occupant location and movement, and window blind position and manipulation. Try to place the camera in an unobtrusive place within the room, either hanging from the ceiling, or fixed to the wall, so that it does not affect the normal behavior within the space. You will have to set the time recording facility on the camera to make it record at the same time as the Hobo's, for example every one hour. Refer Exercise 7 for detailed information on video setup, recording and downloading using Snappy.

3. Set up the temperature Hobos, attached to the upper or in the side surface of the light fixtures within the room. You will need to make a decision here as to how many light fixtures there are within the room and where you want to place the temperature Hobo. You can place one above each fixture (if each fixture is operated separately and you have a number of Hobo's), or else place one Hobo on each representative row of fixtures, for example one for each row away from the window. Using a temperature Hobo is a proxy for

connecting an ammeter into the electrical circuit of that fixture to govern when the lights are turned on and off. You can use the temperature Hobo's as you are already familiar with launching and downloading data from them. They serve as good indicators of when the lights were turned on and off within the space by noting the jump and drop in temperatures recorded.

4. Record at least two days worth of data so that you have a recording of the diurnal change in illuminance levels within the space. Another important consideration is to synchronize the data from the various Hobos. If you have a Hobo with the delayed start option, this is not an issue, but if such an option is not available, you will need to fake a start point, so that both the Hobos are correlated. This can be done by turning the lights off in the space, for some time just after launching. When the lights are turned on the various Hobos can be synchronized by lining up the data to the point where the jump in light levels is seen in the data.

**EVALUATION**

1. A report including a statement of exactly what you are examining, method of testing and setting up the experiment, drawings of the space showing location of the light Hobo's as well as fixture location and temperature Hobo positions.

2. Sections, 3-d plots and graphs of the space showing illuminance levels over time within the space, illuminance levels at one point etc. Correlate these to the data obtained from the temperature Hobo's to determine whether the light is natural or electrical in source.

3. Try to graph the relation between illuminance levels within the space (data from Light Hobo's) and the manipulation of artificial lights as well as controls within the room.

4. Your observations about

When were light controls manipulated, and their relation to solar position and location. Use the captured video images for this analysis.

What were the light levels within the space, and their variation with any manipulation in the lighting controls.

When and where were the lights turned on in the space.

Discussion about method, behavior of light, performance of lighting controls and occupant interaction with the controls as well as artificial light over the period. Also discuss whether the blinds were being used effectively by the user within the space. Prepare a comprehensive report of the same.

# ASSIGNMENT TEN - DEVELOPING AND CONDUCTING AN OCCUPANT SURVEY

**OBJECTIVE**

To conduct an occupant survey to evaluate the quality of the visual environment and occupant satisfaction within the space.

**DISCUSSION**

The primary purpose of an occupant survey is to analyze and understand how to design optimum environments by evaluating existing conditions in buildings. In Assignment Six you measured light levels in spaces over time. However you have no record of whether the occupants within the space were comfortable with their lighting environment. This information is necessary to be able to extrapolate useful information from the data, and make recommendations about lighting levels and occupant comfort within the space.

By now you have developed a reasonable understanding of which issues are critical to visual comfort within a space. Prepare a survey to evaluate the quality of the lighting environment in the space which you chose to measure from assignment six.

**EQUIPMENT**

You do not need any equipment. Keep copies of your blank survey form along with pencils to hand out to survey participants.

**METHOD**

1. State the hypothesis you wish to test.

2. List all the criteria you want the occupant to rate.

3. It is preferable to keep the scaling constant in any one survey. Develop a rating scale for your questions.

4. Develop the survey questions in terms of light adequacy, reasons for discomfort within the space, manipulation of lighting controls and overall comfort within the space. Refer the generic questionnaire presented as an appendix in "Environmental quality in offices" by Jacqueline C. Vischer, Pg. 230.

First draft the survey. Then go and survey 10 occupants in the buildings you had measured earlier in Assignment Six.

**EVALUATION**

1. One blank survey form.

2. Analysis of survey results: This could be in the form of graphs, charts etc., identifying problem areas, complaints and comfort requirements within the space.

VITAL SIGNS

3

# APPENDICES

# APPENDIX A - ANSWERS TO REVIEW QUESTIONS

**Lesson One**

1.1 The eye can detect wavelengths from around 475 nanometers (nm) through 725 nm.

1.2 The cones in the eye sense colors. They are found on the retina.

1.3 The lens is the focusing device of the eye. The iris is the exposure adjustment device of the eye.

1.4 Large amounts of light (high illuminance levels) do not invariably cause glare. Small amounts of light sometimes do cause glare. It depends on what the eye has adapted to. A flashlight can cause glare on a dark night, but it is difficult to note whether or not it is turned on a sunny day.

**Lesson Two**

2.1 A material must be transparent in order to produce refraction, since the light must pass through it in order to be refracted. Note that mirrors can focus light as well as lenses, but they do so by reflection, not by refraction.

2.2 Diffuse light is much less likely to produce glare and veiling reflections, because it comes from all directions, and more or less creates the background adaptation level.

2.3 Color temperature describes the color shift of the light, towards blue or towards red. Color rendering index describes the accuracy of different subsets of the spectrum.

2.4 The steradian is the unit of measure for a solid angle.

2.5 The lux (SI) or the footcandle (SAE) is the unit of measure of illuminance. The candela/$m^2$ or candela /$ft^2$ is the unit of measure of luminance. Illuminance is the measure of light arriving at a surface, luminance is the measure of light leaving the surface.

**Lesson Three**

3.1 Color corrected sensors match the visual sensitivity of the human eye in the photopic range.

3.2 Daylight factor is a useful calculation because it measures the fraction or percentage of the light available on an exterior horizontal which will arrive at an interior workplane. This is useful because the DF doesn't change very much for a given geometry, which gives us a single number to associate with the room being examined. It is especially useful in cloudy climates, where it gives a reasonably accurate measure of the illuminance for most of the time.

3.3 It is necessary to normalize (or cross calibrate) sensors if you are using more than one, because sensors drift out of adjustment in different directions and at different rates. In fact, most sensors are not exactly accurate even when new.

3.4 You may calibrate manually using the formula:

$C_x = E_{ave} / E_x$

where:

$C_x$ is the multiplier for the reading from the current sensor

$E_{ave}$ is the average of all the sensor readings

$E_x$ is the reading from the current sensor

This calibration is not perfect, but is very useful, nonetheless. Nonlinear behavior causes further complications, but there is no simple manual way to account for that, nor is the nonlinearity function commonly available. It also varies from meter to meter.

**Lesson Four**

4.1 Illuminance is the light arriving at a surface. Luminance is the light leaving a surface. We actually see luminance, not illuminance. Aiming a device at a workspace is measuring the luminances within the workspace. Placing a device within the workspace could measure luminance, but is more likely to be measuring the illuminance arriving on the surface on which the device has been placed.

4.2 Reflections do not always cause glare. In fact, you are probably reading these words from the light reflected from this paper. If you are reading a display screen, the reflection is more likely to be annoying.

4.3 Adaptation establishes the size of the iris opening and the amount of light admitted to the eye. Glare occurs when there is too much light admitted and sensors are overloaded. The Glare Index includes a factor in the denominator, the general level of adaptation ($B_b$), which accounts for that factor. The formula for the discomfort rating is given by

$$G = \frac{f(B_s)f(Q)}{f(B_b)f(B_i)f(\theta)}$$

Where:

($B_s$) is the luminance of the light source

(Q) is the size of the light source

($B_b$) is the general level of adaptation

($\theta$) is the position of the sources and field of view

($B_i$) is the luminance of the surrounds to the source

**Lesson Five**

5.1 There is usually no difference between a model of the space and the space itself because light behaves uniformly in the scale of the model and the scale of the real building. Both scales are large compared to typical visible wavelengths.

5.2 When photographing a model, it is important to include the simulated date and time on something which is visible inside the model because it is too easy to mix up photographs and slides, losing complete track of which one simulated which time and event. If the information is within the slide itself, it is always possible to sort the data again.

5.3 One inch to one foot (or 10:1 metric) is an effective minimum size for photographing interiors. This allows for fairly detailed surface and furniture treatments which makes a huge difference in the perception of the space.

5.4 The biggest problem with an oversized sensor in inside a model is that it disturbs the light level by changing the average reflectances. A second problem comes from trying to measure illuminance at the work plane when the sensor is larger than 30 inches in scale. It becomes necessary to punch holes in the floor in order to drop the sensing surface down to the scaled workplane height.

**Lesson Six**

6.1 A resistor bridge converts amps to volts. It is a resistor of known value placed within a circuit, with the voltage being read on both sides of the resistor.

6.2 The minimum interval between samples in extended sampling depends on the number of data points which can be stored and the length of time over which the behavior should be recorded. Interval is length divided by number of observations which can be stored.

**Lesson Seven**

7.1 A handheld meter can be carefully calibrated and gives single number answers rapidly and easily; video based systems are more difficult to calibrate and require longer processing times but yield much more data.

7.2 A known luminance in a video image vastly simplifies the processing, and provides a permanent record of a base value in each image.

**Lesson Eight**

8.1 An isolux plot is a contour plot showing illuminance levels, or lines of constant lux value. It is created by interpolating for integral values between grid points, in order to find where the isolux line would cross the grid line. Then all the crossing points of a particular value are connected to one another forming the isolux line. Some guessing of curves is done to avoid discontinuities, which are quite rare in real experience.

8.2 A control case is a version of the room to be sampled in which there are no alterations and in which the pattern of behavior is the same as the room to be sampled. A base case is the version against which other variants are going to be compared. They are usually the same.

8.3 A thesis is a complete discussion composed of hypothesis, antithesis, testing, and synthesis. Perhaps the most important aspect is the idea that the experiment is designed to test something specific, and thus we make certain that we test the values of that variable or variables and minimize the variations in the values we are not testing. Such a discussion might begin with the hypothesis when natural illuminance is sufficient, the occupants will turn off the lights. (The antithesis is that they would not turn the lights off when there is sufficient natural illuminance. The fact that they turn them off for some other reason does not disprove the hypothesis.) The test is to monitor illluminance levels from natural light (which may require some careful thought if artificial light is mixed into the environment) and to check what happens when the recommended values are exceeded. The conclusions will have to sort out the observations and make careful sense of them.

**Lesson Nine**

9.1 Solar gain on East, West or North exposures is best controlled by using the difference between summer and winter azimuth angles, whereas South exposures are best controlled using differences in altitude angles. Use of vertical controls relate to azimuth angles.

9.2 If you shut off the lights when there is only 1.5 times the design level present, then there will be only .5 times the design level after the lights are off, which is not sufficient. (The correct solution is to shut half of the lights off, or to design lighting systems which allow that.)

9.3 Occupancy sensors may be infrared or ultrasonic, and may be wall mounted, scanning the room horizontally, or ceiling mounted, scanning the room vertically. Wall mounted sensors can be blocked by partitions, ceiling mounted sensors can miss movement in corners.

9.4 The benefit of a stepped photosensing system relates to question #2 and to the fact that when it is completely shut off, there is no residual power usage. The primary liability is that it cannot exactly match the variations in natural lighting very efficiently, and the occupants usually notice each step change in the overall level.

**Lesson Ten**

10.1 Post occupancy surveys are important because there is often a phenomenon which can be rectified with simple changes, if it is known. This is true both in the existing building, and in the next buildings which the designer will design.

10.2 Test cell surveys are important because there are some questions which can be answered only under controlled circumstances, so that external variables can be more nearly eliminated or held constant, while precise measurements are taken of the interaction of the variables being studied.

10.3 Surveys sample the experience of a moment and the overall experiences in a spatial environment. In fact, some of the problems with making sense out of a survey is sorting out which experience the user is commenting on during the survey, since occupants do not usually divorce the two unless they are careful.

# APPENDIX B - ANNOTATED BIBLIOGRAPHY

### BOOKS

MCGUINESS, WILLIAM J., STEIN, BENJAMIN, REYNOLDS, JOHN S., MECHANICAL AND ELECTRICAL EQUIPMENT FOR BUILDINGS, JOHN WILEY AND SONS, 8TH EDITION, 1992

A useful reference text for lighting fundamentals, especially Chapter 18, Page 911. The latter half of the section on Illumination deals with lighting design and lighting applications. The first two chapters on Lighting fundamentals and Light sources and their characteristics are particularly useful for understanding the fundamentals of the lighting environment. This is one of the few books which deal with illuminance, luminance, reflectance and intensity measurements and how to make them. It also embarks on a discussion on the subject of lighting quality and quantity, glare and glare control, which is trenchant as well as informative.

DNNA/SCHILER, MARC E., SIMULATING DAYLIGHT WITH ARCHITECTURAL MODELS, DNNA.

This is an excellent guide on how to use physical models to develop and study daylighting in buildings. The text is well supported with photographs, illustrations and appendices. The information is organized in a progressive manner with very few assumptions made about the reader. It is an extremely useful guide to have if you are intending to use physical models to study light in buildings.

SCHILER, MARC E., SIMPLIFIED DESIGN OF BUILDING LIGHTING, JOHN WILEY & SONS, INC., 1992

A compact and very useful text to understand the behavior of light, light availability, calculation methods and the actual process of lighting design written with a practical and concise approach. Both natural and electrical lighting issues are covered along with IES recommended methods and definitions. The book is light to read and covers all terms and conventions commonly heard of in the profession.

EGAN, DAVID M., CONCEPTS IN ARCHITECTURAL LIGHTING, MCGRAW-HILL BOOK COMPANY, 1983

A valuable collection of the principles of vision and the behavior of light in the built environment in a graphical format. The illustrations are particularly useful, they are not as supplements to the text but rather as a core to the coverage of the principles of vision, natural and electric light sources as well as lighting measurements and controls. This is a handy book to have as it also contains an illustrated glossary of lighting terms and definitions. The technical definitions are slightly out of date.

ROBBINS, CLAUDE L., DAYLIGHTING DESIGN AND ANALYSIS, VAN NOSTRAND REINHOLD COMPANY, NEW YORK, 1986

Although essentially a book on design and analysis of daylighting systems, it offers a useful discussion on vision and perception as well as analysis techniques necessary to determine lighting, visual comfort and energy performance characteristics in daylighting systems. Chapter 11 offers a condensed view of the process of employing physical scale modeling and chapter 14 talks of daylighting and electric lighting integration which includes a discussion of electrical control systems.

IES, LIGHTING HANDBOOK REFERENCE AND APPLICATION, 8TH EDITION, IESNA, NEW YORK, 1993

The Illuminating Engineering Society is the recognized authority in the field of illumination engineering. This handbook provides careful definitions and standards employed in the field of lighting design. To be used as a reference for standards and codes as well as for forms for recording measurements, lighting calculations, light sources and energy management etc.

VISCHER, JACQUELINE C., ENVIRONMENTAL QUALITY IN OFFICES, VAN NOSTRAND REINHOLD, NEW YORK, 1989

A compact and very useful guide to understanding the process of a complex building-in-use assessment. Although this deals with all aspects of a building diagnosis, the book is good reading to understand the actual process of building performance measurement and environmental psychology and to recommend courses of action to remedy assessed weaknesses. Rating questions and concerns for a lighting system evaluation are directly useful and applicable.

**PAPERS**

BENTON, CHARLES C., DIMINUTIVE DESIGN, LIGHTING DESIGN + APPLICATION, MAY 1990, PG. 4

This is a good article written on the use of physical models for daylighting analysis, and demonstrates the power of these models in accurately modeling the daylighting distribution within a space. It defines techniques for accurate modeling as well as a brief description of 10 projects in which daylighting models played an important role during the design stage. Models were used in these buildings to predict quantities of daylight in interior spaces as well as to assess the qualitative aspects of daylight distribution. The usefulness of this article is further strengthened if these projects could be used as examples of well lit daylit buildings and field measurements conducted in each of these buildings to determine the actual performance of the daylighting systems.

BENTON, C., WARREN, M., SELKOWITZ, S., JEWELL, J., LIGHTING SYSTEM PERFORMANCE IN AN INNOVATIVE DAYLIGHTED STRUCTURE: AN INSTRUMENTED STUDY, INTERNATIONAL DAYLIGHTING CONFERENCE, LONG BEACH, CALIFORNIA, NOVEMBER 1986

This is an excellently written paper which presents the results of a one-year instrumented study of the daylighting performance of an office structure. It describes the monitoring program followed to measure within the building, although a more detailed explanation of methods, protocols followed and data gathering process would have been more useful.

BENTON, C., ERWINE, B., WARREN, M., SELKOWITZ, S., FIELD MEASUREMENTS OF LIGHT SHELF PERFORMANCE IN A MAJOR OFFICE INSTALLATION, PROCEEDINGS OF THE 11TH NATIONAL PASSIVE SOLAR CONFERENCE, BOULDER, COLORADO, 1986

This is yet another useful paper on field measurement and instrumentation of existing buildings. The paper evaluates the monitored performance of an integrated lighting system of an existing building. Decentralised data acquisition systems at 62 different locations in the building monitored the lighting systems for a year, recording average illuminance levels and light power usage. The section which describes the quantitative evaluation is particularly interesting as it describes the actual instrumentation and installation on site. This is a valuable paper to keep as a reference while undergoing extended field measurements.

DULANSKI, GARY, AN OVERVIEW OF MANAGING ENERGY WITH LIGHTING CONTROLS, LIGHTING DESIGN AND APPLICATION, NOVEMBER 1987, PG. 44

This is a good article on the use of lighting controls in a good lighting design to deliver energy efficient designs. It discusses some developments in control equipment utilizing on/off switching and older time clock controls, occupancy sensors, photosensor switching etc. It however does not discuss dimmable lighting controls. It is useful as an introduction to lighting control systems.

EDWARDS, IAN K., COUNTING COUP, LIGHTING DESIGN AND APPLICATION, DECEMBER 1993

This is an excellent paper describing the basic principles of photometry as applied to hand held photometric equipment. In a very simple to understand format, it discusses the foundations of photometry as well as the various corrections and calibrations which need to be accounted for while using these equipment.

IES, 1994 SURVEY OF ILLUMINANCE AND LUMINANCE METERS, LIGHTING DESIGN + APPLICATION, JUNE 1994

This is a digest of the IESNA survey of Illuminance and Luminance Meters. 53 meters from 18 different companies are described. Along with the general characteristics and functions of the photometers, there is also a list of some standard and optional features. Another added attraction is the retail price range listed for each type of meter. This can serve as an excellent guide for equipment description.

MOORE, B. E., LEAVER III, J. F., MCQUEEN, T., LIGHTING SCHOOLS IN HOT HUMID CIMATES: A CASE STUDY, INTERNATIONAL DAYLIGHTING CONFERENCE, LONG BEACH, CALIFORNIA, NOVEMBER 1987

This paper is a case study which explores existing schools in Baton Rouge, Louisiana. The schools were studied in terms of physical configuration as well as computer simulations on DOE 2.B to determine most energy efficient window and lighting configurations. Additionally each window configuration was also studied in terms of visual comfort to determine a balance between energy efficiency and light quality. This study is important in understanding the broader implications of performing a building lighting evaluation. The paper is a good example of what a lighting study entails, and what analysis is drawn from such a study. This paper is not about physical measurements within the building, but it succeeds in developing protocols for computer simulations and analysis.

WHITE, R., AN ANALYSIS OF DAYLIGHT IN BUILDINGS DESIGNED BY LOUIS KAHN, INTERNATIONAL DAYLIGHTING CONFERENCE, LONG BEACH, CALIFORNIA, NOVEMBER 1986

This paper presents the performance analysis of five daylighted buildings designed by Louis Kahn. The measurements included illuminance and color temperatures on vertical and horizontal planes as well as luminance variations perceived in different observer positions and glare areas from sky sources. The project looks objectively at how key buildings can teach us about the light interaction with the building surfaces as seen by the observer and the limits of physical measurements of lighting which are unable to describe this interaction in essence. The paper is valuable in that it describes the field measurement techniques as well as the occupant survey which was conducted.

**OTHER RECOMMENDED READINGS**

GILLETTE, GARY, EVALUATING OFFICE LIGHTING ENVIRONMENTS, LIGHTING DESIGN + APPLICATION, MAY 1987, PG. 4

ERHARDT, LOUIS, THE VISUAL TASK, LIGHTING DESIGN + APPLICATION, JUNE 1991, PG. 2

DIEMER, HELEN K., PHOTOMETRICS IS A DESIGN TOOL, LIGHTING DESIGN + APPLICATION, JANUARY 1988, PG. 25

DILAURA, D. L. (1975). ON THE COMPUTATION OF EQUIVALENT SPHERE ILLUMINATION, JOURNAL OF THE ILLUMINATING ENGINEERING SOCIETY, JAN. 1975.

DILAURA, D. L. (1976). ON THE COMPUTATION OF VISUAL COMFORT PROBABILITY, *JOURNAL OF THE ILLUMINATING ENGINEERING SOCIETY*, VOL. 5, P.207, JULY 1976

HELMS, RONALD, AND BELCHER, M. CLAY (1991), LIGHTING FOR ENERGY EFFICIENT LUMINOUS ENVRIRONMENTS, ENGLEWOOK CLIFFS, NJ, PRENTICE HALL.

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NAVVAB, MOJTABA, INTEGRATION OF DAYLIGHTING DESIGN TOOLS, LIGHTING DESIGN + APPLICATION, MARCH 1991, PG. 13

ORFIELD, STEVEN J., PHOTOMETRY AND LUMINANCE DISTRIBUTION: CONVENTIONAL PHOTOMETRY VERSUS CAPCALC, LIGHTING DESIGN + APPLICATION, JANUARY

REA, M. S., PASINI IVALDO, JUTRAS LOUISE, LIGHTING PERFORMANCE MEASURED IN A COMMERCIAL BUILDING, LIGHTING DESIGN + APPLICATION, JANUARY 1990, PG. 22

# APPENDIX C - LIST OF NECESSARY EQUIPMENT

### MINIMAL LIST OF EQUIPMENT

GE Illuminance meters

Minolta Luminance meter

Campbell or Licor datalogger

Hobo Light Intensity Loggers

Known intensity Luminance boxes (can be manufactured or borrowed from other sites.)

JVC Video camera, or other camera suitable for time lapse video.

Video board for the PC or a ‘Snappy’ digitizer.

(access to a PC or Mac computer)

# APPENDIX D - SUGGESTED COMPUTER PROGRAMS

Data conversion for Campbell, SAM 6 or Lawson Labs equipment.

Cooper Luxicon, Lumen Micro, Litecontrol or Genesys.

ImagePro, Photoshop or Corel (suite)

DOE 2.1E or DAYLIT

Microsoft Word, Excel or other similar word processing and spreadsheet programs.

# APPENDIX E - LIST OF SAMPLE BUILDINGS

Case studies of Salk Institute or San Juan Capistrano Library.

Coastal Commission Building by Scott Ellinwood.

Huntington Park Elementary School by CHCG Architects.

Verifone Worldwide Distribution Center by Croxton Collaborative Architects.

George Washington Carver Elementary School by RTA/ Blurock Architects Inc.

The Environmental Showcase Home, Consultants: David Scheatzle.

Moca, Los Angeles, by Isozahi.

Los Angeles Public Library by Goodhue/HHP.

Bradbury Building.

Santa Monica Arts Center, Gehry.

Temporary Library, UCLA.

Pacific Design Center.

# APPENDIX F - GLOSSARY

**Absorption coefficient** The percentage of the incoming energy which is absorbed. In measuring radiant energy (light or heat) it is a unit less ratio which may vary depending on wavelength.

**AC or A/C** The abbreviation for either Air Conditioning or Alternating Current, depending on the context.

**Accent lighting** Lighting which is intended to draw attention to a specific object rather than to create ambient lighting.

**After image** The image or negative image which remains on the retina as a result of adaptation, after the original stimulus is removed.

**Alternating current** An electric current which changes direction, back and forth, 60 times per second (Hz) in the U.S. and 50 Hz in Europe. A plot of the voltage over time looks like a sine wave.

**Altitude angle** The angle which measures the height of the sun up from the horizon. Altitude angles range from 0 degrees at the horizon to 90 degrees at the zenith. They are always taken in the plane of the azimuth.

**Ambient** A general or all surrounding condition. In lighting it refers to the background light level, as distinct from light from a visible source.

**Azimuth** The angle which measures the compass orientation of the sun, a wall (based on the normal to the wall) or anything else. In architectural convention, it is measured from due South. East is negative. West is positive.

**ASHRAE** The American Society of Heating, Refrigerating and Air Conditioning Engineers.

**Aspect ratio** The ratio of the height to width of a room (relates to light reflection) or of anything examined.

**Back light** Light which comes from behind a target, usually intended to light up just the edge of the form from the viewed side.

**Baffle** A louver or fin which shields a light source from viewers to avoid glare.

**Ballast** A voltage and current (and sometimes frequency) regulating device.

**Barn doors** Beam adjusting flaps which are sometimes placed in front of and at the edge of spot lights. Barn doors allow the edges of a beam to be exactly matched to the edges of a rectangular target such as a painting.

**Beam spread** The angle which measures the width of the beam. This is usually measured to a specific beam intensity such as 10%.

**Black light** Another term for ultraviolet light, typically in the near or A range.

**Bulb** The glass envelope for incandescent lamps.

**Candela (cd)** The unit measure of luminous intensity. See Chapter 2 for exact definition.

**Candlepower (cp)** The old designation for luminous intensity in the English system. May still be found in manufacturers literature. See Chapter 2 for exact definition.

**Candlepower distribution curve** A portion of the photometrics which gives the intensity of a source in any given direction. It is usually a polar plot, but can be a Cartesian plot, as well.

**CBM or Certified Ballast Manufacturers** The CBM is the manufacturers' association which attempts to enforce the standards set by the USASI or USA Standards Institute for ballast classifications.

**Clerestory** A vertical plane of glass above the viewing pane, such as the high windows in a cathedral, or daylighting windows in an office space.

**Code** A set of rules or prescriptions for the process and product. Building code covers buildings and fire safety. Plumbing code covers plumbing, etc.

**Coefficient of Utilization** The ratio of useful light arriving at the workplane compared to the amount of light emitted by the lamps, or admitted by the window, or skylight. The CU depends on the reflectivity of different surfaces and the aspect ratios of the ceiling, wall, and floor cavities.

**Color Correction** Most meters are currently corrected to mimic human eye sensitivity in the photopic range, since this includes both pattern recognition and color differentiation. Some meters follow the Purkinje shift, and are calibrated to the human eye's scotopic range. Such meters are rare, and will be specially labeled.

**Cones** The color sensitive receptors in the eye. See section 1.2 and Figure 1.3.

**Contrast Rendition Factor (CRF)** A measure of the level of contrast in a particular situation.

**Cosine Correction** A meter correction for light incident at oblique angles and which does not reach the cell due to reflection from the surface of the sensor or housing.

**Cosine Law** Another name for the point method of calculation, referring to the cosine factor applied to the angle between the normal to the receiving surface and the incoming ray.

**CSA or Canadian Standards Association** CSA approved means that an independent testing agency, the Canadian Standards Association, has tested representative samples of the labeled device, and certifies that it meets the criteria of the classification for which it is labeled. The equivalent in the U. S. is the UL, or U.L. or Underwriters' Laboratories.

**Cut off angle** The angle (measured from beam centerline) beyond which the lamp is no longer visible, and is shielded by the diffuser or the edge of the luminaire, or the point at which a collimated bulb has been reduced to 10% of its luminous intensity.

**Cps or cycles per second** A measure of frequency, in electric current or in acoustics, i.e. the number of times something occurs per second. The term has been largely replaced by Hertz. 1 cps = 1 Hz.

**Datalogger** A device which records data from other sensors, over an extended period of time.

**Daylighting** The term for the practice of using light from outside to replace electrically generated light indoors. It produces energy savings in electrical and in cooling costs when properly done, but can cause excessive heat gain when improperly done.

**Daylight Factor (DF)** The fraction of the exterior horizontal illuminance which is present at a particular location inside a space.

**Diffuser** A device through which the light from a fixture is diffused into a space. The diffuser usually effects the distribution of the light and often reduces the concentration, or luminance at the fixture.

**Dimmer** A control which allows the amount of light from a fixture to be reduced some percentage. On incandescent fixtures this may be a simple rheostat which reduces voltage, on fixtures with ballasts this may be quite complex.

**Downlight** A light designed to illuminate a horizontal surface below it.

**Efficacy** The ratio of the lumens emitted from a lamp to the watts used to create those lumens, or the number of lumens of visible light produced by a lamp divided by the number of watts required to produce it.

**Efficiency** The amount of light which leaves a luminaire divided by the amount of light produced by the lamps inside it.

**Emissivity** A factor which represents the rate at which a given surface material releases or emits radiant energy. The emissivity varies from 0.0 to 1.0, where 1.0 is the theoretical emissivity of a perfect black box at the same temperature.

**ESI or Equivalent Sphere Illumination** The illuminance of a surface from a surrounding sphere which equals the same seeing condition generated by a given illuminance from a given source.

**Fill Light** The secondary light source(s) which is(are) used to ease shadows created by the primary source. This softens a scene without losing the three dimensional information which comes from having a strong primary source.

**Flood** A short term which refers to a lamp with a wide beam spread, used to flood an area with light.

**Fluorescent** An efficient, long lived light source.

**Footcandle** The basic unit of illumination arriving at a workplane or other surface. One footcandle = one lumen per square foot.

**FootLambert** The basic unit of illumination leaving a surface. One footLambert = one lumen per square foot.

**Fovea** The area at the back of the retina which has the highest concentration of cones, and therefore the best color sensing capabilities.

**Fresnel lens** A lens which has been collapsed to a thin wafer. The surface is broken into concentric circles or horizontal slices, while the proper angular relationship of the original lens surfaces has been maintained. Images are broken up in transmission, but light beams are generally still focused much like the original lens. The most common examples are automobile headlights.

**Fuse** The piece of metal which melts at a predetermined temperature or amperage, disconnecting an electrical circuit.

**Glare** Objectionable levels of contrast or brightness. It is the result of unwanted light in the visual field, and is caused by the presence of one or more sources of bright light in the field of view.

**Herz or hertz** The basic measure of frequency in acoustics, equivalent to the number of cycles per second.

**HID or High Intensity Discharge** A family of lamps which consist of a quartz envelope inside a glass envelope. The inner quartz tube can stand higher temperatures, and allows for the current to arc between the two electrodes exciting a plasma of either mercury, metal halide or high pressure sodium. (The three lamp types in the family.)

**High Pressure Sodium** A high intensity discharge lamp.

**Index of refraction** A comparative number which allows the calculation of the bending of a ray of light as it passes through the surface between two materials.

**Indirect lighting** Lighting which is bounced off of a surface before striking the workplane.

**Incandescent** The original electric light source. Incandescents have grown to a large group of lamp types, characterized by a filament, short lamp life, good optical control, and excellent color rendition.

**Illuminance and Illumination** The amount of light, or the intensity, falling on a surface, usually expressed in lumens/square foot (used to be footcandles) (English) or lux (SI). This is similar to the luminous flux, but different, in that luminous flux was a light energy flow rate (dQ/dt). Illuminance is a flux (or flow rate) density.

$$E = \frac{df}{dA} \quad \text{(arriving)}$$

It used to be called the illumination, and was defined as

$$E = \frac{F}{A} \quad \text{(arriving)}$$

where F was the flux and A was the receiving surface area.

**Infrared** The wavelengths which are longer than the those of the visible spectrum, which we perceive as warmth or heat, and which result from lower temperatures than visible light sources.

**Inverse Square Law** A physical principle which states that the intensity of a phenomenon is inversely proportional to the square of the distance from the source to the measuring device. It is true of point sources of light, and many other natural phenomena.

**Iris** The portion of the eye which controls the amount of light which enters, or the equivalent portion on a camera or theatrical spot light.

**Key light** The dominant light source, from which most of the shadows are generated.

**Lambert** An SI unit of measure for luminance.

**Lambertian surface** A surface which emits or bounces light so that it has the same brightness viewed from any angle.

**Laser** An acronym for Light Amplification by Stimulated Emission of Radiation. Lasers are characterized by exact spectrum, exact beam collimation, and all the waves being exactly in phase.

**Lens** An object used to focus a beam of light, usually because it has an index of refraction different from its surrounding medium, and an adjustable shape.

**Libbey-Owens-Ford method (L-O-F)** Another name for the lumen method of calculating daylighting.

**Light Emitting Diode (LED)** A display grid made of components which glow depending on an electric charge. LED's are visible at night, but decrease in comparative visibility when external light levels increase. LED's are generally invisible in direct sunlight.

**Light shelf** An overhang, either outside or inside or both, which is used with a clerestory to reflect light up onto the ceiling, and reduce direct light adjacent to the window below.

**Line Frequency** The line frequency is the term for the frequency of the alternating current in the circuit to which a fixture is attached.

**Line Voltage** The line voltage is the term for the voltage available in the circuit to which a fixture is attached. Circuits often have 110, 208, 220, 277 and other voltages, depending on building supply, transformer and wiring.

**Liquid Crystal Display (LCD)** A display grid made of components whose transmissivity varies between clear and opaque levels depending on an electric charge. LCD's must be lit by some other source, or backlit, but they remain perfectly visible in high light levels.

**Low Pressure Sodium** An extremely efficient, monochromatic source lamp.

**Lumen** A unit of light, defined as the amount of light passing through one steradian from a one candela source.

**Lumen method** The method used for calculating illuminance levels in uniform situations (of artificial and natural lighting sources) which takes room shape and internal reflection into account.

**Luminaire** A complete light fixture, including lamps.

**Luminous Energy (Q)** The amount of energy transmitted in the visual spectrum. It is measured in lumen-seconds (lm-sec), or occasionally in Talbots (T).

**Luminous Flux (ϕ)** The amount of luminous energy, or light, flowing through an imaginary surface or solid angle. The unit of measure is the lumen. The flow through one steradian from a source of one candela would be one lumen. The mathematical definition of flux is :

$\phi = dQ / dt$

where Q is the luminous energy.

**Luminance (L)** The luminous flux leaving a projected surface in a particular direction is luminance (L). The unit of measure is candela/sq. ft. or candela/sq. m.

**Luminous Intensity (I)** The amount of light put out by a source in a particular direction is called the luminous intensity (I). The Candela is the unit of measure. The magnitude of the unit is basically the same as a candlepower, but the meaning is slightly different, and is a more accurate way of thinking about the process

$I = df / dw$

**Lux** The SI unit of measure for illuminance.

**Mercury vapor** A high intensity discharge lamp.

**Metal Halide** A high intensity discharge lamp.

**Mounting height** The height above the work plane at which a fixture is mounted.

**Munsell system** A system for cataloging colors based on the smallest discrete increment of color change recognizable by a human. The Munsell system uses hue, chroma, and value to organize the complete range of possible colors.

**Nanometer (nm)** The distance unit used to measure wavelengths, equivalent to 10-9 meter.

**Near infrared** The portion of the infrared spectrum nearest the visible spectrum, namely 770 through 1400 nanometers.

**Near ultraviolet** The portion of the ultraviolet spectrum nearest the visible spectrum, namely 300 through 380 nanometers.

**NEC** National Electrical Code

**Occupancy sensor** A device which is capable of sensing whether the room is currently occupied, typically used to control lighting.

**Parabolic Aluminized Reflector (PAR)** A lamp made of two glass parts, one is the reflector, welded together.

**Photometrics** The data which describes the beam characteristics of a lamp, or lamp and fixture. See also candlepower distribution curve.

**Photosensor** A device which is capable of detecting the illuminance on a prticular surface, or the average luminance of a space, typically used to control light levels.

**Point method** The most basic method of calculating the direct contribution of a light source to the illuminance on a given surface.

**Post Occupancy Evaluation** Checking the behavior of a building after it has been occupied by the client.

**Purkinje shift** The phenomena which shifts peak eye sensitivity towards blue at very low light levels, as the rods take over from the cones.

**Quartz lamp** Halogen, tungsten-halogen, and quartz-iodine are all names for the same lamp source, which is a sophisticated type of incandescent.

**Rapid start lamp** The most common fluorescent lamp.

**Reflectance [rho]** The fraction (usually expressed as a percentage) of the incoming light energy which is bounced back from a surface.

**Refraction** The process by which light is bent when passing from one medium to another.

**Retina** The internal receiving surface of the eye, which actually contains the sensing devices, the rods and the cones.

**Rods** The color sensitive receptors in the eye.

**Scotopic vision** Vision based on light sensed by the rods, typically at low light levels.

**Sidelighting** Fenestration which is on a vertical surface, or the process of using vertical fenestration for daylighting.

**Skylight** The most common form of toplighting, or horizontal fenestration.

**Spectrum** A range of electromagnetic radiation, usually referring to a portion of what is within the visible range.

**Specular reflection** A reflection which retains the original image.

**Spot** A short term which refers to a lamp with a narrow beam spread, used to spotlight a particular object.

**Starter** A device which starts the arc in a fluorescent, cold cathode, or neon lamp.

**Steradian** The unit of measure of a solid angle. It can be understood in terms of a surface area one square unit on a sphere of one unit radius.

**Strobe light** A lamp capable of being flashed very rapidly, used in photography for brief but very high levels of light, or for special effects. Also used in experiments for measuring change over very brief periods of time.

**Task lighting** Lighting which is located at and focused on a particular work function. It is often amenable to manipulation by the nearest worker.

**Talbot** A rarely used unit of light equal to one lumen-second.

**Toplighting** Fenestration which is on a horizontal surface, or the process of using horizontal fenestration for daylighting.

**Tungsten-halogen lamp** Quartz, Halogen, and quartz-iodine are all names for the same lamp source, which is a sophisticated type of incandescent.

**UBC** The Uniform Building Code. One of several codes used as models for establishing local building codes. Predominant on the West Coast.

**UL, or U.L. approved** UL approved means that an independent testing agency, the Underwriter's Laboratories, has tested representative samples of the labeled device, and certify that it meets the criteria of the classification for which it is labeled. The Canadian equivalent is the CSA or Canadian Standards Association.

**Ultraviolet** The wavelengths which are shorter than the those of the visible spectrum, which result from higher temperatures than visible light sources.

**Veiling reflection** A reflection superimposed on a surface which interferes with the perception of the information on (or behind) that surface.

**Visual acuity** The ability to distinguish visible information.

**Visual comfort probability** an index which describes the percentage of the people occupying a certain position who would not complain of glare as a result of the lighting considered in the calculation.

**Wavelength [lambda]** The length of one complete cycle or waveform of radiation (typically light). It is the reciprocal of the frequency. The dominant wavelength determines the perceived color or colors.

**Watt** The basic unit of electrical power, equal to the product of volts and amperes in direct current systems. 1 Watt = 3.41 Btuh

**Zonal cavity method** Another name for the lumen method of calculating illuminance.

# APPENDIX G - A PROTOTYPE PAPER

The real purpose of examining buildings is to provide information for decision making, of some sort. In the most immediate case, an owner might need to make an adjustment in something, the position of the blinds or the artificial lighting, for example. But that sort of immediate response is usually obvious and/or preprogrammed. The more likely scenario is that there are long term decisions to be made about improving the quality of the environment, about equipment sizing, building function, or other major changes. Indeed, a good portion of the measurements are likely to be used in determining basic theories, formulae or other ways of predicting building behavior so that the next building may be of better design or the existing one may be retrofitted.

For the last two categories, the report of the data is extremely important. The more rigorous of the two is the report which helps determine how future buildings will be designed. This report is most often in the form of a published paper. Even less formal reports benefit greatly from understanding what goes into a paper and why.

**ABSTRACT**

The abstract contains the succinct definition of what data was collected and why. In its longest version that includes what the problem was, what the test was (and who did it and where) followed by a simple version of what the conclusion was.

An extended abstract is not typically a part of a paper, but rather a shortened version of the paper, covering the same issues. An extended abstract is not included in the paper, it is usually sent in advance of the paper to determine whether a paper is suitable for publication in a particular conference or journal. It is also sometimes used in a library, where it might be translated into several languages, so that individuals who do not speak the original language have an idea of what the paper contains, and whether or not to get it translated.

**INTRODUCTION**

The introduction to a paper includes the problem in greater detail, and often includes background research published by others on the issue in question, or previous work done by the same individuals.

**METHOD**

The body of the paper defines the methods, equipment, time frame, site and other incidentals to the project. In some cases, the real point of the project is the equipment, or some development in protocol. In other cases, the real point of the project is the data, the analysis and the conclusions, but the method in which the data was collected is critical to the validity and applicability of the conclusions. Although it sometimes seems tedious, it is very useful to record such details.

**DATA AND ANALYSIS**

The data should be included in some form or another, depending on the format of the paper, and how much data is involved. Graphic presentation is by far the best. Again, the average reader can assimilate far more information graphically than verbally. This means that figures, charts and graphs are most important, tables next, and text should be there only to clarify the graphs, charts and tables.

Sometimes this section immediately becomes the analysis section, as well. This means that the authors of the paper begin to point out the patterns in the data. They clarify observations, and then begin to pose the relationships. This can mean they suggest that one variable is the result of another, or that both are following some third driving variable. They might suggest that certain ranges of illuminance, luminance, or contrast are acceptable and others are not.

It is also appropriate to include information about the number of samples, or the size of the subject pool. Part of analyzing data is keeping track of how solid it is. Again, repeatability is important, and testing only one case limits the confidence with which we can extend conclusions to other cases. Since this is always true, it is most appropriate to include the limitations of the data in the analysis and conclusion sections.

**CONCLUSIONS**

The end of the paper is the determination of the conclusions. There are actually several types of conclusions. The most important, of course, is the summation of the analysis. What behaviors are confidently observed, and what might be predicted. The limitations of the data are also included in the conclusions. When do the predictions and observations apply, under what circumstances, and with what cautionary notes. Finally, the conclusions usually include what work should be done next, in order to further the work at hand, or verify the current analysis. Answering one question often leads to another question.

**ACKNOWLEDGMENTS**

In the life of the researcher, and probably in the experience of anyone who gets time and equipment to monitor buildings, there is the need to recognize the sources which made the endeavor possible. This is not only fair, in giving credit, but very useful, in identifying entities who are interested in such problems. It is also critical in obtaining the next grant, if the work was funded!

**CONCLUSIONS**

It is necessary to be able to clarify and express your experiences and conclusions, both for your own understanding of experiment or project, and also in order to make the information available in a useful manner for others.

An example of a well written paper on a measurement project is: "Lighting System Performance in an Innovative Daylighted Structure: An Instrumented Study", by Benton, C., Warren, M., Selkowitz, S., and Jewell, J., presented at the International Daylighting Conference, Long Beach, California, November 1986. Refer Appendix B for an annotation.

The following exercise gives you the chance of writing a paper based on your recorded data which you have assembled while working on the earlier exercises.

**REVIEW QUESTIONS**

What is the difference between the abstract and the introduction to a paper?

Where would you include alternative experiments or future research suggestions?

**ANSWERS TO REVIEW QUESTIONS**

1 The abstract succinctly states what the paper will cover. The introduction begins to introduce the reader to the problem, previous work done on the subject, etc.

2 Alternative experiments or future research suggestions are typically included in the conclusions.

# ASSIGNMENT - WRITING A PAPER

**OBJECTIVE**

Presentation of the results of the project in an easily comprehensible but rigorous manner.

**DISCUSSION**

Half of the work in performing an experiment or evaluating a building is defining the problem, design the testing, getting the data and understanding it. The other half is presenting it to others. The best way to bring closure to your understanding of the measurement process is to prepare a document which would be presentable as a paper to others who are knowledgeable on the topic.

**EQUIPMENT**

There is no unusual equipment required for this assignment. You do need access to word processing software like Word, or WordPerfect etc. which have importing capabilities, as you will need to import graphics and graphical information prepared with different software. You will need to check your particular word processing software for file import types.

**METHOD**

Take the work done in the earlier exercises and distill from it a presentable paper. It is clear that this paper does not necessarily bring any new information to the arena, but imagine that it does. Imagine that there has been little or no research of the type which you have just completed, and that you need to disseminate your work in a careful and clear manner.

Following the guideline presented by the Lesson on Preparing a Paper, prepare a succinct Abstract. Produce a complete Introduction. The Introduction may be somewhat imaginary when referring to the problem which prompted the study, but there should be real references to work done on the topic before. Ask your instructor for references, or go to the library and look up names which have been used as references by the previous lessons or other books you have read. Remember that once you have identified people who do interesting work, you can look their names up in a publications index and they are likely to show up again and again. There is a great deal of information in "trees" which run through computerized indices. When you read a paper, check the references for new names you have not identified before. In turn, be careful to footnote your work.

Present the data and the analysis in the body of the paper. You may use the graphs prepared for any of the previous assignments. Make careful and clearly defined conclusions from the work which you did.

**EVALUATION**

1. Produce a simple version of a paper, complete with abstract, main body, and conclusions. This paper should be from four to six pages long, single spaced, including reduced plots, graphs and tables. For added realism, you should include a title, your own name and affiliation and some formatting, i.e. heavier typefaces and fonts for headings and subheadings, and perhaps even a two column format. Number all figures and tables, and provide captions.

VITAL SIGNS

## SUMMARY

A complete range of exercises, covering everything from an understanding of how your own eye works to how to do image processing on a digitized videoscan has been covered. In between we have talked about illuminance and luminance, about models and buildings, about lighting controls and occupant responses. There is actually still a great deal which has not been covered. The image processing may result in new theoretical understandings of glare, especially if we could use test cells with a range of conditions and a range of test subjects. The tools which you have learned allow you to understand design decisions better, evaluate existing buildings and propose specific changes, or test models of a building before it is built.

You are encouraged to develop these techniques and protocols further. If you are interested, you are welcome to get in touch with us, as we would be happy to hear from you.

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