# An Analysis of the Integration of Daylight in Museum Display Spaces

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ABSTRACT

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Museums and galleries have been lit by daylight since their inception. Although artificial lighting took precedence during the middle of this century, daylight has been used again in recently built museums for its high color quality, modeling and variability.

The requirements of the museum's visual environment, such as contrast, glare avoidance, modeling, brightness, color rendering and interior finishes are studied. The special limitations imposed by conservationists due to the deterioration caused by radiation on objects are analyzed. Daylight and artificial lighting systems are evaluated with respect to these requirements. The interaction and conflicts between competing requirements of damage control, visibility and color rendering are studied and related to the spectral power distribution of source radiation and reflectance. Daylight luminaire design concepts and the geometry of openings are evaluated through a taxonomy of designs.

Built examples of many methods of integration of daylight in museum display spaces are evaluated through findings of 16 case studies. It was concluded that daylight, if skillfully employed, can meet the communication and conservation requirements.

Data (illuminance levels, U.V., U.V./lum, color temperature), spatial documentation (drawings, details, photos), and interviews were collected in 7 recently built museums through field studies. The conclusions showed excessive illuminance levels, varying color temperatures and color rendering, and excessive veiling glare in all examples when compared to established standards. Daylight luminaire design, the geometry of openings, and the interior finishes were found to affect the resulting quality of the visual environment.

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# CHAPTER I

## 1.1 INTRODUCTION

Light makes the museum possible. To view works of art in museums, light is the most important factor of the functional environment. In creating a visual environment, the designer should know museum functions, and significant advances of lighting in museum and similar buildings.

The appropriateness of this topic is particularly timely today as there has been a burst of museum building in the past few years continuing into the present. In Ottawa three major museums are being designed. In Montreal the Musée d'Art Contemporain will be built. The Royal Ontario Museum in Toronto will soon open after a major renovation and in the United States there are major recently built museums (Dallas, New York City, Boston, Los Angeles) - all of them predominately daylit.

This study examines the requirements and characteristics of the visual environment in relation to museum functions. Factors affecting the visual environment such as sources of light, finishes of museums, human perceptual limits, color and finally the conservation of works of art particularly in relation to daylight will be studied. In designing the required visual environment, we will study daylight luminaire design, in terms of concepts and existing museums. In order to evaluate and set guidelines for future designs, existing museums are documented and collected data are analyzed. Finally a number of museums are studied in relation to factors affecting the integration of daylight in museum display spaces.

## 1.2 MUSEUM FUNCTIONS AND LIGHTING

Today's museums are defined as: Institutions devoted to the care and display of objects of lasting interest, in such a manner and environment that communication between the viewer and the works of art for education, and pure enjoyment can take place indefinitely. The origins of museums and the evolution of their functions are discussed in detail in Appendix (1).

The key functions that affect lighting design are communication and conservation. With respect to communication, lighting should provide for a detailed study, as in a school room, and should catch the eye as in a store display. The object is primary and dominant in the visual environment. As an original it must be shown accurately with respect to form, texture, and color. If this is not done a copy can replace it, but then we would not need a museum. With respect to conserving the object for the future, lighting should have the minimum damaging effect on the object.

The requirements of these two functions are in conflict. For example the first demands high illuminance and the second requires minimum illuminance levels. The visual requirements imposed by museums are to allow:

1. Critical viewing to study details.
2. Dramatic lighting to get the viewer's attention.
3. Viewing by a constantly moving observer.

4. A constantly changing content of the cone of vision, with respect to size and numbers (one object or several objects).
5. A long duration of viewing.
6. Illuminance adaptation as he/she moves from gallery to gallery. One gallery may be dimly lit and the second brightly lit which requires time for adaptation.
7. Perception of color.
8. The correct placement of the object on display. This is an integral part of the visual environment, in a direct three way relationship to the light source and the viewer. In other building types the effect of light on the object is incidental to its function, but in the museum the quality of the lit object affects the message being communicated.
9. Minimal damage by the effects of radiation on irreplacable object, since the object is held by the museum in trust for future generations. Note that in store displays the objects are replaced quickly and have no long term value.
10. Minimization of exposure to light. The museum must resolve the magnitude of potential damage with the communicative requirements.

These requirements make the lighting of museums a unique problem. As we shall see, the research and experience with lighting for other building types are only applicable to museums in a general sense.

## 1.3 USE OF DAYLIGHT

The use of daylight in early and recent museums is discussed in Appendix (1). Daylight was necessarily the only source of light in museums for decades, before it was replaced by artificial light in the 20th century. Recently built museums have again introduced daylight as the primary source of light in the gallery spaces. A number of older museums, which have effective daylight design, such as the Dulwich Art Gallery, are being used as a precedent. The changing methods of museum displays makes the copying of these examples dangerous.

Daylight is used for many reasons. It's changing character, the color response, and the viewers' needs make the use of daylight a necessity in order to communicate the object's multiple characteristics. The decision of whether to use daylight has usually been based on personal experience and taste of curators, directors and architects. Lack of research in this area has made decision making very difficult. One has to apply the existing information on artificial and natural lighting for other building types to the museum's needs, in order to evaluate design options and predict performance. This study will assess these needs and provide the designers with the required tools for making decisions.

## 1.4 METHODOLOGY

A major issue for this thesis was to determine how to study the problem. Lighting research has met with considerable scepticism by designers due to the complexity in understanding the nature of primary visual processes. For example, the fundamental theory of color perception is being revised by Land [117], which raises questions with respect to the interaction of sources and object reflectivities. The ESI concept to evaluate the effect of contrast reduction due to veiling reflections for a fixed task and observer has been dismissed by many eminent researchers as inadequate for most important visual tasks. The other major area of research which attempts to refine the mathematical approach to lighting design favoured by illuminating engineers has stressed the calculation of these quantities that are easiest to calculate rather than the measures of what we actually see. These major research areas require that the parameters be reduced in number and that major simplifying assumptions be made. See for example the careful work of Rea [134] or DiLaura [135]. Such assumptions are the reasons for their limited application and for the difficulties in bridging the gap between the science and the art of lighting.

For example, the basic radiative transfer equations require that surfaces have uniform luminance, that they are Lambertian, that the source direction and output remain constant and that all room surfaces and geometrical relationships can be described and calculated. For even a simple room however it is possible to have 100 different surfaces which would require the solution of a 100 x 100 matrix. Similar assumptions, by no means insignificant, are required for glare studies. In fact for modeling, discomfort glare and color constancy, no accepted mathematical description exists. What we do know is how to identify the problem where and when it might occur and qualitative ways to eliminate it. Major design failures are due, it seems, not to the inability to make one of the limited types of calculations, but the neglect of all the parameters that affect the lighting design and especially their interactions. Lam [72] and others have tried in different ways to resolve the problems but the current discussion in the IES Journal [137] shows that these issues are real and urgent.

It would thus seem difficult to resolve the same types of issues in a difficult lighting problem - museums - with an intractable lighting source - daylight. However, if the above discussion is correct it is the lack of understanding of all the parameters and the limits to their understanding that has led to poor lighting solutions. If the designer is ignorant of some parameters, then no matter how skillful the use or understanding of the others may be, the design is likely to be deficient. Accordingly, the first priority for an understanding of museum daylighting is to identify and understand the nature of all the parameters affecting it. These must be related to museums and not borrowed unchanged from other applications. For example, we are interested in vertical (not horizontal) luminance and illuminance, moving (not seated fixed) viewers, exact color rendering and deterioration of organic materials under a variety of radiative sources. A precondition for this parameter study is to determine the function and nature of the museum including the location of displays, the nature of movement, the characteristics of tasks and contemporary practice. This is best obtained by looking at the evolution of museums and understanding why museums have begun and how they are expected to change. These studies are found in Chapters 2,3,4 and in Appendices 1 and 2.

Secondly, one must identify the nature of the source and the "fixture" that will distribute light in the space. Daylight sources differ greatly from the artificial sources and thus design techniques must be related to the nature of these sources. The use of daylight in museums would seem to further restrict the types of daylight luminaires that could be used. Since daylight is so involved with the room geometry and architectural features, the kinds of daylight openings in the room should be determined. Chapter 5 describes the range of day-light luminaires organized into a taxonomy. These categories are derived from an extensive survey of contemporary museums. Altogether 16 museums were documented in a resource file including 650 slides. Unfeasible daylight options never seen in museums were not included. The taxonomy is useful to show the range of practical options and variants possible to the designer. The examples of luminaires are rated with respect to illuminance distribution and veiling glare.

The individual parameters discussed in chapters 2,3 and 4 are inadequate to understand the interactions in real museums. Note that no two museums were alike. The study of museums was done in two parts. Field studies in Chapter 6 were made in seven museums to determine the distribution of vertical illuminance, color temperature at wall surfaces, U.V. levels and the luminance distribution. The measurements made call into question the standard design criteria for deterioration, illuminance levels suggested for museums and show that daylight sources pose considerably different lighting design considerations than do artificially lit museums. Case studies (16) in Chapter 7 establish a wider context to extend the results of the field studies. The field study examples included in the case studies provide a tie between the two approaches. Finally a set of recommendations has been made to guide future designers of daylit museums.

## 1.5 THE INTEGRATION OF DAYLIGHT

The integration of daylight and artificial light sources with other factors affecting vision is the key to a successful design. The following are a list of factors that will be considered in this study:

I. Light Source & Luminaire:

A - Artificial light and its control

B - Daylight, its variations and control

C - Illuminance levels and distribution

D - Spectral power distribution of sources

E - The modifiers of light, ie. re- reflectors and lenses

II. Viewer:

- A - Contrast
- B - Glare (veiling and discomfort)
- C - Modeling
- D - Perceived Color
- E - Visibility
- F - Adaptation

III. Objects and Space:

- A - Object's reflectance, color and characteristics
- B - Display methods
- C - Wall, ceiling and floor finishes

## 1.6 A BRIEF REVIEW OF LITERATURE RELATED TO DAYLIGHT IN MUSEUMS*

Museum lighting has been studied by three groups of professionals. Each group has looked at the problem from their point of view and often has ignored the concerns of others, since museum lighting requirements are mostly in conflict with each other.

1. Conservationists

This group has documented studies of damage and deterioration due to light, U.V. content and its effect on museum objects, such as: Feller [3][5][6], Harrison [1][32][38], and Thomson [2][3][14-18][29]. Due to

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* A more extensive literature review by topics is included in Chapters 2,3,4.

problems with experiments, such as duration for normal deterioration and over heating in light fastening processes their conclusions are not applicable to lighting design. For example the U.V. content and its damaging effect is used to reject daylight, without the proposal of any standard, the evaluation of alternatives or the study of means to minimize its effects through design. The damage factor method has been devised, but it has not ben based on long term experiments, with museum objects. The conclusion suggested by conservationists is that we have to keep museum objects in as dark as possible spaces (dark basements). The characteristics of light sources have been studied in the laboratory but no useful recommendations for on site application have been made. This is due to the fact that a light source functions very differently in isolation due to interreflections with spatial surfaces [IES Handbook]. Brommelle [26][39][35][51], Thomson [70] have documented studies in museum lighting applications but do not provide any applicable recommendation in building design and construction. For example the recommended illuminance levels by various conservationists have a range of 50 lux to 250 lux. In application, measured ranges are from 30 lux to 2000 lux.

2. Lighting Designers

This group has tried to apply techniques used in other building types with predominantly artificial systems to daylit museums. The lighting designer's role is to provide what is recommended by conservationists and asked for by the architect. If neither know what they want, the final product is unsatisfactory.

The I.E.S.'s recommendations for lighting [71] are oriented towards artificial lighting and conservation. Unfortunately the illuminance criteria is applied to daylit museums. The integration of factors are not considered by the I.E.S., and lighting engineers. There have been no systematic studies by lighting designers of built museums. Published post occupancy evaluation studies by lighting designers are non existant; thus the potentially rich resource of built examples of museums has been ignored. Indeed there seems to have been a coverup of lighting problems as discovered in several prominant museums visited by the author. Curators wanted anonymity and were sometimes very careful about their statements to the author. A few articles have discussed daylight in museums, encouraged its use and showed how to control and calculate the relative damage due to light. See Ne'eman [33] and McCandless [36][37].

3. Architects and Building Engineers

This group has studied museums with respect to architectural concepts, such as planning, circulation, orientation and zoning. See for example Stein [48], Rosenfield [42], Weiss [73], Rykwert [78] and Scully [84]. Brief descriptive studies have been done with respect to daylight and buildings in general, such as Brawne [92], Lam [72], and Evans [68]. The museum interior and exhibition design have been documented by Brawne [132] but overall studies in museum lighting recommendations and the evaluation of the performance of existing solutions have not been undertaken. There is no systematic study and documentation of daylight luminaires, as exist for artificial lighting. Where prototype daylight fixtures have been studied the results are given in terms of daylight factor contours for horizontal illuminance [60]. The distribution of vertical illuminance or UV has not been done.

Architectural studies have discussed the issue of daylighting in museums at a conceptual level, however no form of guidelines for future designs exist. Many other articles and studies are published in the museum and lighting field that affect the integration and study of daylight in museums, such as Hopkinson [123], McDowell [120] Pevsner [114] and Searing [109].

## 1.7 PRESENT PROBLEMS AND MUSEUM LIGHTING

It is thus evident that museum daylighting requires an analysis that integrates previous research, examines apparent conflicts, assesses the state of contemporary museums and establishes guidelines for design and future research. The more important problems that should be addressed in the following are:

1. Museum functions: lighting should be designed according to functional requirements.
2. Museum's Lighting Sources: this study will help the designers evaluate their options and make decisions.
3. Application of lighting methods used for other building types to museums: for example the problem of veiling glare

as studied for offices cannot be directly used for museums, but it can be used to evolve solutions to museum conditions.

4. Deterioration in actual museum conditions: how can the damaging effect of light sources be minimized? What standards and recommended levels of illuminance, U.V., I.R., etc. are required? These standards should be based on experiments and documentation in functioning museums.
5. The Museum's Visual Environment with respect to all the effecting factors, i.e. contrast, color, glare etc. The visual environment with respect to all factors (particularly in daylit galleries).
6. Lack of study of daylight in general, so prediction for future performance of daylight luminaires can be made.

This study did not attempt to resolve all these issues however it was felt that it was important to:

1. determine the scope of museum functions
2. determine if daylight is practical for museum lighting
3. examine if current recommendations for illuminance and U.V. are observed in recently built museums
4. determine where important aspects of museum lighting interact and how they might be integrated.

To make these assessments it was important to determine the scope of historical and contemporary examples of daylit museums including the types of spaces and their components such as daylight luminaires. Finally because of the complexity of all the factors it seemed essential to survey several important recently built museums, to look at the results of the best professional practice and to use this documentation for further studies in creating a systematic evaluation, since this study is clearly a beginning which creates as many questions as it may answer.

## 1.8 OVERVIEW

The scope of museum functions is discussed in Appendix I. Through this study, the use of daylight and its application to museum functions has been defined. Factors affecting the visual environment, i.e glare, contrast, modeling, color, and their application to museums are discussed in Chapters 2 and 3. These factors are examined with respect to museums documented. In Chapter 4 the deterioration of objects due to light is undertaken. The cause of deterioration and means to reduce it, are discussed.

The taxonomy of daylight luminaires are collected, studied, and evaluated in Chapter 5. Daylight luminaires are evaluated and ranked with respect to illuminance distribution and veiling glare.

The application of factors, discussed in Chapters 2-5 to actual museums and the evaluation of existing museum's lighting is undertaken in Chapter 6. The analysis of data and ranking of museums are presented. Finally a number of case studies are discussed in Chapter 7.

as a continuation of Chapter 6. Some of the case study museums have been visited and one of their galleries is documented and analyzed in Chapter 6. The rest present solutions to application of factors affecting the visual environment as have been discussed through Chapters 1-5.

# CHAPTER II

## MUSEUM VISUAL ENVIRONMENT AND DAYLIGHT

### 2.1 INTRODUCTION

Light, as part of the sun's radiant spectrum and as reflected or emitted radiation from other sources has certain characteristics, which separately or together affect human perception and the conservation of works of art. These characteristics differ considerably, depending upon the source (natural - artificial) and their perception by viewers. This perceptual interaction and the influence of the visual environment particularly in relation to daylight will be discussed below. The characteristics and nature of museum light sources' possibilities and problems in the use of each source and finally factors affecting the visual performance of the viewer, such as adaptation, contrast, glare and modeling will be studied.

### 2.2 NATURE OF LIGHT

Seeing and understanding, is comprised of three functions: 1. the physical process of producing an optical image of the objects on the light sensitive receptors in the eye; 2. the transformation of the signal to the brain; 3. the interpretation of the signal by the brain. Here we limit ourselves to the first process; we look at: (a) the light (signal); (b) the production of an image.

The radiant energy spectrum extends from $10^{-16}$ to $10^{15}$ meters, but the visible radiation is from 380 x $10^{-9}$ to 770 x $10^{-9}$ m (380 to 770 nm). Visual radiation is generated by: (1) sunlight (2) skylight (3) moonlight (4) lightning (5) northern and southern light (6) bioluminescence (7) man made sources, i.e. incandescence and luminescence [71].

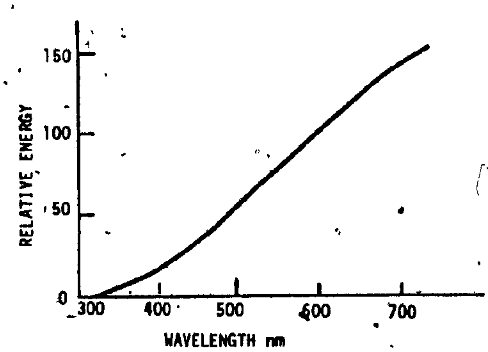
The common museum light sources are Daylight: (1) Sunlight (2) Clear sky light (3) Overcast sky light, and Artificial light: (a) Incandescent lamps (b) Fluorescent lamps. Often two or more sources are combined, or some radiation of a source is eliminated in order to obtain a required radiant spectrum.

## 2.3 ARTIFICIAL LIGHT

As was described in Chapter I, the use of electric light had increased during the 20th century particularly around the 1950's with the availability of fluorescent lamps. There are different sources (i.e. color lamps) available in the market for artificial lighting, but due to their spectral power distribution we will be limited to incandescent and fluorescent lamps, which are commonly used in museum exhibition areas (other lamps such as mercury vapour and High Pressure Sadium lamps - are used in storage areas [47]).

## I. INCANDESCENT LAMPS

Light is produced by a wire or filament heated to incandescence (2400°K to 3650°K) by the flow of electric current through it. Only 10% of the radiation in these lamps is visible. The lamp life is short and its luminous efficacy (lum/w) is low, ranging from 4 to 24 lum/w (averaged 15 lum/w)*. The luminous efficiency or relative spectral sensitivity depends on the spectral distribution of the lamp. Plate (2.1) shows the relative energy distribution of two typical incandescent lamps.



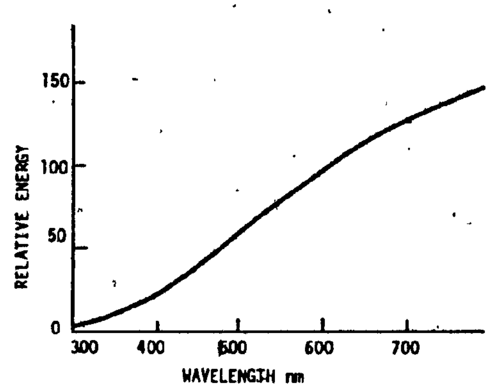




Plate (2.1), The spectral power distribution of 2 incandescent lamps [23]

* See charts (2.2 a,b,c) at the end of this section for comparisons with other sources.

## II. FLUORESCENT LAMPS

The fluorescent * lamp is an electrical discharge source where a mercury arc generates ultraviolet energy which in turn activates the phosphor coatings to produce light. Due to their "negative resistance", fluorescent lamps require a ballast to start and limit the current flow. This process of light production creates many possibilities in terms of spectral power distribution (SPD). Depending on SPD there are 9 different lamps available, Table (2.1) and Plate (2.2). The value at certain wavelengths (the line spectrum) is due to the production of visible radiation directly by the mercury arc. The smooth curve is due to the U.V. radiations' attack on phosphors coating of the tube and creation of visible radiation. Halophosphates are used in fluorescent lamps which absorb radiation at 253.7 nm and emit at a wide range of wave lengths, depending upon the phosphor and colors of tubes.

Fluorescent lamps have a much higher efficacy than incandescent lamps; 22% of total radiation is in the visible region giving a higher efficacy of approximately 40-85 lm/w. Fluorescent lamps also have longer lifetimes (7500 hours). Charts (2.2) illustrate the comparison of artificial sources in terms of efficacy. The color variation and high efficacy have made these lamps popular in museum lighting, particularly in conjunction with daylight, as in the Boston

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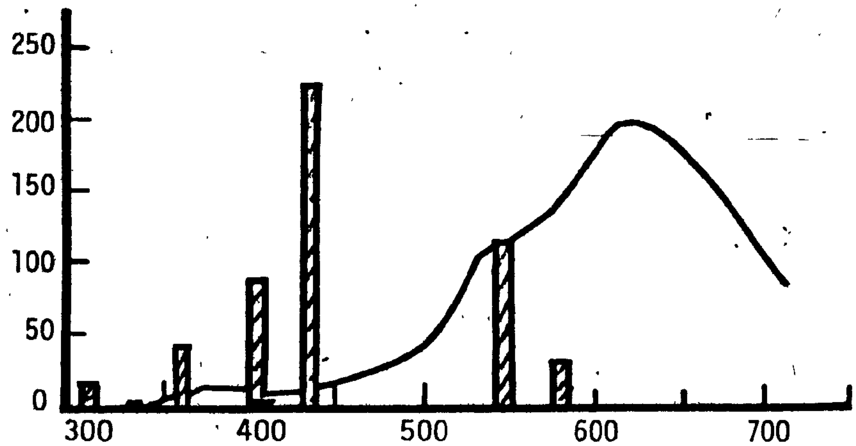
* A substance is said to fluoresce if it absorbs radiation and re-emits it at a longer wavelength.

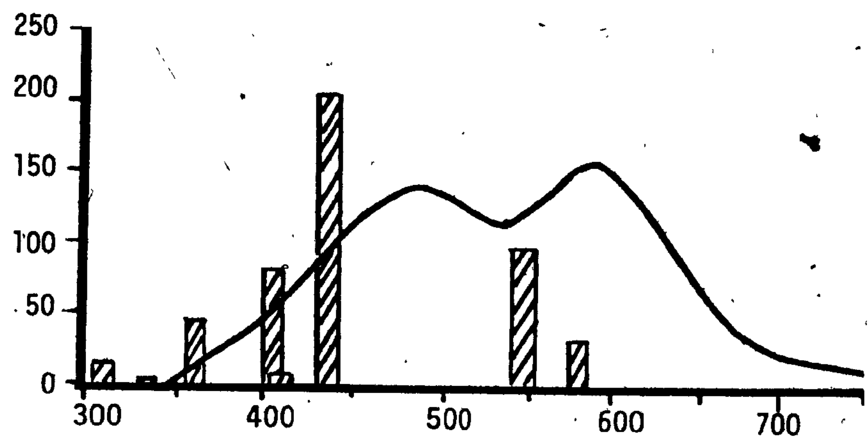
**TABLE 2.1**

| | Name | Tint | Color Temp. °K | lum/40 w lm |
|---|---|---|---|---|
| 1 | Softwhite | As Incandescence | 2700 | 1700 |
| 2 | Deluxe warm white | white | 2800 | 1750 |
| 3 | Warm white | white | 2950 | 1800 |
| 4 | Warm white | warm white | 3000 | 2000 |
| 5 | Daylight | white | 4000 | 1750 |
| 6 | White | white | 4000-4300 | 3200 |
| 7 | Cool white | cool white | 5000 | 1900 |
| 8 | Artificial day-light | sky white | 6000-6500 | 2400 |
| 9 | Color matching north light | cool white | 6500 | 3050 |

Principal Fluorescent Tubes and their Characteristics [23]




a) Artificial Daylight, C.T. = 6500 °K




b) Warm White, C.T. = 3000 °K

Plate (2.2), The Spectral Power Distribution of two types of fluorescent Lamps.

**CHART 2.2(a) [116] - Source Comparison Based on Equal Watts (400 W)**

| LAMP | Quantity | Watts (Total) | Lumens (Each) | Source Efficacy (Each) lm/w |
|---|---|---|---|---|
| Incandescent | 4 | 400 | 1,740 | 17.4 |
| Tungsten-halogen | 1 | 400 | 7,500 | 18.8 |
| Fluorescent | 10 | 400 | 3,150 | 78.9 |
| Low-pressure sodium | 3 | 405 | 21,500 | 159.3 |

**CHART 2.2(b) [116] - Source Comparison Based on Equal Lumens (30,000 lm)**

| LAMP | Quantity | Total Lumens (Each)* | Watts (Each) | Source Efficacy (Each) lm/w |
|---|---|---|---|---|
| Incandescent | 17 | 29,580 (1,740) | 100 | 17.4 |
| Tungsten-halogen | 4 | 30,000 (7,500) | 400 | 18.8 |
| Fluorescent | 10 | 31,500 (3,150) | 40 | 78.9 |
| Low-pressure sodium | 1 | 33,000 (26,000) | 180 | 183.3 |

* Values in parentheses are for individual lamps

CHART 2.2(c) - Light Source Summary

| LAMP | Watts | Lumens | Source Efficacy lm/w | System* Efficacy |
|---|---|---|---|---|
| Incandescent standard | 100 | 1,750 | 17.5 | 17.5 |
| Tungsten-halogen | 250 | 4,850 | 19.4 | 19.4 |
| Gaseous discharge - low pressure fluorescent | 40 | 3,150 | 78.8 | 68.5** |
| Low-pressure sodium | 180 | 33,000 | 183.3 | 150.0 |

* System is the luminaire
** HPF-RS two lamp ballast, 92W

Museum of Fine Arts. Other artificial sources are not usually used in museums, particularly due to their SPD, lumen output and the colour of the source which is directly related to the SPD.

## 2.4 DAYLIGHT

Daylight, if skillfully employed can be effective as a means of energy conservation, of orientation and perception. Radiant energy from the sun is emitted over a very wide range of wavelengths. However, most wavelengths shorter than about 292 nm or longer than about 2500 nm are absorbed by the atmosphere layer of ozone before they reach the earth's surface, and ordinary glass filters out radiation less than 310 nm [11]. Thus light radiation passing through common glazing materials is limited from 310 nm to 2500 nm.

A belt of maximum radiant energy moves back and forth across the equator as the seasons change and from east to west as the earth rotates. Its luminance is evaluated in terms of clear sky or totally overcast sky. The partly cloudy sky is not considered since the present data is insufficient for use in calculations. Overcast sky and clear sky each have their own characteristics and differ substantially in terms of spectral power distribution, color temperature, and luminance values Plate (2.3). Overcast sky luminance varies as a function of location, time, density, cloud cover and uniformity of cloud cover. The luminance of a point in the sky is independent of its azimuth angle but varies with the altitude angle, and for no snow conditions it is three times greater at the zenith than at the horizon. Clear sky or blue sky luminance is a function of the sun's location and it is greater near the horizon than at the zenith, except around the sun. The average luminance of the sun is 1600 mega candelas/$m^2$ viewed at sea level. The

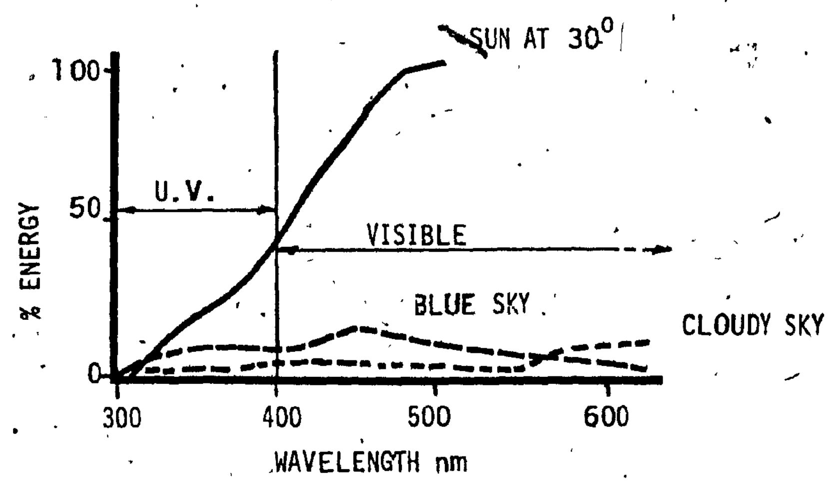


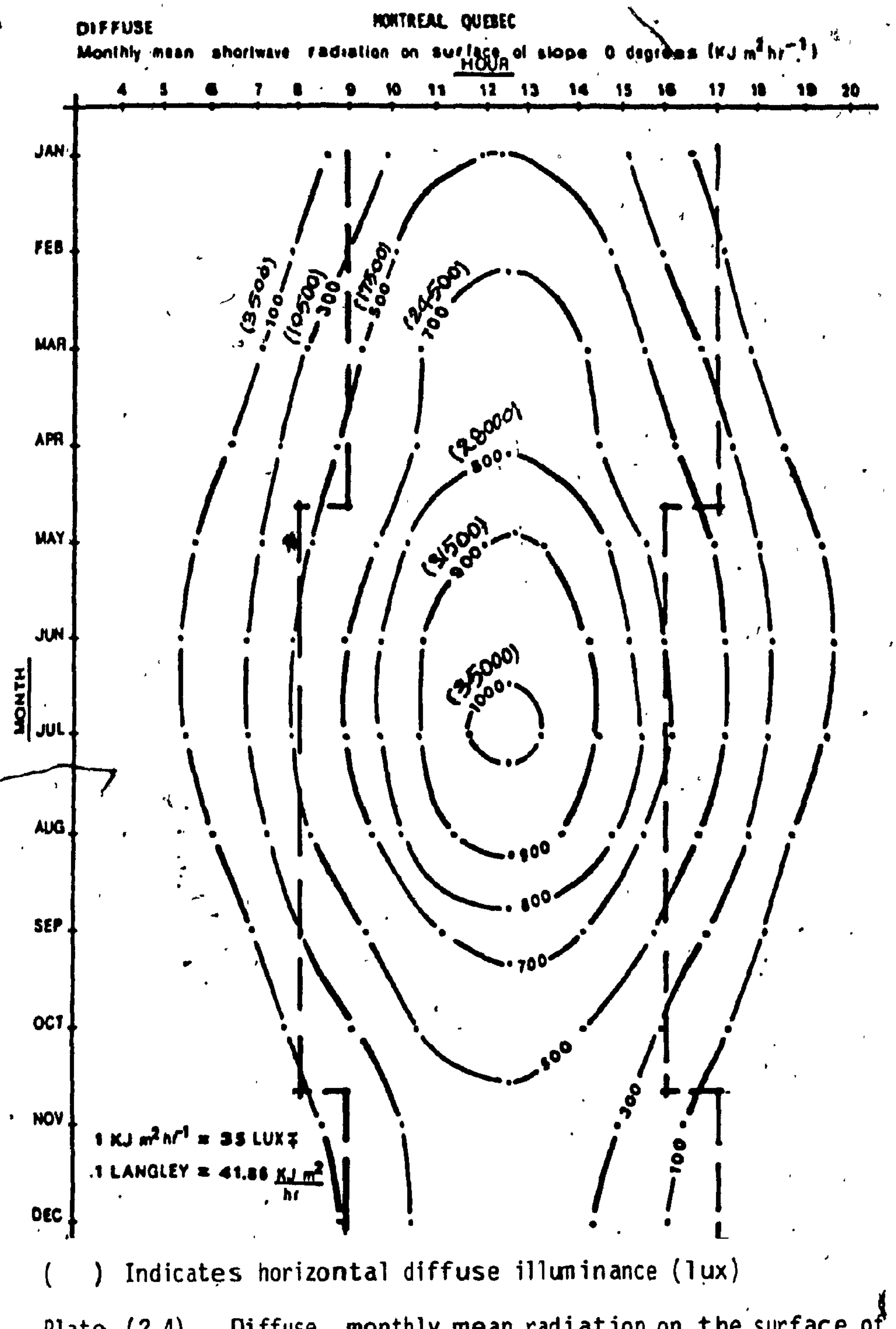

Plate 2.3, Graph of SPD of 3 phases of daylight (sun, diffuse sky, cloudy). [2 3].

illuminance on the earth's surface by the sun may exceed 100 kilo lux or drop to 10 kilo lux on cloudy days.

The daylight factor is used for daylight calculations of the level of light reaching any point inside the room. It is defined as daylight illumination at a point inside, expressed as a percentage of the simultaneous illumination from the whole sky, on an unobstructed horizontal plane. The daylight factor has two components, a sky component and a reflected component. These factors are used for calculating the level of light reaching a point, in order to design for maximum illuminance. But as will be seen later, due to the introduction of many more factors, a maximum of interior illuminance is not a concern in museum lighting.

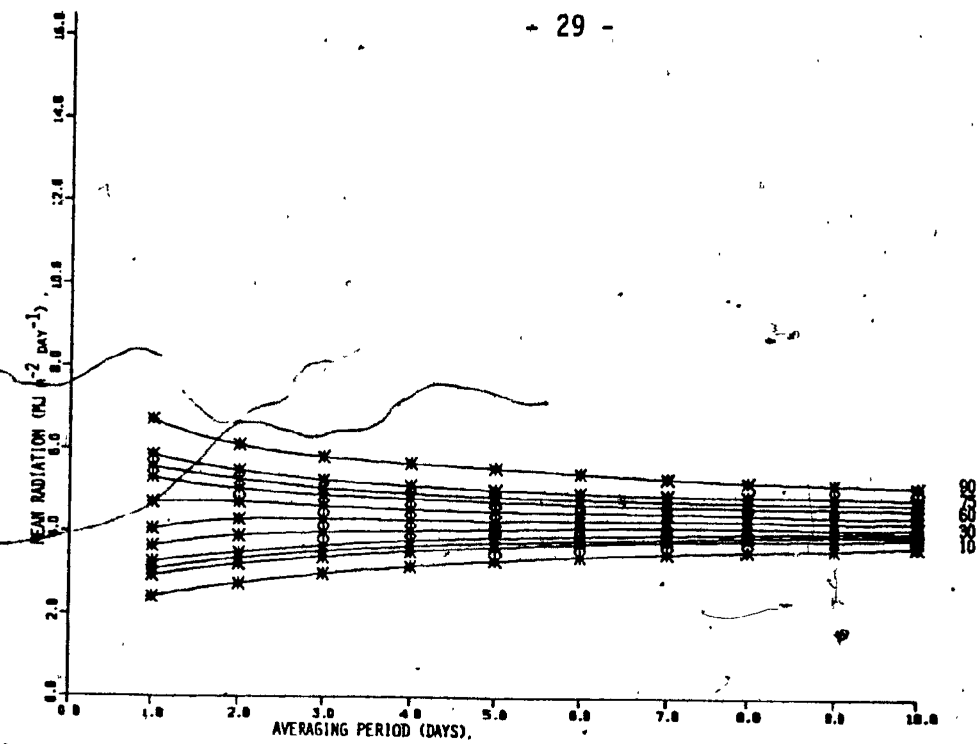
Daylight varies in quantity and quality with respect to location, time, orientation and atmospheric conditions. Illuminance levels of daylight change throughout the year; this is shown in Plate (2.4), for Montreal, from January to December. The contours indicate radiant energy on a surface of 0° slope in Kj $m^{-2}$ $hr^{-1}$ which is equal to approximately 35 lux.

These variations impose special problems in museum lighting design. They could be advantageous with respect to comfort in the visual environment or disadvantageous with respect to controls. These contradictory needs and problems are what make museum lighting a unique design process.

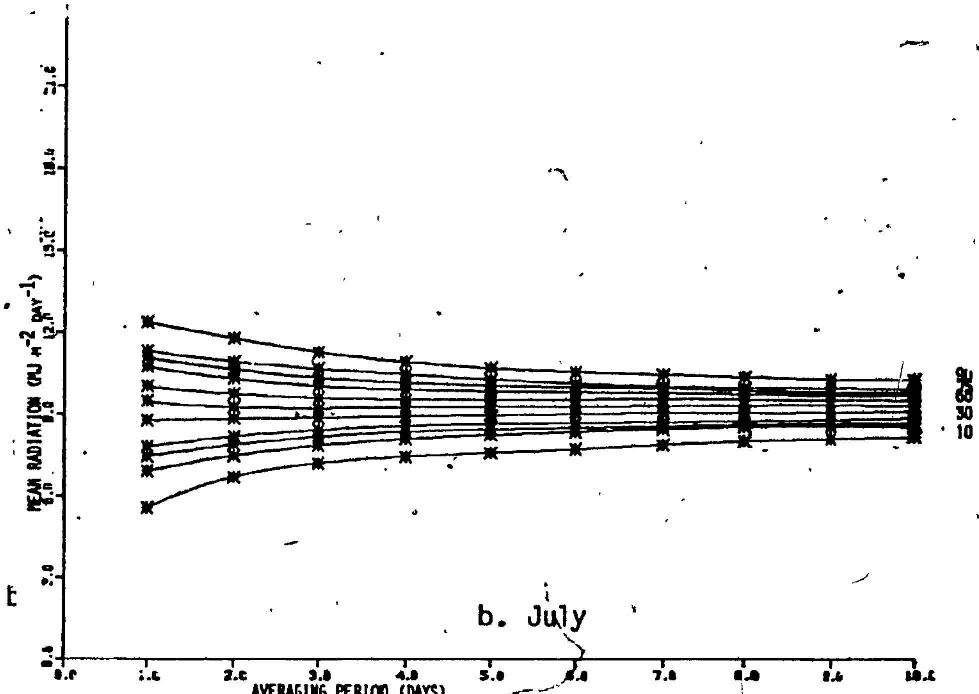



( ) Indicates horizontal diffuse illuminance (lux)

Plate (2.4), Diffuse, monthly mean radiation on the surface of slope 0°. ($kJM^{-2}$ $hr^{-1}$), in Montreal Quebec [137]




a. February




b. July

Plate (2.4 a,b) Ten percentile and quartile values of diffuse shortwave radiation on a horizontal surface for one to ten day averaging periods for Montreal [137]

## 2.5 QUALITY OF DAYLIGHT

The I.E.S. suggests two approaches to the lighting design process: (1) luminous environment (2) Visual task. It states that the design process must be considered on a larger scale than that of an analytical and engineering one. The common factors between the two approaches emphasize the quality of light. In the visual task approach, the factors to be considered are [71]:

1) Quality of illumination
2) Quantity of illumination
3) Selection of a lighting system (sources and luminaires)
4) Selection of a lighting control system
5) Economic considerations
6) Coordination with the mechanical system
7) Coordination with furniture
8) Interior - exterior relationships

In the luminous environment approach, which is more applicable to museums, in addition to the above factors, these are suggested:

1) Visual composition of space
2) Desired appearance of objects in space

These factors are very general and they cannot be applied to all building types, but considering the factors which are applicable to museums, the need for a qualitative approach is apparent. This is stressed by the fact that museums present a unique problem, since they occupy an undefined area between the theater and the school room: to achieve emotional acceptance by dramatic effect and to provide eye comfort for examination and study. By quality of illumination we mean freedom from glare, good modeling - not unidirectional or too diffuse - and variability to show the static object by some "movement" in the illuminance.

In order to provide the required lighting quality, one has to consider all the points not only from a technical point of view but also from a conceptual point of view. "... Concepts, not hardware, are the missing ingredients in the conventional approach to the design of the luminous environment (1)".

## 2.6 USE OF DAYLIGHT

The use of daylight in museums is the most controversial subject in museum lighting, from one extreme view that "Natural light should be as available in a museum as water from a faucet or cool air from a duct" (2) to "...it is really desirable from a display point of view to have a building with no windows .." (3). The evolution of the eye which has developed under natural light makes it necessary for us to see and judge our environment under natural light. Paintings and sculptures are generally conceived under natural light and should be viewed under the same quality of light. Evaluation of the quality of artifical light is based on natural illumination [36].

During discussions with museum curators, a majority of them preferred daylight as a source of illumination but under certain conditions. For example the curator of the American wing, the curator of the Johnson Museum and the curator of the Lehman Galleries, have stated, based on their practical experiences that daylight is the most desired form of illumination in museums. " ... a museum is a daylight institution. Any works of fine art it may contain were made in daylight and were meant to be looked at in daylight" (4). The idea that daylight is reproducable, or, not all works of art are being produced under daylight will be looked at later on, but it has been stated that even "if the museum's policy is to employ artificial light to reveal paintings as they really are, then the illumination employed should translate to viewers the widest possible scope of color differences. Such rendition is of course, produced by sunlight or daylight" (5).

## 2.7 THE CHANGING NATURE OF DAYLIGHT

The constant variation of daylight is one of its most important characteristics evoking both positive and negative reactions. James Gardner and Caroline Heller in their work on daylight concluded that "Daylight is rarely satisfactory as exhibition lighting: it is too temperamental in cold climates; in any climate it changes direction and quality throughout the day (6)". Whereas Louis I. Kahn emphasized the changing character of daylight as an important factor for his love for daylight, which is so expressive in his museum designs (see Chapter 7 for his works), "... the museum has as many moods as there are moments in time and never as long as a museum remains as a building will there be a single day like the other .." (7).

The variability of daylight affects the distribution of sky luminance, the exterior illuminance and the SPD which in turn affects the color rendering and deterioration of objects. The yearly average variations in illuminance and daily variations are shown in Plates 2.4, 2.4a and 2.4b. Instantaneous variations are random and will fall in the extreme limits for the season or month of the year but are documented with respect to daylight.

There is a critical lack of weather data on these variations in North America. Plate 2.4, derived from total radiation data shows a yearly variation of 35000 lux to 3500 lux from June to December at midday or 10 times. If sunlight is excluded from the gallery space, the extreme variation throughout the day can be roughly derived from the daily ranges shown in Plates 2.4a and 2.4b. Note that the dramatic changes due to the partly cloudy sky "switching" the sun off and on directly in the space, are discounted limiting the range to variations in the diffuse sky. For example, one day variations can be expected, at the 10 and 90 percentiles, to be 40% below to 65% above the 50% values in February. Instantaneous variations can be even higher.

Interior illuminance and its effects are proportional to the exterior illuminance; thus the perceived brightness distribution on surfaces will be changing as the exterior illuminance changes. There is considerable adaptation to brightness variations which is not very well understood; thus the foregoing debate about the value of illuminance variation can not be resolved.

The variations in sky luminance distribution will affect the interior brightness distribution. However since most good daylight luminaires are skylights or clerestories, see Chapter 5, which are in turn well baffled, the luminance distribution variations from clear and overcast skies are not great for altitude angles above 35 degrees. Also atmospheric pollution will not greatly affect the distribution, however much it may reduce levels in the space.

As will be discussed in Chapter 4, deterioration is a function of exposure which affects daylight in two ways. First is the actual distribution of daylight and UV and second is the level of exposure. Proper controls are required for both aspects which will be discussed in chapter 5 dealing with the daylight luminaires.

The variation in the SPD of daylight affects the color temperature (CT) to the object and its color rendering. Daylight exhibits wide variations in CT from low values (2500K) at sunrise and sunset to extremely high values from the blue sky (11,000 K) [71]. A skylight that "sees" the sky away from the sun will thus transmit light of very different color properties which is very difficult to control. As long as deterioration is controlled, the variations in color rendering will probably be an advantage to allow the object to be seen "under a different light". No research exists exploring this problem in museums.

## 2.8 VISUAL PERFORMANCE

The human eye mechanism has its particular needs. If viewing means "viewing and understanding", and in museums, it means "viewing and communicating", then the needs of the eye must be understood in order to provide the required environment for better performance of the eye. The apparent brightness of an object, accommodation and adaptation of the eye, the presence of contrast and glare plus modeling are examples of the requirements that affect museum lighting design which either have to be provided for or minimized.

## 2.8.1 BRIGHTNESS

Brightness is defined as a subjective evaluation of luminance (luminance is dependent on the amount of light striking a surface and the amount of light reflected back to the eyes L= x E for a matte surface). There is no conventional system of units for brightness, but scales of apparent brightness luminosity have been devised [116].

According to Fechner's law [70] which applies to touch, taste, sound and smell, the subjectively felt strength of the stimulus is proportional to the logarithm of the stimulus' strength. In other words to double the sensation we have to square the strength of the source. This theory does not hold with respect to lighting in terms of absolute value; a ratio of 10 to 1 creates twice the apparent brightness due to the contrast in the visual environment. Objects of the same surface luminance will be seen as brighter or darker depending upon the relative luminance of the visual environment. This is illustrated in comparing the three galleries in Plate (2.5) (a) objects are seen much brighter than in (b), and objects in b) have higher apparent brightness than in (c). Apparent brightness in itself is not the key to comfortable viewing although the illuminance decreases in c, b, and a, respectively. Comfort is dependent upon the luminance patterns in the visual field while visibility is affected by the adaptation state and quality of luminance patterns. As shown in (a) the eye would be under strain to adapt to a high level of variation. Viewing is therefore a function of visual capacity, the level of light provided on the work and the distribution of light to avoid exaggerated adaptation [123].

a

b

c

Plate (2-5), Comparison of contrasts within three galleries. (a) only objects are lit, (b) the paintings and walls are lit but ceiling is kept dark, (c) the overall flat lighting system needs more light to create the same contrast as (b). (72)

## 2.8.2 ADAPTATION

Adaptation is defined as changes in the eye's sensitivity to light so that it can detect details in low luminance and not be overloaded by brighter sources [71]. The luminance range over which the eyes can function is very large but it cannot adapt in a very short time Plate (2.6). Adaptation is very important in museum lighting since galleries which require low levels of illumination may be located adjacent to bright areas. Adaptation should not take place in the gallery but rather before entering the gallery. Therefore the planning of galleries should take this into consideration and provide transition areas. In the Rockefeller wing of the Metropolitan Museum of Fine Arts, New York, transition was not planned for; the visitors were asked to close their eyes for a few minutes in order to adapt to the lower illumination level of the gallery they were about to enter Plate (2.7) [70]. In the Johnson Museum no solution was sought to the problem of adaptation from dimly lit oriental art galleries to the bright view of the scenic mountains around Ithaca. As illustrated in Plate (2.8) (c) is the view of the galleries at the door (a) turning the eyes 130° is the view of the exterior to the unadapted eyes b) is the same view to the adapted eye. The unadapted eye misses a lot of information in the visual field and suffers from strain and fatigue.

Note that the eye can see a very wide range of luminance simultaneously called "transient adaptation" which does not require adaptation.

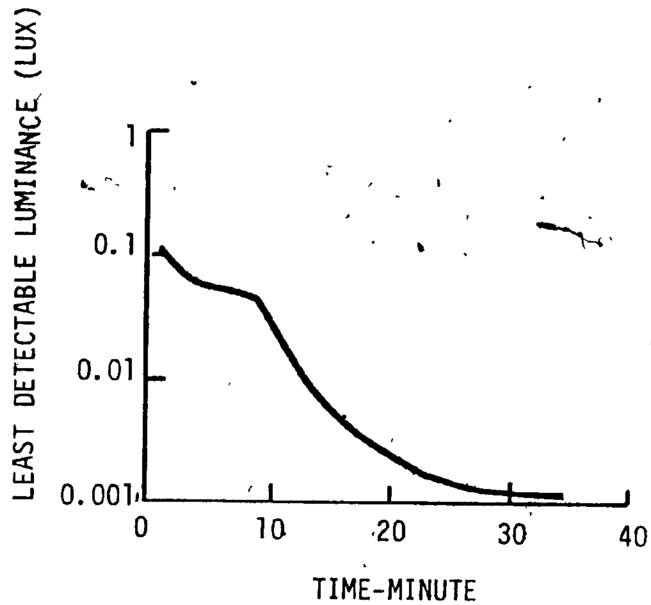



Plate (2.6), The light to dark adaptation process. [115].

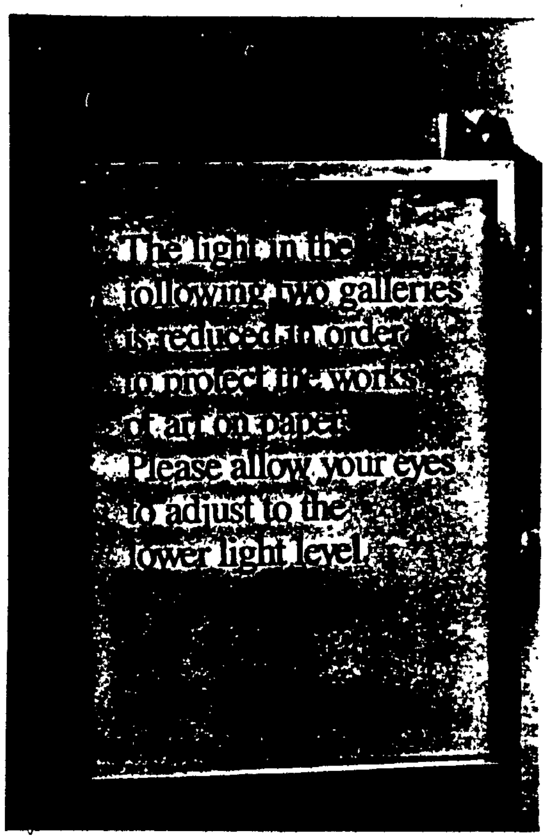
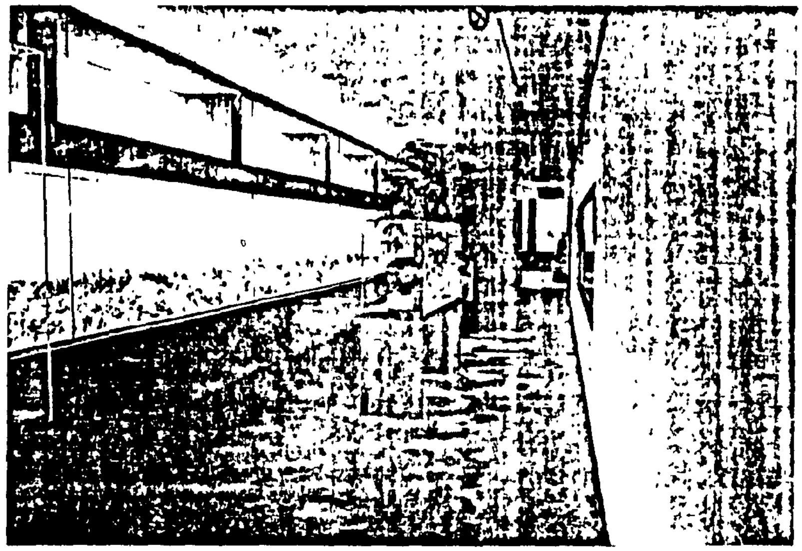



Plate (2.7), Sign advising visitors to close their eyes before entering darker galleries.

(a)



(b)

(c)

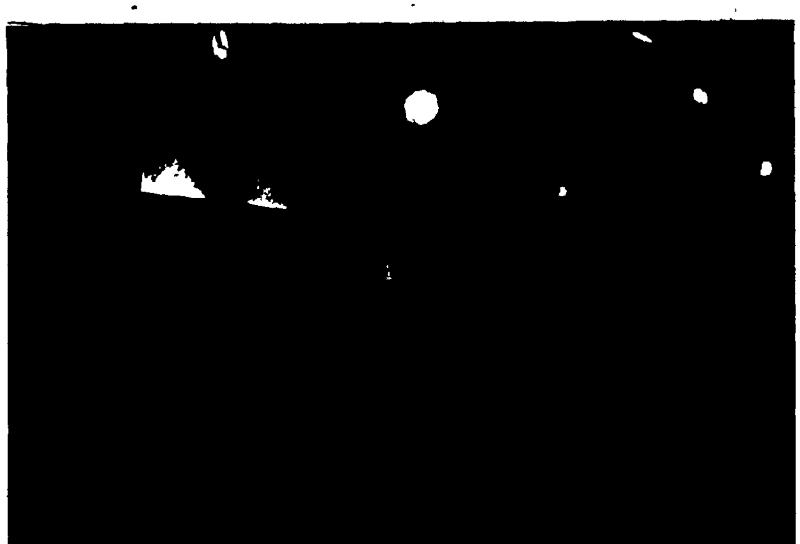


Plate (2.8), The view of the exterior to an unadapted eye (a), and to an adapted eye (b), looking away from low lit gallery (c).

To avoid the effects of adaptation, the eye should be given time to adapt. Entering a dark gallery (50 lux) from a brightly lit gallery (500 lux) requires 1.5 minutes of transition (chart 2.3 illustrates the time and distance). For example if one walks 1 M/Minute. In a museum then one must walk through a transition space of 1.5 meters. This speed is assumed based on discussion with curators and it could be modified if it is too fast or too slow. Based on any assumed speed the required distance can be calculated.

| RATIO OF ILLUMINANCE LEVELS | TIME REQ'D MINUTES | DISTANCE REQ'D METERS |
|---|---|---|
| 1 | - | - |
| 0.5 | 0.7 | 0.7 |
| 0.1 | 1.5 | 1.5 |
| 0.15 | 9 | 9 |
| 0.01 | 13 | 13 |

Chart 2.3 - The distance and time required for bright to dark adaptation in the transition space. Ratios larger than 1 to 100 should not exist in museums.

### 2.8.3 CONTRAST

A work of art can be seen because of its contrast with surfaces or objects which are adjacent to it (called the "background"). The "contrast" of a task is the relative difference in luminance between an object and its background as defined by the Blackwell Formula [116].

$$C = \left| \frac{L_o - L_b}{L_b} \right|$$

$L_o$ = luminance of the object

$L_b$ = luminance of background

For the work of art itself, it can be shown that putting 2 times the light on objects does not cause 2 times the contrast and therefore better viewing, since the law of diminishing return applies. If the background is receiving the same amount of light, at 1 F.L., the eyes have 57% of maximum visual acuity*; at 10 F.L. it is increased to 78% and at 20, the increase is only to 81%, or from 1 F.L. to 20 F.L., the increase is 24% of maximum visual acuity.

Generally the factors that cause or affect contrast in a gallery are:

1) room dimensions
2) surface reflectances
3) luminance distribution of luminaire
4) illuminance levels
5) intensity distribution from the luminous surface

---

* "Visual acuity" is defined as a measure of the ability to distinguish fine details.

6) the reflectance qualities of works of art (specularity, value and hue)

7) viewing angle

8) viewing direction.

All these factors should be considered when the texture and color of gallery surfaces are chosen. High contrast between the art object and its background not only does not provide for better viewing, but it causes another major problem in museum lighting namely glare. This is clearly demonstrated in unprotected windowed galleries and dimly lit interiors which have very high contrast areas and thus high glare indices as shown in the Johnson Museum (Ithaca) Plate (2.13).

A boutique or a department store tries to capture the attention of visitors and not to communicate with them but this is not the function of a museum. In museums harsh contrasts in light are not needed. There can be bright sources at points in the space, but the lack of light from walls, ceiling and corners, confuses the viewer in locating himself in the space and creates an overall sense of discomfort. The visual environment as a whole should provide the required contrast for viewing.

Certain methods are used to create "contrast":

1) To keep the space very dark and to concentrate the light on the painting as in Plate (2.10)

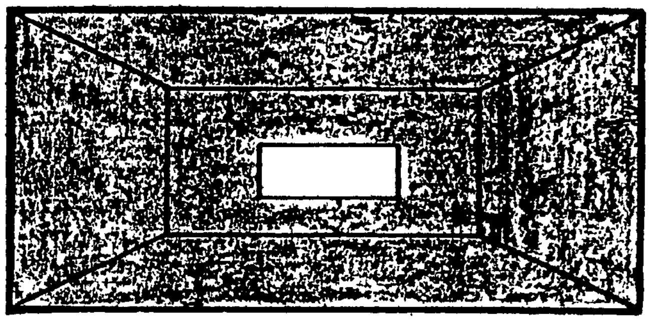


Plate 2.10

2) The illuminance of the space is kept low, but the walls are washed with light as illustrated in Plate (2.11).

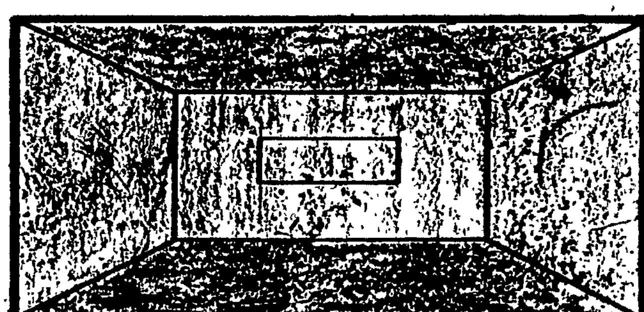


Plate 2.11

3) The illuminance level in the space is kept at a comfortable level. At the same time contrast is created on the wall in relation to the space, and on the painting in relation to the wall by control of reflectances and illumination. Plate 2.12 illustrates this type of lighting.

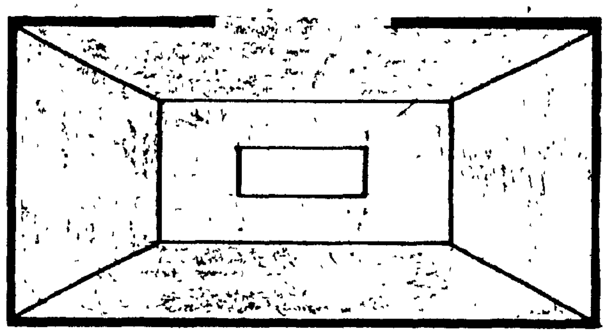


Plate 2.12

In comparing the three methods it is concluded that the third method is most desirable since it creates a comfortable ambiance as well as a needed contrast. The required level of contrast for comfortable viewing is a ratio of 1 to 10 between the object and the background whereas in some measured galleries the contrast provided is much higher (in the range of 1 to 20). Windows can be sources of high contrast, Plate (2.13). For daylit galleries, skylights provide the visual environment required for comfort and the avoidance of fatigue as well as proper contrast. Two exceptions must be mentioned: 1) where very sensitive works on paper are exhibited, transition spaces for adaptation should be provided 2) when exhibiting three dimensional objects to be lit in a special manner, as the sculpture in the Museum of Contemporary Art, Plate (2.14).

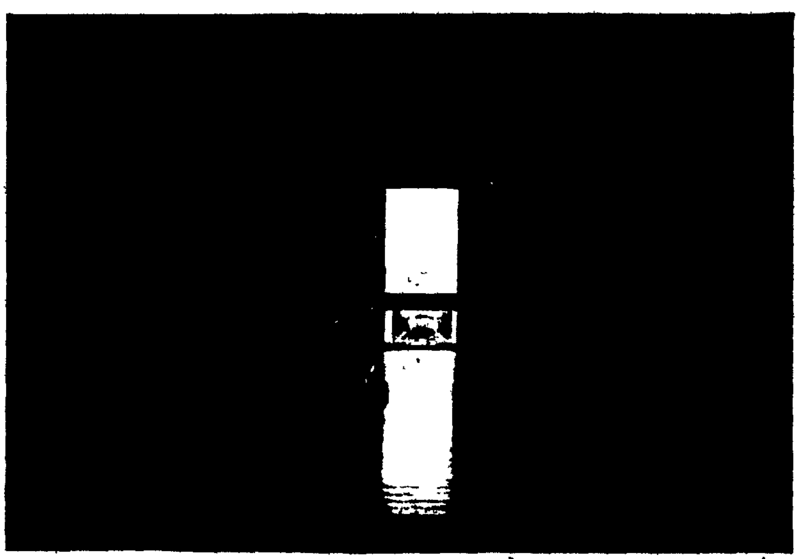
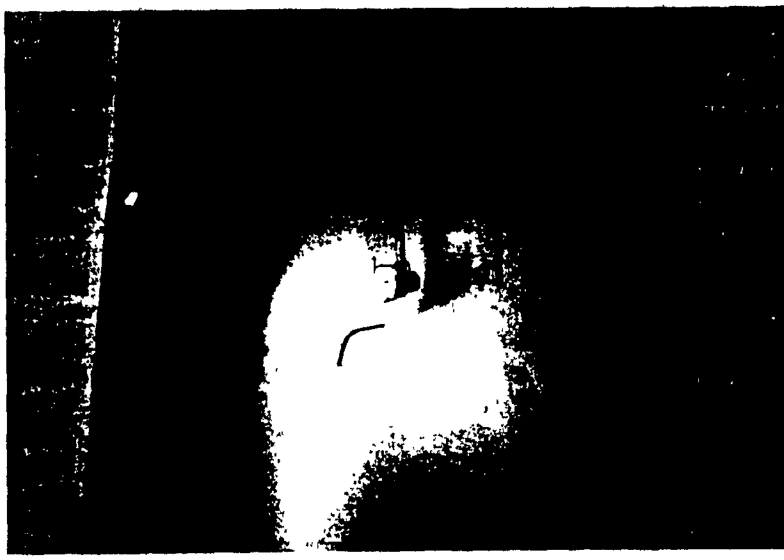


Plate (2.13), The view of the window, creating high contrast, veiling glare, Johnson Museum.



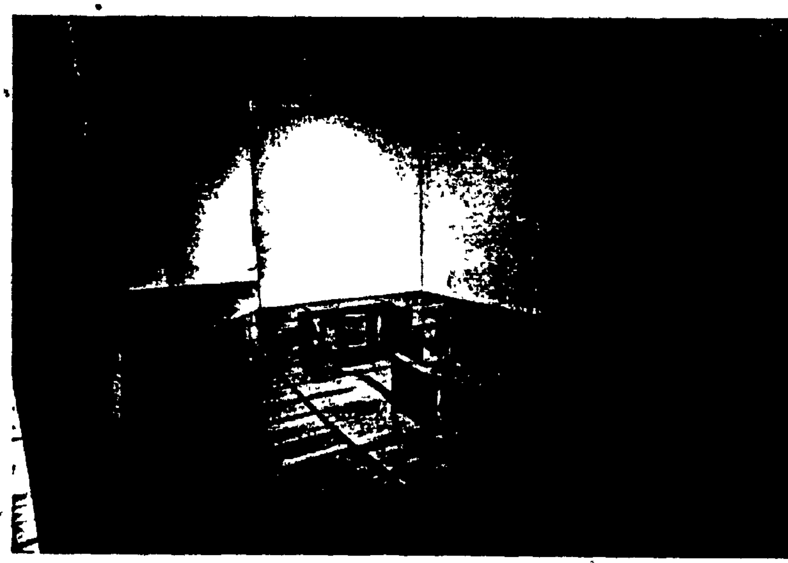


Plate (2.14) Special lighting (a), designed particularly for the object or display (b)

In the American wing, overall lighting is provided by the skylight and spots are employed to create contrast as task lighting. In the Everson Museum the artificial light has created very dark ambiance and very bright objects. For conservation purposes it is suggested that in order to reduce the level of light we should create very dim environments [19] [23] [122]. Therefore a very low density light will appear very bright, but catching the eye is for selling goods and not communicating ideas. Many museums which have used general daylighting as ambient lighting in combination with spot lights as task lighting, to create contrast, in addition to other factors, have been successful in providing the recommended level of contrast between the object, background and the space as will be illustrated in Chapter 7.

### 2.8.4 GLARE

Glare is one of the most important phenomena for designers of museums since the viewer is not in a fixed place in the gallery and his/her directions change constantly. Glare is defined as excessive luminances or excessive contrast in the field of view [115]. There are three types of glare: a) Disability glare is caused by very bright sources of light in the field of view, as illustrated in Plate (2.15), resulting in loss of visibility in the viewing direction. b) Discomfort glare. c) Veiling glare is caused by the reflected source's brightness off the painting and other semi-specular surfaces causing a loss in visibility as seen in Plate (2.16). The reflection of the spot light is superimposed on the painting, making seeing impossible. In the Johnson

Plate 2.15, Glare caused by spot lights. Montreal Museum.

Plate (2.16),
Reflection of spot light into the glass of the show case, causing Veiling glare, MMFA.

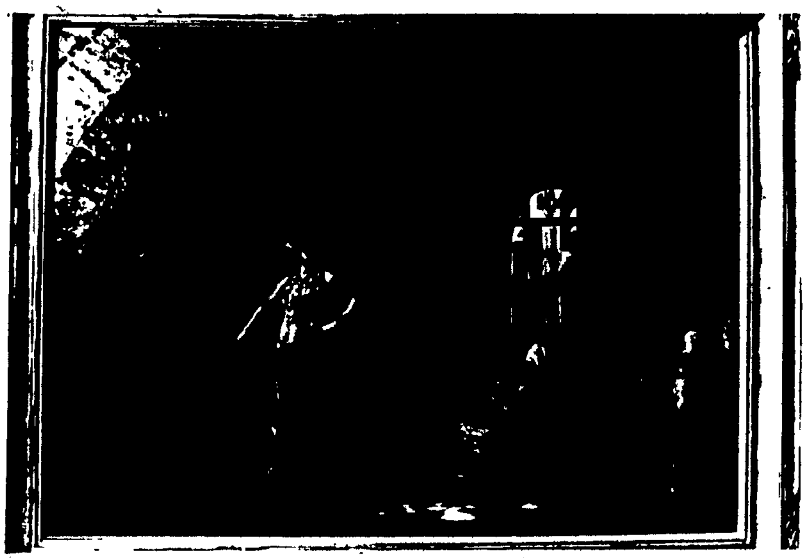


Plate (2.17), Reflected glare from the painting due to the window on the right. The viewer is not able to see the corner of the painting.

Museum; Plate (2.17) the corner of the painting is invisible due to the reflection of light coming from the window. Veiling glare is also caused by a specular or glossy surface such as glass over the painting which reflects a bright source reducing contrast of the surface, as can be seen in Plate (2.18).

A - Discomfort Glare

Discomfort glare is measured in terms of visual comfort probability (VCP) which takes into account the field luminance, position index, size and luminance of the source. It uses the discomfort glare formula as described in the I.E.S. handbook. Indirect or disability glare is more difficult. It is usually judged subjectively or E.S.I. values are used to indicate its magnitude. Because of the varying position of the viewer no adequate glare index exists. The designer should analyze each problem graphically and locate potential sources of glare. At times, compromises should be made in which one of the two kinds of glare is eliminated.

B - Veiling Glare

The problem of veiling glare is due to the geometry of the relationship between the viewer, the picture and the source. The first assumption is that the source intensity is sufficient to cause veiling glare which is true for typical artificial fixtures and daylight sources including windows and roof lights. The second assumption is that the picture surface is semispecular which can essentially be represented by

Plate (2.18), Tapestry seen in glare (a), loss of detail, and free from glare (b).

a plane mirror to determine what sources cause veiling glare. The viewing position, picture height, width, tilt and distance to the ceiling all affect the size of the veiling glare zone. If the picture surface is curved then the zone is further enlarged or compressed depending on whether it is concave or convex.

As one moves through the gallery space, the viewers position, viewing direction and distance to the object constantly change. Thus the veiling glare* zone moves, expands and contracts. When the veiling glare zone overlaps a fixture with intensity in a direction to the surface, veiling glare will occur. If the source is bright the glare problem is very distinct. If the surface is very specular then the source is seen more distinctly reflected from the surface.

The key to locating the glare zone with geometry is the fact that the angle of incidence is equal to the angle of reflection. Plate (2.19) illustrates the process graphically. The viewing angle of 30° is assumed. The observer can move back and forth between E and F. At F position any object below F' ~~is in~~ the glare zone. At E position any object below E' is in the glare zone. Therefore in order to avoid the glare zone the object should be located below E' for (E) position. The geometrical analysis of glare is discussed in Chapter 5, with respect to daylight luminaire concepts.

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* Veiling glare at a small scale gives objects their sense of "shininess" or sparkle.

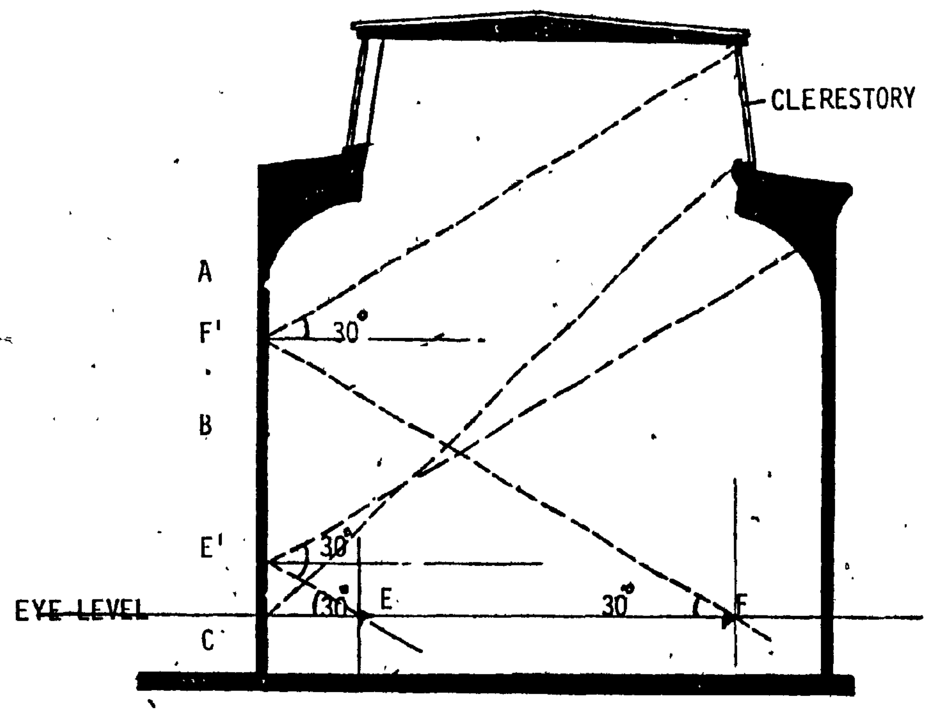



Plate 2.19 Incident and reflected rays are shown for positions A, B and C on a wall. The possible viewing zone is from E to F. Pictures mounted high on the wall have more VG than lower positions if the room is large. For high narrow rooms there is a zone E' to F' on the wall on which is reflected the clerestory as seen from E to F. This assumes the viewer is perpendicular to the wall; for oblique orientations the objective is to effectively widen the room.

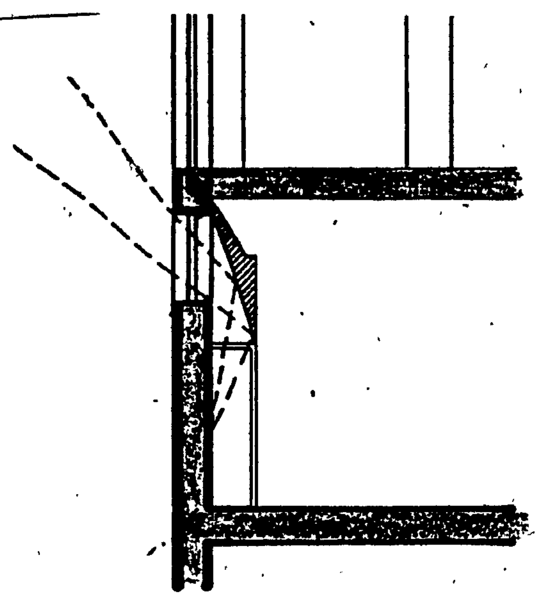


Plate 2.20, Clerestory window is blocked from the view and light is reflected to the wall.

The problem of glare has been with designers since the first galleries. At that time windows were the concern. Pseudo windows were drawn in order to decide where the painting should be located and how to block the window from the field of view Plate (2.20). In terms of sky lights, the offending zone can be graphically illustrated, since the angles of incidence and reflection are equal. It was indicated by museum curators that "glare cannot be avoided" since the use of point sources of light, such as track spot lights shining in several directions creates almost inescapable glare problems Plate (2.21). Glare can be avoided by proper planning and lighting design as in the Ontario Art Gallery Plate (2.22). In other museums such as the Montreal Museum of Fine Arts the sources of light are left bare and shine into the eyes of the viewer Plate (2.23).

The problem of avoiding glare has to do with the location of the source in relation to the ceiling height, the distance of the viewer from the wall and the location of the painting on the wall. Plate (2.24) illustrates where the light source should be located and at what angle it should be directed in order to avoid glare and provide for seeing details. Note that the concept of modeling becomes almost an integral part of glare solutions.

The curator of the Montreal Museum of Fine Arts stated that the problem of glare cannot be solved in museums. The light is coming from many directions and a moving observer is bound to suffer from it. One can demonstrate very easily by looking at existing examples that it

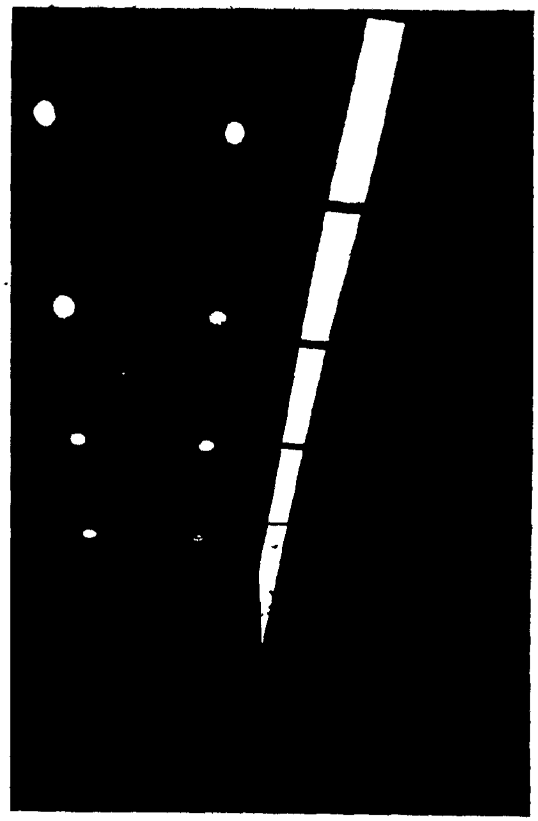


Plate (2.21), Spot lights shine in all directions creating glare problems in some directions.

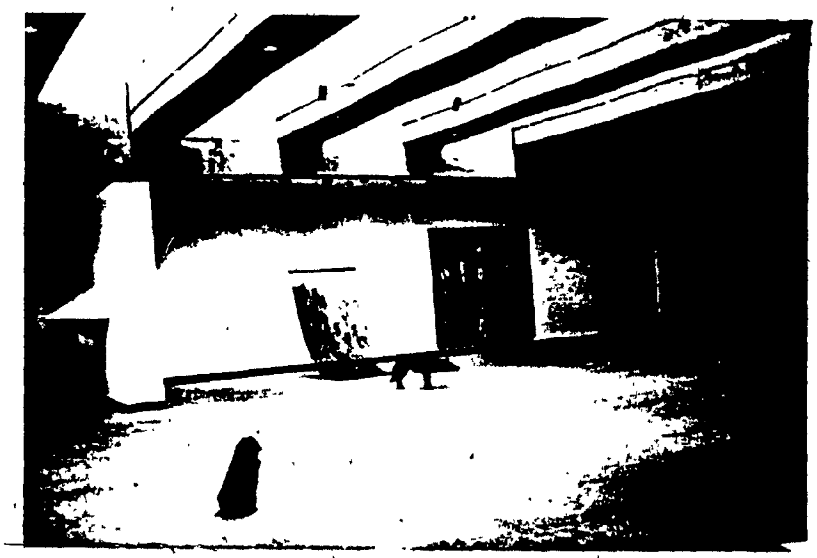
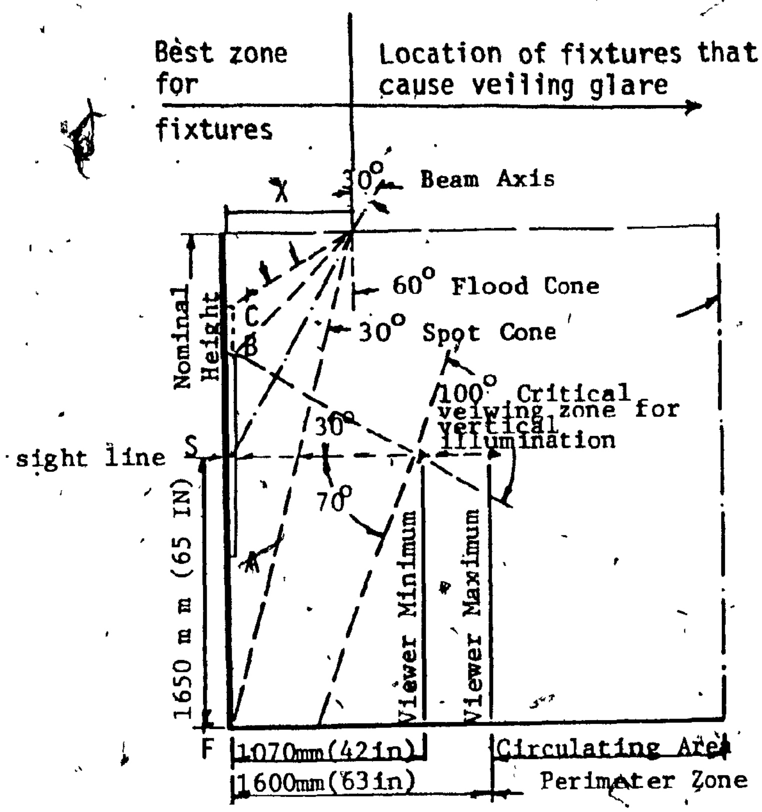


Plate (2.22), Ontario Art Gallery, view is glare free.

Plate (2.23), Exposed wiring and lights causing glare. MMFA.




Model perimeter (viewing) zones at normal ceiling height. Model based on: (1) primary diffuse component (of vertical illuminance) at approximately 40 per cent of horizontal illuminance at S, (2) height of wall-hung display, (3) ideal utilization of beam cones, and (4) minimum effective viewing distance relative to a nominal height of object (A to B=1320 millimeters (52 inches) for a 30-degree cone, A to C=1650 millimeters (65 inches) for a 60-degree cone). To calculate viewing zones for higher objects, increase horizontal dimensions 38 millimeters (1.5 inches) for each 25-millimeter (1.0-inch) increase in height of object.

X=(ceiling height - eye height) (.577)

for an aiming angle of 30 degrees from the vertical. [122].

Plate (2.24), Optimum location and aiming direction for artificial fixtures.

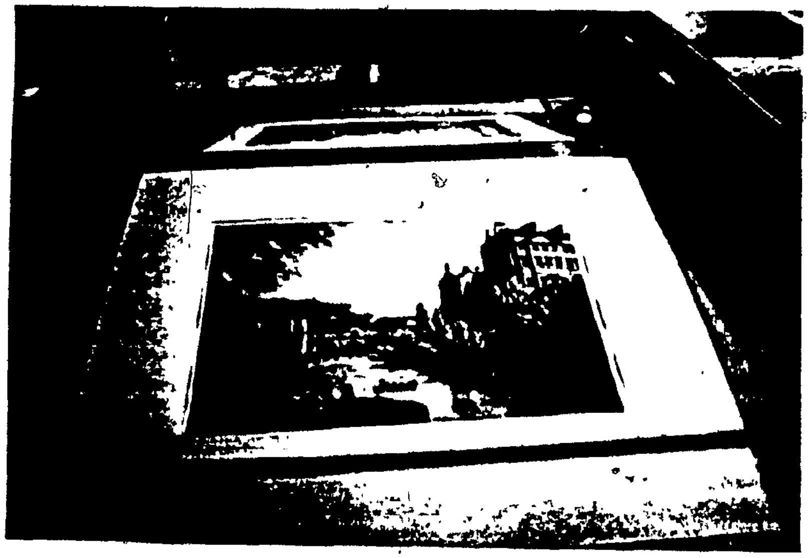


Plate (2.25) The source is aimed in such a way as to minimize glare. Yale Art Gallery.

Plate (2.26), The strong glare caused by looking at the source.

can be solved or at least minimized. Having to look up and seeing the source is a glare situation which can be avoided by the viewer; viewing a painting and seeing reflections and light sources on the painting is another type of glare which cannot be avoided. For example at the Yale Art Gallery, Plate (2.25), one has to look up at the ceiling in the direction of the light in order to be affected by glare. In normal fields of viewing art works there is no glare. In the (L) Gallery of the Montreal Museum of Fine Arts the glare source is in the field of view Plate (2.26).

Design for Glare Control

Daylit museums must block direct sun rays and light must be introduced through multiple reflections. Still the problems with veiling reflections and indirect glare exist, particularly with windowed galleries. (See Gallery (14.A) of the Johnson Museum in Chapter 6). Discomfort glare is the most serious problem in museums. In daylit galleries, glare is removed by the use of a reflecting surface and proper location of the source. In older galleries the pseudo window or clerestory is used to locate the glare zone to avoid exhibiting in this area. Since the daylight source is so bright, quantitative distinctions are unimportant.

The calculation of veiling reflections from specular surfaces is mathematically defined but tedious in practice. If however, the designer defines veiling glare zones on a ceiling plane and locates sources outside that zone the glare problem will be minimized. Only a full scale mockup of the space can detect all glare problems and while this is a common practice for a typical museum gallery, all conditions in a gallery cannot be mocked up.

Models are of use but are limited by their dimensions and survey techniques. Better modeling techniques need to be developed for glare studies. Polarized light sources can eliminate veiling glare; however polarizing filters are expensive especially when used for large area sources like daylight.

## 2.8.5 MODELING

The direction of light whether direct or diffused causes works of art to be seen differently. To designers the process of designing the angle of light direction is called modeling.

Modeling is clearly illustrated in Plate (2.27); depending on the direction of the light, different shadows are cast at a large and small scale. The designed angle of incidence is based on, a) what has to be revealed b) the avoidance of glare. Modeling is also employed to create patterns on the wall, Plate (2.29). In Plate (2.30), a,b,c,d are comparisons of angles of incidence of light on the works of art, with varying effects on texture rendition and coverage.

Modeling is characterized according to how directional it is. Two opposite descriptors are direct and diffused light. When the rays come from a predominant direction, strong shadows are cast on the object. Diffused light is either reflected from a surface or transmitted through a glazing material. An example of reflected or diffused light is the skylight system in the sculpture Gallery of the Ontario Provincial Art Gallery Plate (2.31). A diffusing material located between the daylight source and the object such as the daylighting system in the American wing at the Metropolitan Museum of Fine Arts Plate (2.32) is an example of diffused transmitted light. Color will be discussed later on in relation to modeling. Colors look different depending on whether the light is direct or diffused. This is due to interreflections of light

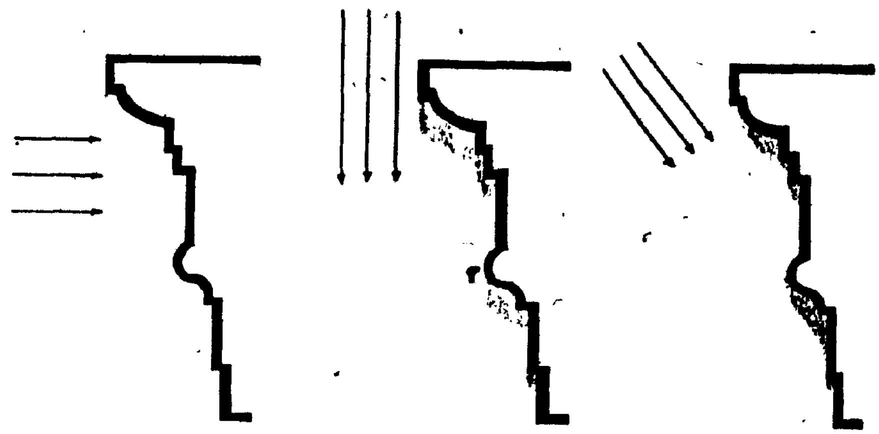
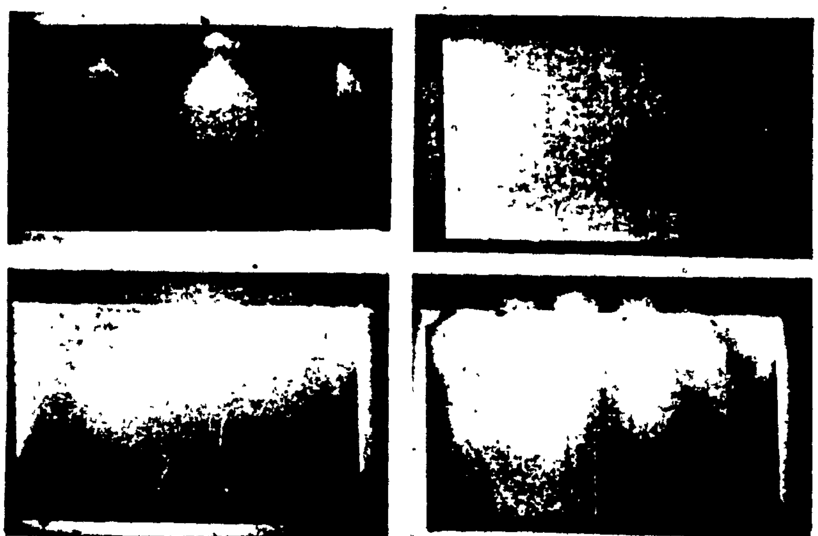


Plate (2.27), The way object is seen is directly related to the direction of the light.

Plate (2.28), The spot light is aimed to minimize glare. Yale Art Gallery.

Plate (2.29), Pattern created by spot lights. Note that the painting in the middle is missed.



a b c d

Plate (2.30), The wall washers are used for modeling, illustrating modeling techniques.

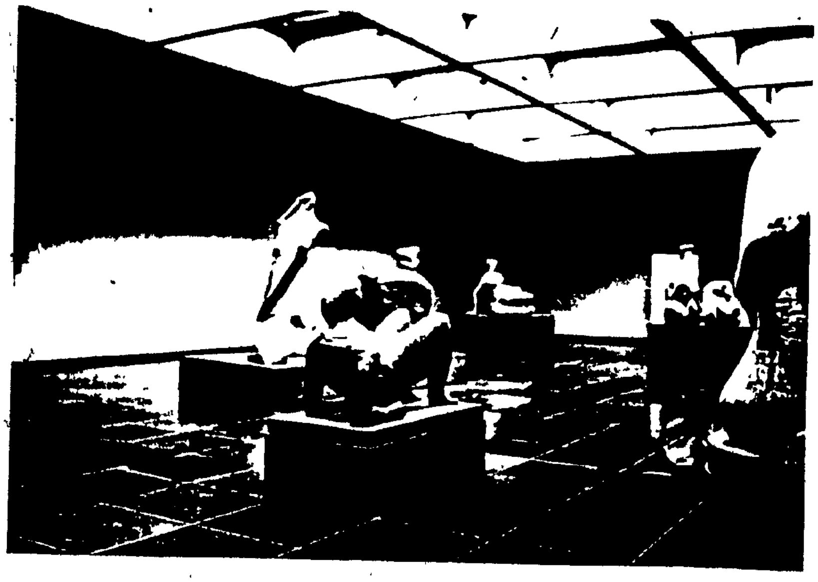


Plate (2.31), Sculpture gallery of Ontario Provincial Art Gallery.

Plate (2.32), Transmitted diffused light. American wing from the colored surface. Modeling should consider the works of art, background and the possible positions of the viewer. Glare and modeling, as was indicated, are two basic problems in museum lighting design, but unfortunately they have not been resolved even though they have been discussed at length and solutions have been proposed.

Modeling is directly related to glare; the location of the source is very crucial in order to avoid glare. In museums, light should be partly directional and partly diffused. As in our exterior environment, light comes from above, partly direct and partly diffused. The location of a light source should be designed in relation to the ceiling height. The location of a source is more critical with glazed works or glass cases due to reflections. This problem can be avoided if the source is not installed in the glare zone. As seen previously veiling glare control limits where fixtures can be located.

The texture of a work of art and its kind of finish is important. If highly textured, the light source should not be installed in high angles since it will cause strong shadows. The optimum incident angle is suggested to be 60-30, since the light will be reflected from the glass to the floor and not to the eyes of the viewer. Glossy finishes are more difficult to illuminate particularly with beam lighting, since they will reflect the light into the eyes of the viewer and at times distort the shape of the object. Therefore reflected light or ambient light is best for glossy finishes. Matte finishes reflect the light in a cosine distribution and thus directional beams can be used to light these types of surfaces.

The curator of the Johnson Museum pointed out that the carpet in some galleries altered the quality of light. The light beige color carpet, made the light much softer, whereas in the wood floor gallery the light is more red. In some museums, the use of extensive sky-light tends to create a sense of flatness and monotony which can be overcome by the use of a proper finish. This was the case with the Israel museum. The curator complained about the lack of contrast in the space. In changing the carpets on the floor a new plane was created in allowing the viewer to concentrate on the wall, the focal point.

In order to avoid glare in partially artificially lit galleries, the incandescent light can be located behind a layer of laylight, which creates a uniformly lit ceiling. A good example of the use of laylight is at the Chagall Museum in Nice where the density of laylight is changed to create 3 zones of brightness which creates concentrated as well as general lighting Plate (2.33).

## Design for Modeling

Display lighting should have two designed components - diffuse and direct light such that the vector to horizontal scalar illuminance is 1.2 (angle of vector at 30° from the horizontal) to 1.7 (angle of vector at 75°) according to unpublished studies carried out by Lynes in the U.K. [94]. The minimum 30° angle is usually unacceptable for veiling glare reasons because daylight changes. A gallery with direct fixed artificial lighting and diffuse daylight will have those ratios change thus the modeling condition is constantly changing. This can produce a dramatic difference between day and night; thus an ambient artificial system should imitate roughly the daylight system.

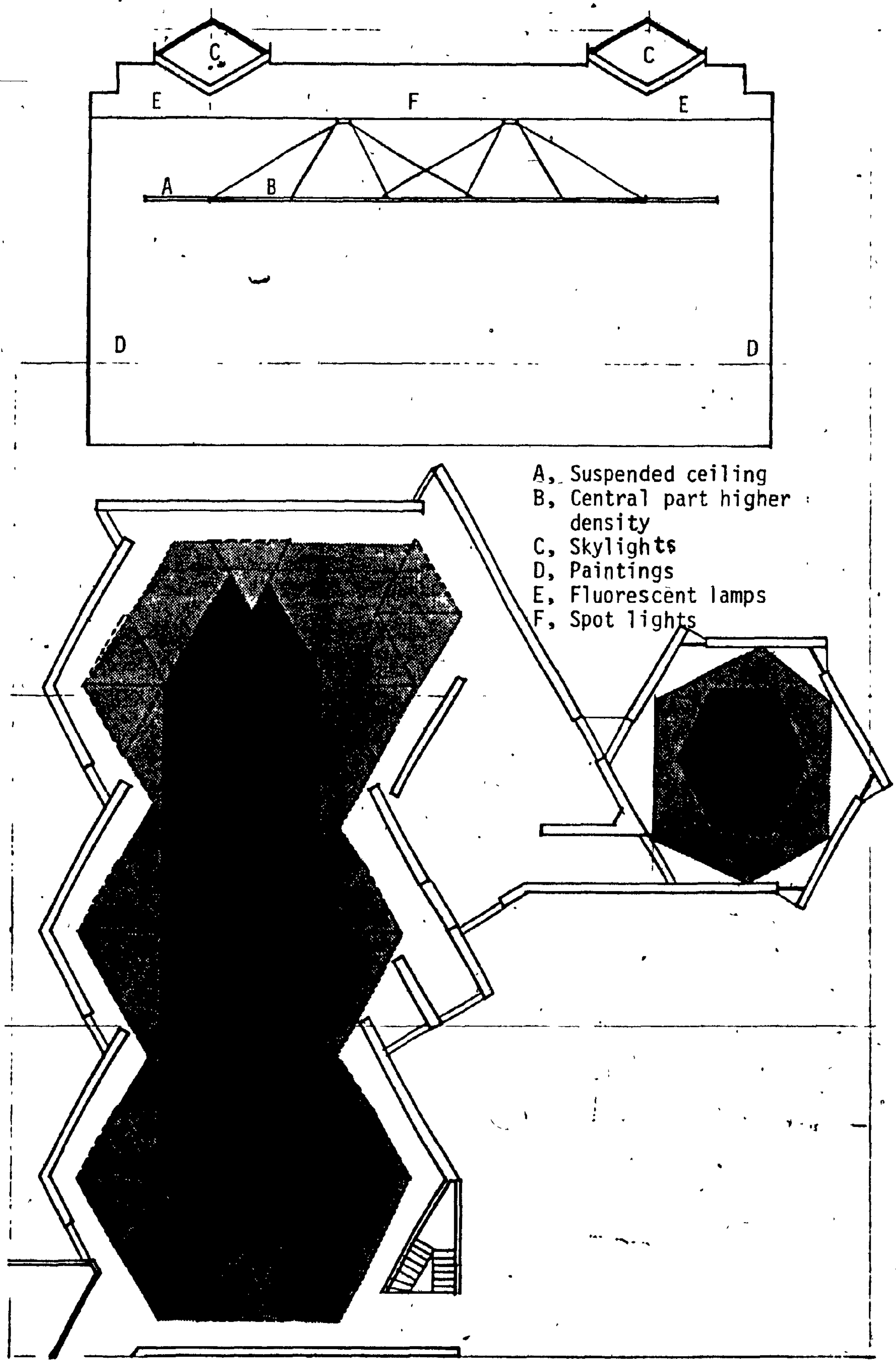



Plate (2.33), Section and reflected ceiling plan, Chagall Museum in Nice, three zones are defined in terms of contrast.

## 2.9 CONCLUSIONS

Human perception, the eye's characteristic and response, the light that makes seeing possible, the sources of light, should be considered individually and as they interact with each other. Providing for one or two of these factors should not cause the designer to ignore other factors. The integration of these factors becomes more acute in "museum" lighting design.

With a proper design of museum lighting, taking advantage of available daylight and color of sources, adequate illumination of objects can be accomplished by satisfying the requirements of the visual environment. Daylight should be used extensively and controlled substantially in order to meet the requirements. It should be capable of being introduced in the viewing area from above, behind and from each side of the viewer in varying proportions depending upon the object being viewed. It should be capable of being regulated and varied in intensity according to the nature of the material being lit. It should be so diffused and so directed to the object that glare and reflection are minimized. We shall see examples that meet if not all, most of these criteria.

1) Daylight and artificial sources are very different in the stability of illuminance, modeling direction, color temperature variations and glare potential. Average exterior illuminance can vary from 40% below to 65% above the mean value

thus affecting interior lighting conditions. Therefore it should be used for ambient lighting. Artificial lighting can provide a good base for the task visual environment if the CCT is matched with daylight. Daylight's variations then allow subtle qualities of the object to be shown.

2) Very bright sources as well as flat lighting should be avoided.

3) Transition spaces should be provided for adaptation. These spaces should be designed with respect to the time required for adaptation.

4) The glare problem should be analyzed analytically and geometrically. The glare zone should be located and its effect on the viewer should be removed or minimized. The veiling glare zone from one viewer position can be defined exactly. For the space as a whole the optimum positions for sources to avoid veiling glare can be defined.

5) Modeling is the key to seeing an object's texture, form and size. The distance of the viewer from the object, the object's characteristics and the angle of incidence of light should be considered in designing modeling. The ratio of vector to horizontal scalar illumination should be greater than 1.2 at a 30° vector angle.

6) The above points affect each other. For example, the relationship of the viewer to the source(s) affects the interaction of veiling glare and modeling.

7) Scaled model studies can be used with some caution to analyze the visual environment; however, full scale mockups are the most satisfactory solution.

## 2.15 FOOTNOTES CHAPTER II

1. William, C. Lam, Perception Lighting as Formgivers for Architecture (New York, 1977) p. 18.

2. Wilcomb E. Washburn, "Natural Light and the Museum of the Future," AIA Journal, (January 1965), p. 60.

3. Ibid, p. 61.

4. Benjamin I. Gilman, "Glare in Museum Galleries: The Psychological Factor in the Lighting Problem," Architectural Record 38 (Aug. & Sept. 1915), p. 362.

5. Lawrence S. Harrison, "Visual Experience and Museum Lighting", International Lighting review, 5 (1955), p. 158.

6. Washburn, p. 61.

7. Barbara Weiss, "American Museums, Three Examples," Lotus International, 34, p. 103.

8. Walter Gropius, "Museum Lighting," AIA Journal, (January 1965), p. 58.

CHAPTER III

# COLOR

## 3.1 INTRODUCTION

The human eye is able to discriminate between approximately 7,500,000 different colors through a matrix of intensity, wavelength and purity. If wavelength alone is considered, the eye is able to distinguish 128 different colors, some as close as 1 nm, some as far apart as 22 nm. Seeing in color is such a common experience that it is difficult to imagine how many factors are involved in studying color [22]. These factors in isolation could be put in three groups: (1) The physiology and psychology of the human receptor, the sensitivity of the eye, color adaptation, color constancy, color memory and metamerism (2) the characteristics of the object, the combination of pigments and their overall spectral distribution (3) the characteristics of the source such as spectral distribution, color temperature, color rendering index, etc. A study of color in museum lighting must consider these elements together and how they interact. Needless to say color is one of the most important factors of communication and conservation in museums.

## 3.2 RADIOMETRIC SPECTRAL DISTRIBUTION OF COLOR

The sensation of color is created by the action of visible radiant energy on the retina of the eye. The normal eye is most sensitive in the green and yellow region and least sensitive to blue and red light.

The band of visible light (approximately 300 nm to 780 nm) contains the whole color spectrum from dark purple to dark red, depending on the wavelengths. The color response of every light source fits into this spectrum, depending on its relative energy content at each wavelength.

To be precise, three distinctions have to be made regarding the question of color a) color b) color of an object c) the perceived color of an object, depending under what illumination the object is seen. Color is the basic distinction made by an observer between different patches of light in terms of relative energy content at each wavelength. The reflected color of an object is a spectral power distribution reflected from that object illuminated by a standard source (CIE). The perceived color of an object is the psychological response to the object when seen by an observer under daylight [71]. The eye does not behave as a spectrophotometer to detect each wavelength; instead it detects relationships among wavelengths by cones and rods (cells in the retina). The exact mechanism is not well understood. The visual clarity of scenes containing colored objects is dependent on the illumination. The perceived color of an object therefore is dependent on:

1. the response of the eye/brain
2. the nature of the light cast on the object
3. the reflectance of the object

These three factors are used in studying and evaluating color in museums.

### 3.3 THE EYE AND COLOR

Plate (3.1) illustrates the relative sensitivity of the human eye. The spectral radiation of any source seen by the eye could be transformed into the visible spectrum in order to find out theoretically what color should be perceived. Actual perception is subjective and highly dependent on context and thus predictions are risky. For example Plate (3.2) illustrates the spectral energy curves of an overcast sky and a "daylight" fluorescent tube (dotted line). In multiplying each curve by the luminosity curve of Plate (3.1) we get the reflected luminosity curves for the two sources Plate (3.3). It is apparent that the ultra-violet and infra-red regions of the sources have registered zero in the eye.

**Plate (3.1), The relative Sensitivity of human eye to different wave-length of light [18].**

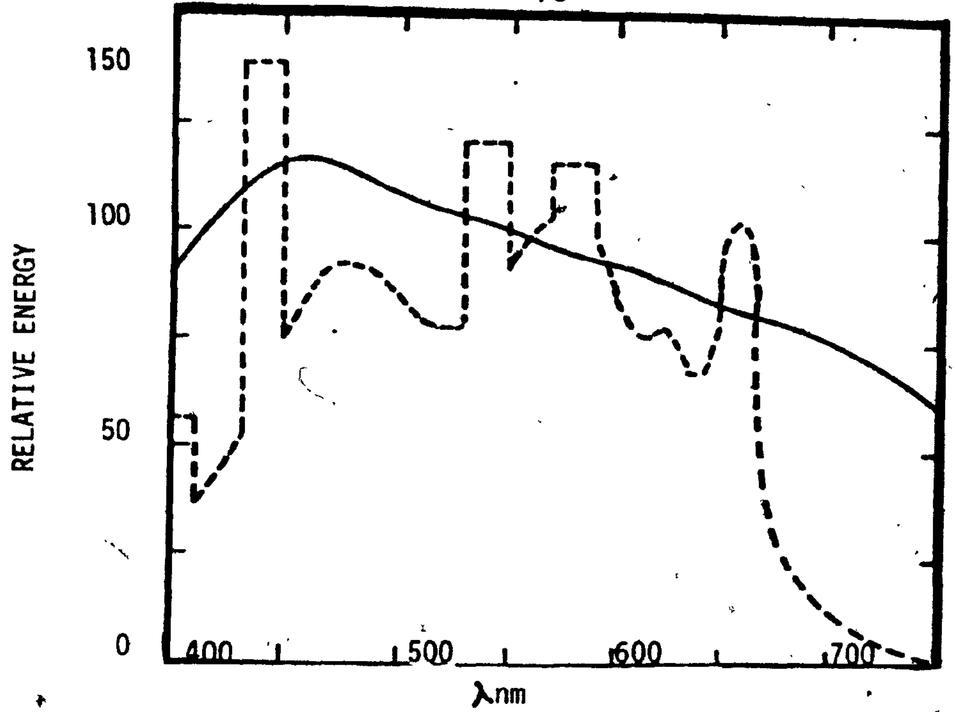



Plate (3.2), Spectral energy curves for an overcast sky (fullline), and a 'daylight' fluorescent tube (dotted line). Nearest colour temperatures 6400°-6500°K. [18].

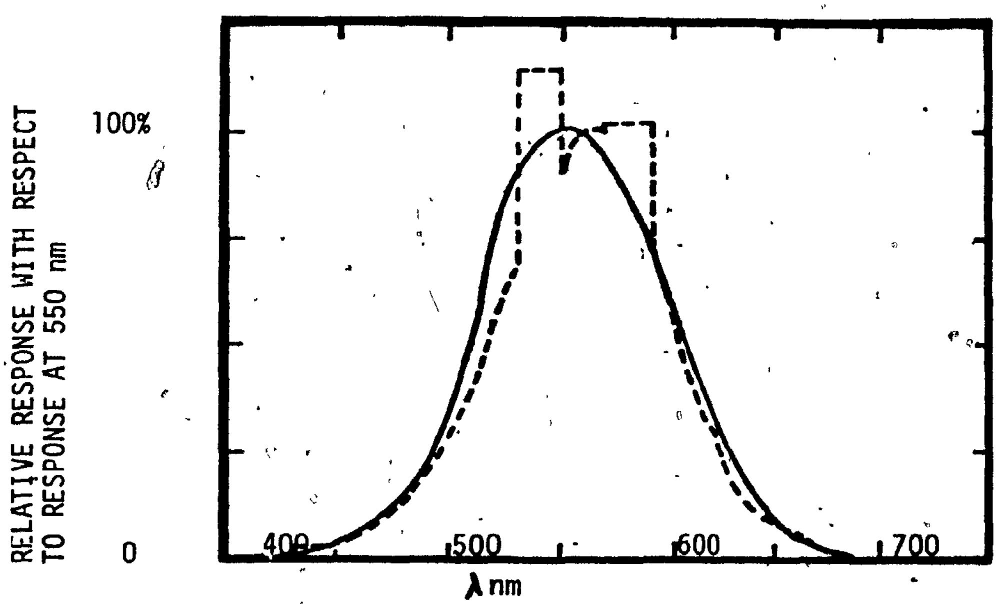



Plate (3.3), Luminance curves for the two illuminants. These curves have been obtained directly from those in 3.2 by multiplying each curve by the luminosity curve shown in 3.1. The color rendering quality of the tube compared with true north sky light may be assessed by measuring the differences between the two luminance curves. [18]

### 3.3.1 COLOR ADAPTATION

Visual adaptation was discussed in Chapter Two; the concept of color adaptation basically follows the same principle in the eye. It has been experienced for example that: if the eye is viewing red light for a long time, then it is exposed to a yellow object, it will see green. This is due to the reduced sensitivity of the red receptors of the eye. The response to the green region of the reflected light from the yellow object becomes predominant, but the eye will soon adapt to the new SPD of the reflected light and will see yellow. The idea of adaptation is taken to extremes in justifying the use of any light source in museums, regardless of its color characteristics. "... Whatever the light source, as long as it can roughly be called white, the eyes will see white objects as white under it." (9). Color adaptation is determined by the total visual environment which is composed of objects of different color and light sources of different color characteristics.

### 3.3.2 COLOR CONSTANCY

Color constancy is a phenomenon that compensates for minor different changes in illumination in a normal (vs. critical) eye as long as the same object is not illuminated by a different source in the field of view. For example the view from a window reveals the same green color of grass whether illuminated by the sun or blue sky. Color constancy requires time to be effective, along with adaptation, and if changes are too fast, color constancy cannot compensate. Color constancy relates to color memory (a psychological phenomena) [72] and is such a common experience that we tend to take it for granted. These functions take place in general viewing conditions of day to day life experience. But how much compensation could be made by a critical viewer in nature or the museum visitor who looks at color and its relationships for communication? The eye/brain do not behave like a camera, but if we record a scene with color film which is responsive to different color temperatures, the change of color is apparent. This change might be insignificant to the passer-by but not to the artist viewing the scene with critical eyes. One can imagine these scenes, a) the snow which is lit by both the sun and the sky (seen as white), b) the snow in a light shadow (seen blue if one pays attention) c) the snow under the tree mostly in darker shade (seen as darker blue). Due to color constancy, color memory and color adaptation, in all locations the snow is said to be white to the skier coming down the mountain. A person who pays attention is aware of a tint of blue in the shade and a darker blue in the trees, which is the case in museums. The viewer is aware of colors, he/she has come to see. The design should provide the lighting that makes the viewer aware of the color, even if he/she tends to ignore it. Color constancy, is useful to a certain limit but should not be taken to extremes.

### 3.4 MEASUREMENT OF COLOR

The C.I.E. chromaticity system, correlated color temperature, color rendering index and Munsell are some of the methods used in measuring color. These methods are discussed in Appendix (2). Color temperature in evaluating museum lighting will be briefly defined in the following section.

#### 3.4.1 CORRELATED COLOR TEMPERATURE

Color temperature is a specification of chromaticity only and does not express anything about the SPD of the source [70]. Two sources may be plotted very close in the color temperature locus but have totally different SPD curves. Plate 3.4 illustrates spectral distributions of different color temperatures. (For a basic discussion of color temperature see Appendix 2).

In museums, the measurement of color temperature indicates the effects of all the color sources on the objects in the actual visual environment. The mixing of two sources (daylight and incandescent) with different color temperatures are not additive ie. the two C.T. cannot be added. The source with a higher intensity has more influence on the reading. The SPD of sources are additive and are a better indication of the color properties of the combined sources. Table 3.1 shows the color temperature readings taken at museums studied. One finds large variations in measured color temperatures in daylit spaces which raise questions as to the effectiveness of color constancy and color adaptation.

Table A-2.1 illustrates the color temperature of common museum light sources. It is recommended that a C.T. of 5000 °K be provided in museums [51].

### 3.4.2 COLOR RENDERING INDEX

The color rendering index is defined in Appendix (2). The key element in the definition is the CCT of the unknown source compared to a known CCT referenced source. If the CCT of the sources to be compared are different, logically, the CRI has no meaning. Thus one cannot compare the CRI of incandescent and daylight sources. In certain galleries measured in the field (Plate 3.1), the CCT varied greatly. Thus the CRI will not be a useful concept for daylit museums.

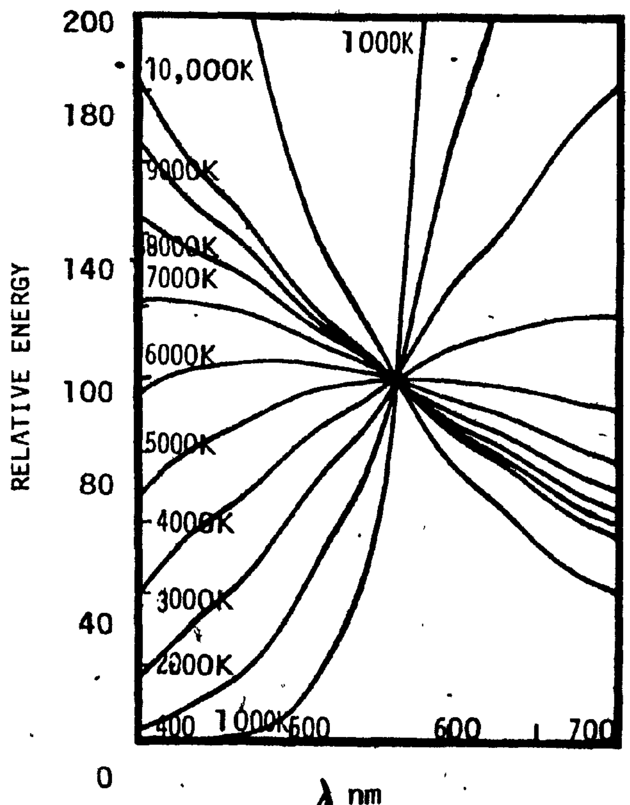



Plate 3.4 Family of Planckian distribution curves. [71]

TABLE 3.1

Color Temperature (°K) Measured in Museums Documented.
(See Table (A.3.1) for C.T of Common museum sources)

| Museum | C.T. (°K) | | |
|---|---|---|---|
| | Min. | Avg. | Max. |
| Johnson Museum | 3000 | 4200 | 8000 |
| Museé d'Art Contemporain | 2800 | 3000 | 3400 |
| American Galleries | 3100 | 3200 | 3700 |
| Islamic Galleries | 3000 | 3700 | 4200 |
| Everson Museum | 2800 | 2900 | 3000 |
| Lehman Galleries | 3000 | 3200 | 3500 |
| Montreal Museum | 3000 | 3100 | 3100 |

## 3.5 COLOR OF DAYLIGHT

Museum objects, paintings, carpets and sculptures demand lighting which expresses their true color. Color depends on the lighting source, museum objects and museum interior finishes. The light source should have the widest spectral distribution, in order to provide the viewer with a tool to see colored objects. The question to be asked: is the color of the source important, and if yes, are we trying to reproduce daylight? The answer to the first question is obviously yes, since color has been used by artists under daylit conditions. The answer to question two is also yes. We are trying to imitate daylight because all existing artificial sources are compared with daylight for evaluation as seen in Chapter 2 (some are more different such as incandescent and some are less different such as daylight fluorescent). It has been stressed many times throughout this study that daylight is our benchmark for seeing color. To reproduce daylight artificially in gallery areas is not economical and has not been technically developed since its continuous spectral distribution would require artificial light sources filtered approximately to 5000°K (natural white light) [51]. By combining cool-white, delux fluorescent 4300 °K and daylight incandescent lamps 3200 °K in the ratio of approximately 4 to 1, a color temperature of 4200°K can be produced [1] [35] which is still below the recommended level. This could be achieved if one has to cut daylight for some obscure reason and ignore other qualities of daylight, but the question is if we can have something at our disposal why try to reproduce it, although it could be done with limited success. "The true presentation of a painting painted under north light would be to show it under this light."(10)

It is stated that under low levels of light the viewer is more comfortable with a low color temperature [51]. We do not have to lower the light levels at all times; besides other reasons, colors gradually become more and more desaturated as the level of light is reduced in the range of 10-1000 lux [50]. "When we have to reduce the light level from an aesthetically desirable 1000 lux to 100 lux or lower, to preserve an object, there will be a loss of discrimination of color in the order of 20%." (11)

The measured color temperature of museums studied, illustrates that a combination of daylight with incandescent light can produce the desired color temperature, since daylight is reflected and transmitted and U.V. radiation is filtered. An sunny days daylight alone results in a very good color response (5000 °K to 6000 °K). If only artificial light is to be used, the incandescent source must be combined with a fluorescent light. The color of finishes in the gallery play an important role in the resultant color temperature of the lighting system. This is experienced clearly in the American wing of the Metropolitan. Daylight (clear day) of 16000 lux in the exterior is transmitted through glass combined with incandescent spot lights, filtered through a laylight system producing a color temperature of 3600 °K, which is low for a daylit space. This is due to the fact that the warm color of wood floors is reflected on the wall to the height of 6', Plate (3.5), plus the color temperature of warm incandescent spot lights. Therefore the color temperature and spectral power distribution of sources should be considered in the context of the whole visual environment. The SPD of a light source should be as close as possible to that of daylight and also the final finishes of the space must be considered at the same time, along with the spectral power reflectance of the objects exhibited. The full color spectrum of daylight provides the possibility of viewing objects as they are seen by the artist.

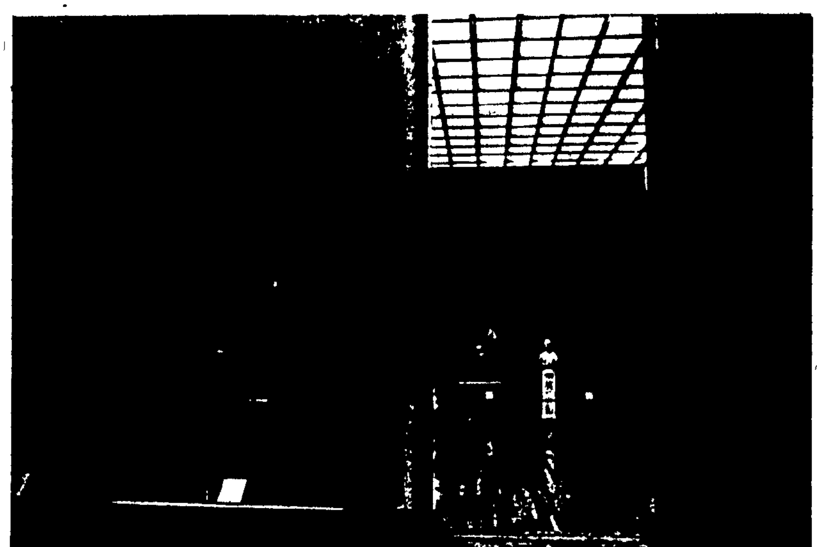


Plate 3.5 Gallery 218 of the American wing at the Metropolitan Museum of Fine Arts. The gradual change of color from floor to ceiling

## 3.6 COLOR OF OBJECTS

An object's color is defined as the color of the light reflected by the object when it is illuminated by a standard light source. Object color is due to selective reflections. The properties of an object's pigments determine the process of color absorption and reflection. Plate (3.6) illustrates the reflectance vs. wavelengths of three colors.

Color at any point on a painting can be measured as a spectral power reflectance, to produce a curve showing the energy content of reflected light from the painting. Two methods have been suggested: a) measuring the complete spectrum at chosen points on paintings b) measuring the reflectance of the whole painting (points are measured and averaged at 6 wavelengths spaced through the visible region). Plate (4.7) illustrates the reflection curve of zinc oxide pigments and their strong absorption of ultraviolet light.

The spectral reflectance distribution of paints on the paintings can be used to detect the change of color, if any, and deterioration of works of art. The spectral power distribution of light sources used in museums, the spectral reflectance distribution of paintings and other objects and the perceptual mechanism of the eye are the deciding elements of color perception and changes of the object overtime. Therefore in designing lighting for a gallery, the quality of objects (approximately) and finishes of the gallery must be known.

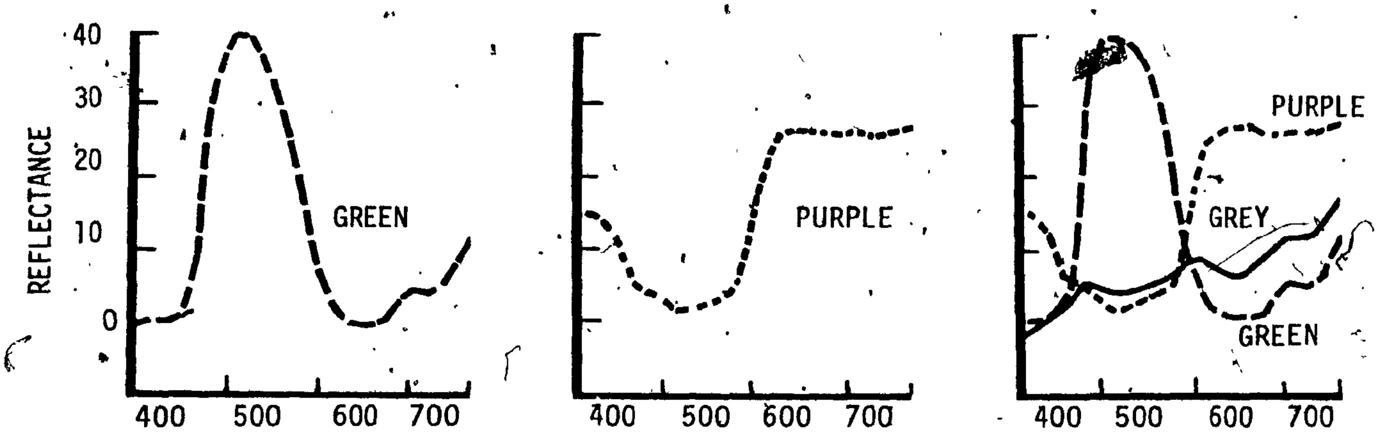



Plate 3.6 Reflectance curves of the three watercolours [70]

## 3.7 CONCLUSION

1. There is a direct relationship between illuminance (100 lux to 1000 lux) and the perception of color. Color discrimination deteriorates as the illuminance is lowered [66]. Thus there is an important trade off between color discrimination and potential damage as related to illuminance level. Filtering of light is crucial to optimize this condition.

2. Modeling or the directionality of illuminance affects the perception of color due in part to veiling reflections from surfaces. When lit by a diffuse source, colors look darker and more saturated.

3. Color temperature (CCT) and the SPD of sources and objects should be ideally specified before any judgement can be made regarding the color of the works of art.

4. The color qualities of the source are one of the important factors to be considered at the design stage. If daylight's color qualities are desired the conceptual design should provide for correctly located openings, Chapter (5). The visual environment is designed as a whole; the finishes, the proportions, the quality of works exhibited and finally the source of light are part of this visual environment. We can depend on the viewer to take advantage of his/her natural abilities such as adaptation, but there are limits which must be recognized. Mismatched color sources caused large variations in color temperature in several visited galleries (See Chapter 6).

5. The Color Rendering Index has no logical meaning for daylit museums with mixed sources giving a varying CCT. The perception of color is more complex than can be described by a single number.

6. Daylight has been used as the standard reference source of illumination.

**FOOTNOTES CHAPTER 3**

9. G. Thomson, The Museum Environment, (Butterworths Ltd.) London, 1978, p. 46.

10 McCandless, "Museum Lighting," Museum News, March 1959, p. 10.

11. Blommelle, N.S. and Harris, J.B., "Museum Lighting", Muséum Journal, Dec. 1969, p. 180.

## CHAPTER IV

## DETERIORATION AND WORKS OF ART

### 4.1 INTRODUCTION

In chapter one we concluded that museums have evolved to be multi functional institutions and it was pointed out that communication and conservation are two of the most important functions. The two functions are related and often in conflict. The conservation of works of art should take place, in order to provide for long lasting communication. Conservation has been considered important for over a century in order to repair, maintain or to avoid deterioration to the works of art. Deterioration has become an unavoidable fact, since the only way to avoid it is by storing the works of art in stable dark controlled environments. Although extensive research in deterioration has been done, particularly by conservationists (see Chapter 1), the problem in relation to other factors involving the viewing of the works of art in museum building design has not been considered.

This study attempts to clarify the issues and show the interactions. In this chapter the causes of deterioration, the types of deterioration, the process of deterioration due to light (especially Daylight), the measure of deterioration in relation to museum objects and finally the possibilities of minimizing deterioration, are discussed.

## 4.2 DETERIORATION

Deterioration is defined as the degradation of a material at a certain pace, and leading to a partial or total destruction of that material. Deterioration takes place in three ways: 1) Natural 2) Mechanical 3) Biochemical and Microbiological. Natural deterioration usually takes place as a result of the presence of light and other air contents. Natural deterioration is also referred to as photodegradation, since it is primarily aided by light. Mechanical deterioration is caused by mechanical forces, thermal expansion or friction (cloth wear) or attack by insects. Finally biochemical and microbiological deteriorations are due to bacteria and fungi. For the study of light in museums we only need to be concerned with natural deterioration. Nevertheless the possibility of the other two types taking place in a museum should not be ignored when dealing with museum environments.

Light shows the characteristic properties of both waves and particles. Waves of light carry particles of radiant energy called photons: $E = h\nu$, where h is the planck's constant, $\nu$ is the frequency of light, and $\nu = \frac{C}{\lambda}$, where C is the speed of light and $\lambda$ is the wavelength. Therefore E, the energy of each photon, is inversely proportional to the wavelength [5]. As the wavelength gets shorter the photons possess more energy. In order to cause any reaction on the material, the radiation should be absorbed by the material.

## 4.3 DETERIORATION DUE TO LIGHT

Deterioration due to the described energy of light could be of three kinds; 1) photolysis 2) photooxidation 3) thermochemical [11].

### 4.3.1 PHOTOLYSIS

Photolysis is primarily caused by the breaking of chemical bonds between molecules. Light provides the activation energy for excitation and breakage of molecules. The excited molecule may then lose the absorbed energy by 1) heat 2) the emission of radiant energy in the form of fluorescence [131]. Light excitation, in some cases, can promote the rupture of certain bonds forming free radicals. The rate of photolysis reactions are often directly proportional to the intensity of the light. In addition, photo induced reactions are dependent upon the penetration of visible - ultraviolet radiation into the pigment. In a thick polymer layer the surface layers act as a protective coating for succeeding inner portions of the sample [16]. Therefore, the process of deterioration is very slow and is related to the intensity of light and the qualities of the object.

For example in a polymer substance, the photolysis will cause a decay or depolymerization of the polymer. Supposing the material has a chain polymer, -A-B-A-B-A-B, the activation energy must be equal to or larger than the energy required to break up the connection -A-B- in the molecule, so it can lead to a total breakage of bonds and depolymerization.

We have seen that the energy of a light photon is $E = \frac{hc}{\lambda}$. For example one can calculate what wavelength of light would be able to break a C-C bond. The energy required to break this bond lies between $58.6 \times 10^3$ cal/mol and $80 \times 10^3$ cal/mol [5].

$$h = 6.6 \times 10^{-27} \text{ erg-sec}$$

$$c = 3 \times 10^{10} \text{ cm/sec}$$

$$m \text{ (Avogadro number)} = 6.03 \times 10^{23}$$

$$1 \text{ erg} = 2.4 \times 10^{-8} \text{ cal}$$

$$\lambda = \frac{hc}{E}$$

$$\lambda = \frac{6.6 \times 10^{-27} \times 2.4 \times 10^{-8} \times 3 \times 10^{10} \times 6.03 \times 10^{23}}{(58.6 \times 10^{3}) \text{ to } (80 \times 10^{3})}$$

$\lambda$ lies between 486 nm and 358 nm or any wavelength shorter than 486 nm can break a C-C bond. Therefore once the required energy to break the bond in any material is known, the wavelength of the light able to break this bond can be found. This range lies partly in the visible spectrum. Other bond types will have their characteristic wavelengths.

### 4.3.2 PHOTO-OXIDATION

Photo-oxidation is always induced by light in conjunction with air content. It can be defined as light induced 'burning,' due to the oxygen and water vapour content of the air. Oxygen in the air can cause oxidative decay of the polymer material. The active oxygen, with water vapour will form hydrogen peroxide, which causes decay. For example considering a dyed cloth, the oxidative decay process has primary processes and secondary processes [5].

Primary process: a) Excitation

HD (dye) + hv (light) → HD* (activated dye)

b) Transfer

HD* + $O_2$ → HD + $O_2$* (activated oxygen)

Secondary process: $O_2$* + $2H_2O$ → $2H_2O_2$ (hydrogen peroxide)

$H_2O_2$ + cellulose → $H_2O$ + oxycellulose

or $H_2O_2$ + HD → $H_2O$ + HOD (decayed dye)

Plate (4.1) illustrates the trace of the activation spectrum of a phythalic polyester resin (note the peak at 325 nm). The energy required for photochemical deterioration can be much lower than that for photolysis. It takes place with light of very long λ, almost into the I.R. region (1200 nm wavelength). Since the energy of the photons is related to the wavelength, there is no threshold of the intensity of light below which photochemical reactions will cease to take place [5].

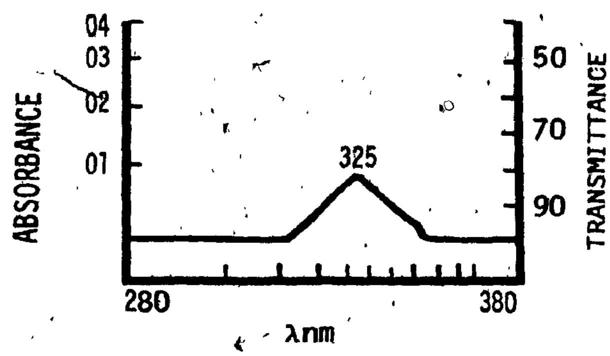



Plate (4.1), Microphotometer trace of the activation spectrum of a phthalic-maleic polyster resin, showing peak of photochemical deterioration at 325. [5].

### 4.3.3 THERMOCHEMICAL DETERIORATION

Thermochemical deterioration is caused by the regions of light, which contain less energy, such as I.R. > 700 nm - 1200 nm. The heating effect of this region causes deterioration in visual appearance (shades of color) and embrittlement of the material. Plate (4.2) illustrates the weakening of fibers occured due to the thermochemical process. The primary effects of heat are drying and speeding up of deterioration. Exposure to light (I.R.) causes embrittlement which will lead to cracking, breaking and other permanent damage [47]. This process is also a function of relative humidity and the rate of air change in the museum. Therefore in evaluating sources of light, the I.R. content should be considered. Conservationists tend to ignore this problem and concentrate on U.V. content [11].

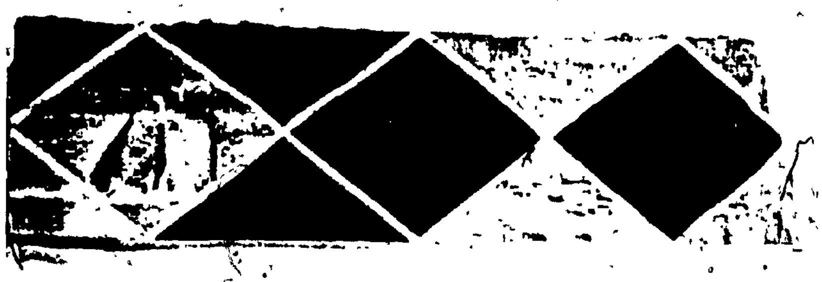


Plate (4.2) The two effects of UV and visible radiation: colour change and weakening. The changes have occurred predominantly on the edge of this cotton curtain where it was turned to the light. Whereas the black dye has been bleached though its textile support is still strong, the yellow dye is unchanged but has passed on the absorbed radient energy to the textile, causing its destruction. (This destruction was not apparent until after cleaning). [70].

## 4.4 MEASURE OF DETERIORATION

By knowing how the deterioration process takes place, one is able to measure the changes in the works of art which have occured as a result of deterioration. This subject is very popular with conservationists but unfortunately practical studies to relate to actual museum's functions have not been done. As was explained deterioration takes place primarily due to U.V. and secondarily due to visible light and I.R. These regions exist in all museum light sources, in different degrees, but most studies have looked at these sources in isolation and not as part of the overall lighting systems and visual environment.

In order to note any objective changes in the color of a painting, spectrophotometry has to be used. The shift in spectrophotometric curves can be used to distinguish changes a) that may be due to the principle absorption band of the pigment and b) that come about through alterations in the color of the vehicle (mixture).

Colorimetry can be used to detect changes in color. Units of color differences which correspond to the ability of the human eye to detect slight differences in color are used. This method is subjective, and accuracy is limited to the ability of the human eye. Duration in time is the main problem with any practical study.

Spectrophotometry has some serious limitations in its use. For example since colors of oil paintings change very slowly, accuracy is limited and problems such as: a) the calibration of instruments is altered during the time (at least 10 years) that deterioration takes place and b) repositioning and aiming at the same spot is very difficult [7].

Although it is difficult to measure, deterioration does take place and has been proved through time. Plates (4.3, 4.4) illustrate the change in the color of pigments due to light. Spectrophotometry is the most viable method among existing methods in judging the effect of any lighting system, before any damage is done as will be shown. We have to account for a) the U.V. b) the visible c) the I.R. radiations present in the light. Two methods have been used to measure the rate of possible damage or the need for remedy (U.V. filters). Both methods take U.V. as their prime concern.

The first method is the Crawford U.V./lum monitor. This device indicates the rate of U.V./lum in light. The dial indicates the reading by flashing the two red lamps. It is suggested [27] that the reading should not be more than 75 μW/lum which is the U.V. content of a tungsten lamp; if it is more than 75, U.V. filters should be used. Knowing the illuminance, we can find the U.V. content [77]. The concept of U.V./lum is logically absurd since by definition a lumen is a measure of visible flux. Thus the U.V./lum will always be zero! One could describe the U.V. content for the total radiant flux of which a portion is visible flux. In any event, the Crawford method was found through field studies to be erratic and unreliable despite its common use by conservationists.

Plate (4-3) Detail from the edge of a Madonna and child G. Signorelli (1441-1523). The frame has protected half of a small plant from the light, so that, it has remained green. The exposed half has turned dark opaque brown. [70].

Plate (4-4), Landscape with sportsmen and game by Adam Pynackner (1624-73), detail. The large leaves, now blue, in the foreground were painted with blue underpaint, glazed or mixed with yellow, looking green. The yellow glaze has disappeared leaving the blue. [70].

The second method was put forward by L.S. Harrison in a very detailed study, prepared for the Metropolitan Museum of Fine Arts [1]. The Harrison damage factor is well respected by museum conservationists. The aim was to study four factors concerning deterioration and museum lighting:

1. To determine the radiation hazards of the respective energy bands, both visible and invisible which are produced in sources of natural and artifical light.
2. To determine the relative energy values of all such bands which are emitted from light sources as they are specified to be used in the Metropolitain Museum: a) sunlight b) clear skylight c) overcast skylight d) incandescent lamps e) fluorescent lamps.
3. To interpret the foregoing determination in a manner useful for gallery lighting design
4. To investigate practical means and methods for reducing such risks of damage as might be found to exist.

The study was aimed at these four factors but it was based on assumptions, not applicable (as will be shown) to actual museum lighting, and did not accomplish its objective number 4.

The D/fc rate of damage per illuminance is produced for each source which can be used to compare sources in terms of index of exposure. The basic formula used for calculations is [5]:

$$D/fc = \sum_{0}^{\infty} H_\lambda \ D_\lambda \ \Delta_\lambda / \sum_{0}^{\infty} H_\lambda \bar{Y}_\lambda \Delta_\lambda$$

$H_\lambda$ is taken from the spectral power distribution of sources as was discussed in Chapter Three. Table (A-4.1) illustrates the value $H_\lambda$ for various sources at 20 nm intervals.

$D_\lambda$ is the relative damage factor of various wavelengths. This factor is taken from studies performed by the National Bureau of Standards (U.S.) to detect the rate of damage due to each wavelength (300 to 640 nm) on low grade paper Table (A-4.2). Most of the museum objects are more resistant to light than low grade paper.

$\Delta_\lambda$ is the wavelength interval (20 nm). $Y_\lambda$ is the luminous efficiency of radiant energy at each wavelength for the average normal eye or C.I.E. standard observer. A number of glasses and filters are examined to find out the D/fc of transmitted light. Table (A-4.3) illustrates the spectral transmittance of these materials. Note that Corning Novial O and Plexiglass LPC - 518K do not transmit any ray below 400 nm. The details of calculating D/fc for a zenith sky light and a zenith sky light filtered through Corning Novial O glass are illustrated in Table (A-4.4). Table (4.1) indicates the D/fc of sources under study. The D/fc for a zenith sky 11000 °K is 4.8 and assumed to be 100%; other sources are tabulated as a percentage of this source [1].

| Filter | Incandescent Lamp (2854° K) D/fc | % | Daylight Fluorescent *(6500° K) D/fc | % | Warm-White Deluxe Fluorescent (2900° K) D/fc | % | Cool-White Deluxe Fluorescent (4300° K) D/fc | % | Sun at 30° Altitude Air Mass 2 (5300° K) D/fc | % | Overcast Sky (6400° K) D/fc | % | Zenith Sky (11000° K) D/fc | % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| None | 0.136 | 2.8 | 0.402 | 8.4 | 0.444 | 9.2 | 0.554 | 11.5 | 0.790 | 16.5 | 1.52 | 31.7 | 4.80 | 100.0 |
| Kingsport Water White | .128 | 2.7 | .392 | 8.2 | .332 | 6.9 | .463 | 9.6 | .619 | 12.9 | 1.19 | 24.8 | 3.38 | 70.4 |
| Window Glass | .106 | 2.2 | .362 | 7.5 | .213 | 4.4 | .294 | 6.1 | .427 | 8.9 | .682 | 14.0 | 1.58 | 32.9 |
| Corning Greenish Nultra | .069 | 1.4 | .282 | 5.5 | .099 | 2.1 | .163 | 3.4 | .225 | 4.7 | .299 | 6.2 | 0.544 | 11.3 |
| Plexiglas LPC-518K | .062 •• | 1.3 | .245 | 5.1 | .086 | 1.8 | .147 | 3.1 | .192 | 4.0 | .243 | 5.1 | 0.407 | 8.5 |
| Corning Noviol-O | .053 | 1.1 | .197 | 4.1 | .069 | 1.4 | .119 | 2.5 | .158 | 3.3 | .199 | 4.1 | 0.334 | 7.0 |
| Pittsburgh Laminated X-Ray | •• | | •• | | •• | | •• | | .079 | 1.6 | .092 | 1.9 | 0.134 | 2.8 |

* Standard commercial rating, 6500°K.

•• LPC-518K filters cannot be used in incandescent lighting fixtures if temperature exceeds 180°F. Plastic laminated X-Ray glass will take prolonged exposure to temperatures not exceeding 130°F. Due to such operating temperature limits and its spectral color transmittance values, peaked at 580 mμ, this filter was proposed only for screening UV from natural sunlight and daylight.

Table 4.1. Probable rate of damage per footcandle and approximate color temperature (degrees Kelvin) for 49 light sources expressed both in arbitrary units (D/fc) and in percent of zenith sky (%). [1].

By studying this table we find out that for an incandescent lamp, the D/fc is 0.136 and for zenith sky it is 4.8 or almost 40 times as much. Before reaching any conclusions we have to notice that:

1) Average museum objects are less sensitive to light than low grade paper.

2) All deterioration studies are performed with the source in isolation and not as an integral part of the visual environment. Therefore direct rays are considered and not inter-reflected light.

3) At the begining of the report, it was suggested that in daylit galleries with sun louvers, the average annual values (based on measured and predicted values) to be considered are:

   | Horizontal | Vertical (35% of horizontal) |
   |---|---|
   | 169 fc | 59 fc |

   In calculation, it makes use of the source and suggests a standard source (sky + sun) of $8000_{fc}$.

4) Considering the foregoing, by examining Table (4.1) we see that the D/fc for a zenith sky transmitted through U.V. filters (i.e. Pittsburg Laminated X-ray) is 0.134, which is usually the case since U.V. filters are always

used with daylit galleries, whereas D/fc for an incandescent lamp is 0.136 or 0.147 for fluorescent (4300 °K) through plexiglass LPC-518 K. This comparison suggests that based on the study daylight can still be used as having the same effect as artificial light on museum objects.

The use of daylight is discouraged by conservationists, primarily due to its damaging effects (U.V. content). This conclusion reveals that the danger due to daylight is not as high as suggested, or at least not much higher than that of any other source. On the other hand the analysis of data taken in actual museums illustrates the high level of U.V.content in all museums, Table (4.6). The U.V. content is a fact to live with and it only can be minimized. In discussing the deterioration of museum objects and evaluation of light sources, the control of light levels, the control of U.V. and I.R. and the quality of museum objects should be considered.

## 4.5 LEVELS OF LIGHT

Museum conservationists propose Table (4.2) which expresses a maximum illuminance of 50 and 300 lux, depending on the sensitivity of materials. Since deterioration is proportionate to illuminance and time of exposure, then the duration of exposure is an important factor [26][105][14] [70].

ILLUMINANCE (LUX) X TIME (HOURS) = LUX HOURS

In other words 100 lux for 10 hours has equal damaging effects as 50 lux for 20 hours, which is equal to 1000 lux hours.

Required illuminance levels that have been suggested do not affect the lighting designer, since the lighting designer is not providing a maximum level of light - as it is believed to provide better working conditions [23][122]. One study in the U.S. revealed that people were comfortable in museums that had 100-200 lux light [104]. Table (4.3) illustrates the illuminances measured in functioning museums. It is apparent that actual levels are, on average, higher than the suggested values by conservationists.

The comparison of these two sets of data make it clear that the suggested values are nothing more than subjective feelings of conservationists. The level of illuminance (lux) is not an important criteria in museums as in other building types. "Once one understands that the brain analyzes and perceives the entire visual field, and not its individual aspects, the irrelevance of single parameter numerical criteria such as foot - candle levels is immediately apparent." (12).

| | Museum Objects | Illuminance (lux) | IES (lux) [122] | IES * Lux Hrs/yr |
|---|---|---|---|---|
| 1 | Extremely sensitive material | 25-50 | 50 | 120,000 |
| 2 | Moderately sensitive material | 150 | 75 | 180,000 |
| 3 | Least sensitive materials | 300 | - | - |

**TABLE 4.2**

Recommended Illuminance levels by Conservationists, and IES for different Museum Objects [71].

* Assumes (lux) (8 hrs/day) x 300 days/yr

| Museum | Illuminance (lux) | | |
|---|---|---|---|
| | Min. | Avg. | Max. |
| Johnson Museum | 325 | 750 | 1330 |
| Musée d'art Contemporain | 210 | 285 | 400 |
| American Galleries | 280 | 400 | 600 |
| Islamic Galleries | 150 | 210 | 300 |
| Everson Museum | 32 | 95 | 200 |
| Lehman Galleries | 250 | 350 | 400 |
| Montreal Museum | 140 | 205 | 240 |

**TABLE 4.3**

Illuminance Levels (lux) Measured in Galleries Documented

Conservationists suggest an optimum level of light for museums. It has been concluded that when we reduce the illuminance level from 1000 lux to 100 lux or lower, to preserve an object, there will be a loss of discrimination. On the other hand it is stated that "while performance improves as the lighting level is raised, the improvement even for the smallest detail is not very considerable above about 500 lux." (13). Therefore the levels above 500 lux and below 100 lux are undesirable for optimum visibility.

The museum object is the deciding factor in terms of what level should be provided. Very sensitive material should be illuminated with low levels in the order of 150 lux. In this case since daylight filtered and reflected to this level is very "cold" (high color temperature), it is preferable to use artificial lighting for viewing the objects. Very low levels of daylight can be used for ambient lighting, as is practiced in the Islamic Art Gallery of the Metropolitan Museum. Sensitive materials such as works on paper and tapestry are exhibited in an average illuminance of 150 lux. The general lighting level is kept low and more intense light is concentrated on the exhibits for limited periods. The white washed skylight and high ceiling along with spots provide the desired environment. We can conclude that the average museum object and overall light level in the environment should be approximately 250-350 lux which will be taken as a bench-mark. The exception is for very sensitive materials which should be lit with the combinations of artificial light and natural light below 150 lux or nonsensitive materials which could be lit with high levels.

Numerous methods are available to reduce daylight to desired levels as will be illustrated in Chapter 5. The geometry of openings, materials and louver systems are some of the options open to designers. Louvers have been used extensively for many purposes such as avoiding glare, besides reducing the light level. The amount of lost light varies according to the depth and slope of the louvers. The only useful statistics are records of daylight transmission in an actual situation before and after louvers have been installed.

It is easier to control artificial lighting. Although strong spot lights produce very high levels of light on the object, the general illuminance level is kept low. Fluorescent lights are usually used to replace daylight or to make up for lack of daylight on cloudy days.

The possibility of controlling levels of daylight and even blocking it during closing hours provides the required condition to use daylight as desired. This has to be considered at the early stages of design since the choice of hardware is limited and the geometry of openings (luminaires) are important (Chapter 5).

Because daylight lasts for 12 hours at the equinoxes and up to 16 hours for Montreal at the solstice, daylight luminaires can cause exposure during non gallery hours. Thus any daylight system needs to be controlled to function only during opening hours. Small aperatures allow easier control than large skylight systems.

**4.6 ELIMINATION OF U.V.**

Studies were conducted and the U.V. content of various sources were measured during field studies. Using the U.V./lum as defined on page 101. Table (4.4) illustrates the laboratory values measured with sources in isolation. Table (4.5) illustrates the quantity of U.V. measured on site in galleries. As indicated in galleries with daylight, the proportion of U.V. is far less than suggested, since the theoretical values considered daylight before entering the space and being reflected. Even when considering theoretical data it is stated that once the density of light is reduced to between 250 lux and 350 lux the damage is of little significance if the length of exposure is minimized. In reference to comparing the U.V. content of different sources Dr. Ne'eman states: "Here again one may jump too quickly to the conclusion that electric light should be overwhelmingly preferred from the point of view of conserving the artifacts. However, this is true only in extreme cases with very sensitive materials. In most cases the overall dosage of U.V. radiation even with north sky daylight stays below the permissible maximum exposure to ultraviolet radiation" (14). Filters can also be used to cut near U.V. radiation for extremely sensitive works of art. Nevertheless damaging wavelengths cannot be filtered out without decreasing our perception of the correct colors of displayed objects, or our ability to view the art works. Some U.V. filters cause yellowing effects to the light, but do not create any problem in viewing colors. Since some damage occurs through visible

| | |
|---|---|
| Blue sky at 15000 K | 1600 |
| Cloudy to overcast north sky | 800 |
| Direct sun | 400 |
| Fluorescent lamps | 40-250 |
| Philips 37 | 40 |
| Tungsten - iodine through glass | up to 130 |
| Normal tungsten | 60-80 |

**TABLE 4.4**

Microwatts of U.V. per lumen daylight and artificial sources [77]

| | Museum | U.V. content (U.V./lum) | | |
|---|---|---|---|---|
| | | Min. | Avg. | Max. |
| 1 | Johnson Museum | 200 | 380 | 500 |
| 2 | Musée d'art Contemporain | 19 | 59 | 47 |
| 3 | American Galleries | 57 | 45 | 330 |
| 4 | Islamic Galleries | 150 | 185 | 240 |
| 5 | Everson Museum | 123 | 170 | 400 |
| 6 | Lehman Galleries | 64 | 60 | 80 |
| 7 | Montreal Museum | 50 | 43 | 50 |

**TABLE 4.5**

Ultra violet content, per lumen of visible light, calculated from data taken in Museums documented.

light one has to live with this factor, or lock the works up in a dark basement.

The U.V. content of any light source can be eliminated by: 1) transmission through filters 2) inter-reflection of a U.V. absorbing plane. U.V. filters usually have a sharp cut-off at about 400 nm [2]. The ideal filter would have a vertical cut at 400 nm but nevertheless most filters have low transmission at shorter wavelengths [6][12]. Radiation below 280 nm do not reach the earth and ordinary glass cuts any radiation less than 300 nm Plate (4.5). The stability of the filter is very important and should be checked often, as it wears out with time. Plate (4.6) illustrates a sample of U.V. filters with their respective spectral transmission curves; many more are available in the market.

Inter-reflected light from certain materials, which have high absorption in the U.V. region, is free from U.V.. Little research has been done in this area and not many such U.V. absorbing materials are well known. Zinc Oxide paint (white paint) has very high absorption below 400 nm Plate (4.7). Exposed concrete is very absorbent in the U.V. region. This was experienced in the Jerusalem Museum of Fine Arts but no graph of its performance is available [33]. In the Johnson museum the readings of U.V. falling on the concrete surface and reflected from it were measured during the site visit and it was concluded that the concrete surface cuts up to 65% of the U.V.. This is due to one

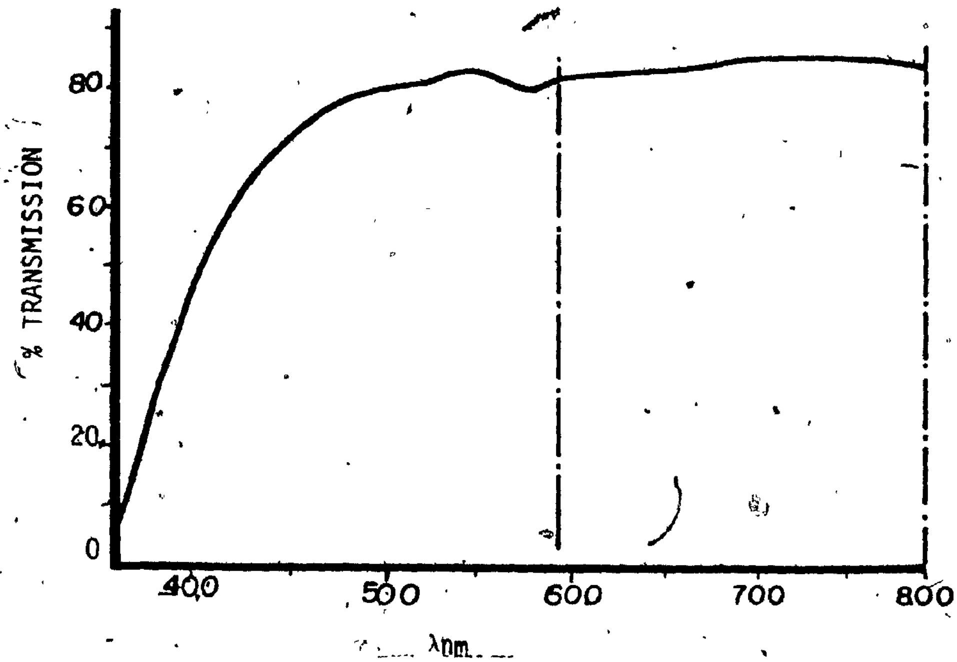



Plate (4.5), The spectral transmission distribution of ordinary glass.

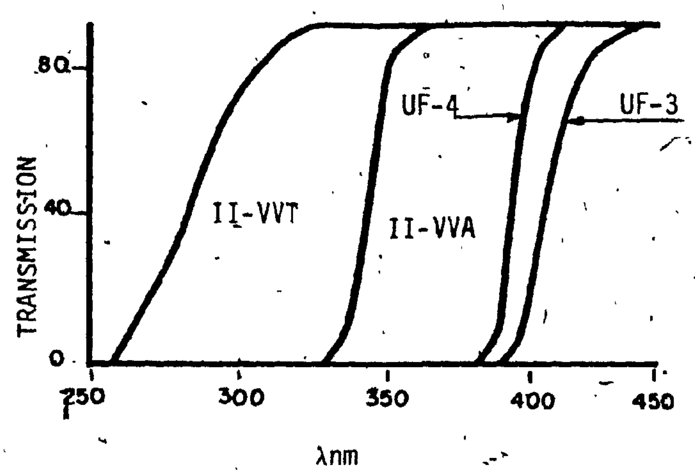



Plate (4.6), Four U.V. filters with the spectral transmission curves. UIF- 4 has the best performance.

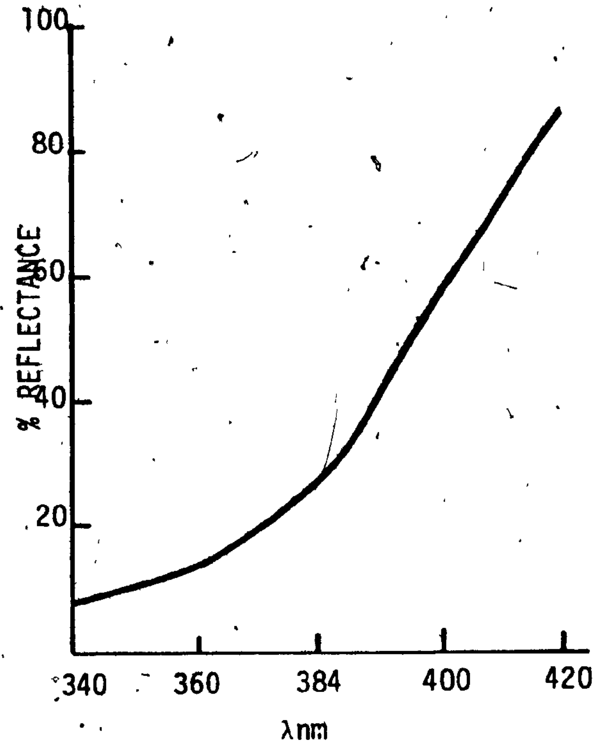



Plate (4.7), The spectral reflectance distribution of zinc oxide paint.

reflection; we can expect that all the U.V. content will be eliminated due to multiple reflections from a concrete surface ie. $.35^3 = 0.042$ remaining.

Table (4.6) illustrates the U.V. content measured in galleries documented. The values are above the recommended level (4.5 mw/$m^2$) [71]. These values are analyzed in Chapter 6.

| Museum | U.V. - mw/$m^2$ | | |
|---|---|---|---|
| | Min. | Avg. | Max. |
| Johnson Museum | 160 | 200 | 260 |
| Musée d'art Contemporain | 4 | 17 | 19 |
| American Galleries | 160 | 180 | 200 |
| Islamic Galleries | 36 | 39 | 4.6 |
| Everson Museum | 14 | 17 | 32 |
| Lehman Galleries | 16 | 21 | 32 |
| Montreal Museum | 7 | 9 | 12 |

**TABLE 4.6**

The ultra violet content (mw/$m^2$) measured in galleries documented

## 4.7 MUSEUM OBJECTS

Plate (4.8) illustrates a list of museum objects and their relative sensitivity*. Sensitivity is important due to the above stated factors in the manner in which radiation would react to the pigments and the spectral power reflectance (or absorption) of the object.

According to the degree of stability to light, museum objects are divided into three groups;

1) High light stable materials such as: metals, stone, porcelain, ceramics, glass, enamels, part of minerals.
2) Moderate light stable materials such as: paintings, wood, bones.
3) Low light stable materials such as: paper support - water colors, textiles, dyed leathers.

Therefore when we consider artificial lighting we also have to study the spectral power distribution in relation to the object's characteristics. For example as illustrated in Plate (2.2) the SPD of fluorescent lamps have very high energy peaks at certain wavelengths, and if the object has high absorbancy at this wavelength, deterioration will be more severe.

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* Sensitivity is defined as the strength of molecular bonds of the matter, the weaker the bond, the more sensitive is the object.

**GROUP 1**

Extremely Sensitive

Textiles

Paper (works on paper)

Dyed leather

Feathers

Vegetable-dyed materials

Lacquer

Multi-material constructed objects

Pigments - particularly watercolor

**GROUP 2**

Moderately sensitive

Bone, Ivory, Horn

Cellulosic materials

Wood, Tapa, Baskets

Reeds, grass

Leather, parchment, rawhide, skin

Fur

Furniture

**GROUP 3**

Least sensitive materials

Metal

Stone

Ceramic

Glass

Plate (4.8) Relative sensitivity of museum objects [26].

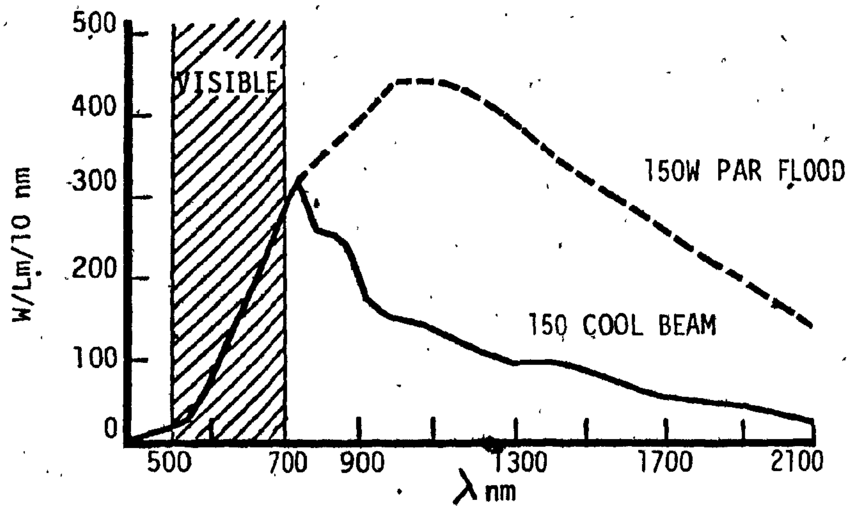



Plate (4.9), Spectral distribution of a tungsten filament lamp, indicating a very large I.R. output.[6]

## 4.8 EFFECT OF HEAT

The other region of spectral power distribution to be considered is the I.R. region of a source. The study on spectral power distribution of sources reveals what proportion of radiation is in the I.R. region. Plate (4.9) is the SPD of incandescent lamps. Thermal degradation must be considered at the same time as photolysis and photochemical deterioration. "A measurable and large amount of I.R. radiation emitted by ordinary incandescent lamps bombards textiles, for example, leading to the deterioration of the fibers of the material particularly the long-chain molecules in a slow but steady rate as time passes. As the radiation bombardment proceeds over the years, more and more molecules are disrupted and the textile weakens and begins to tear increasingly easily, until finally it falls to pieces from its own weight. (15)"

The I.R. radiation is absorbed by most objects regardless of their S.P. reflectance distribution. This is proved by exposing a black and white surface to an I.R. heater that emits primarily the longer of radiations. The difference in the heating rate will be very little since white and black absorb the I.R. at the same rate. The I.R. is the main cause of deterioration due to heat, and temperature rise is directly related to the illuminance level. Filters are available to cut the I.R. radiation. Incandescent lamps are the main producers of heat in the museum environment; nearly 67% of input wattage is emitted as I.R. radiation. Table (4.7) illustrates the different light sources and their respective lm/w. That means if a source is producing ½ as many lumens (light) as another source, then it is radiating twice as much heat. For example, a tungsten lamp produces 8 times more heat than daylight.

| | lm/rad.W | (lm/elect.W) |
|---|---|---|
| Sunlight from which all UV and IR has been removed (theoretical) | 220 | - |
| Daylight through glass, about | 130 | - |
| High-efficacy fluorescent lamp | 130 | 70 |
| Low-efficacy (high fidelity) fluorescent lamp | 85 | 45 |
| Tungsten lamp with dichroic reflector (Coolbeam) | 40 | 12.6 |
| Tungsten - halogen lamp | 20-25 | 15-22 |
| Ordinary tungsten lamp | 16 | 12.6 |

**TABLE 4.7**

Radiant heat and light (lumens/Radiant watt) [35]

## 4.9 VISIBLE RADIATION

The deterioration process due to visible radiation is also of concern to conservationists [8][9][105]. As was discussed the photochemical process of deterioration, is mainly due to visible radiation. The control of the visible radiation hazard is a function of the illuminance level, i.e. blocking the light at times that it is not required. Elimination of visible radiation is contrary to the function of the museum as a place of communication; controlling the levels, creating contrast and proper modeling are used to minimize the damage. Table (4.8) illustrates a comparison made between museum sources, with respect to the above factors.

| | Source | Illuminance Lux (Visible radiation) | Lum Efficiency lm/elect. W | U.V. | Heating Effect | S.P.D. |
|---|---|---|---|---|---|---|
| 1 | Daylight | 200 -up | - | High | Low | Full |
| 2 | Daylight filtered or reflected | 100 -up | - | Low | Little | Full |
| 3 | Fluorescent Lamps (D.L) | 200 | 70 | Low | Low | High in certain λ, could cause damage |
| 4 | Incandescent | 50 -up | 20 | No damage except for quarts iodine lamps | High | High in I.R. |
| 5 | Incandescent filtered | 50 - up | 15 | No damage | Low | High in I.R. |

**TABLE 4.8**

Comparison of Museum light sources in terms of damaging effects

## 4.10 CONCLUSION

Daylight can be used without additional risk as compared to artificial sources. This only applies to average museum objects that are illuminated at levels between 250 and 350 lux. Very sensitive materials could be lit by artificial sources, and daylight should be used for ambient light. If an object is illuminated by an incandescent light, as task lighting and the space is illuminated by daylight, the damage (if any) will occur due to the incandescent light and not daylight. "An exhibition case stands in a room dimly lit by daylight but the objects in the case are brightly lit by tungsten lamps. In this manner they may get most of their damage from tungsten lamps" (16). As a result of the foregoing studies and field investigations we can state that:

1. The damage due to U.V. from daylight need not be as severe a problem as feared by the conservationists.
2. The U.V. content of daylight could be eliminated with filters and reflection without greatly affecting the quality of daylight such as color rendering.
3. The damage due to I.R. content and visible light is as important as damage due to U.V. radiation. Therefore in choosing the source of light all three components should be evaluated.
4. Artificial light can be used for task lighting of sensitive materials, and inter-reflected daylight as ambient

lighting. The limit of 50 lux however makes the use of daylight limited and requires special design.

5. Daylight should be continuously controlled and blocked during closing hours to limit the damage factor. The damage factor approach allows the integration of the SPD, the objects' characteristics and the intensity of radiation exposure to minimize deterioration. This has not been a common design method.

6. All the factors involved, i.e., lux-hour, U.V., I.R., controlling techniques, and other factors affecting the visual environment such as color (the relationship between the illuminance and color perception, Chapter 3), have to be considered in evaluating light sources in museums.

FOOTNOTES - CHAPTER 4

12. William, C. Lam, Perception and Lighting As Formgivers for Architecture, (McGraw Hill Co.), N.Y., 1977, p. 11.

13. Brommelle, N.S. and Harris, "Viewing the Object, Museum Lighting", Part 4 Museum Journal, No. 62, 1962, p. 182.

14. Ne'eman, "Daylighting In Museums", Paper 1983 International Daylight Conference, Phoenix Arizona Proceedings, 1983, p. 72.

15. Carroll, B. Lusk, "The Invisible Danger of Visible Light", Museum News, april, 1975 No. 7, p. 22-23.

16. Thomson, G., The Museum Environment, (Butterworths Ltd.), London, 1978, p. 16.

# CHAPTER V

# GEOMETRY OF OPENINGS
## (Luminaires)

## 5.1 INTRODUCTION

A light fixture is referred to herein as any object or opening which emits light. For example an incandescent bulb with fittings and shades is called a light fixture. Since a window brings light into a room it too is a light fixture without regard to such factors as: the weather outside, the position of curtains or blinds and the glass transmittance. To be more precise a source should be referred to as the light emitting device in its pure form. For example an incandescent lamp without any shade or reflecting surface is a light source. Daylight from the diffuse sky is also a light source. In artificial lighting the combination of fittings, shades, filters and louvers is called a luminaire. By the same analogy, any intermediate means of bringing daylight in such as a window could be called the daylight luminaire. This is illustrated in Plate (5.1), where the sun and diffuse sky are the light sources and the opening as shown is the luminaire.

In this chapter we shall study the design and geometry of luminaires used in museum daylighting. The theoretical requirements and characteristics of luminaires, some existing solutions and means to evaluate solutions will be described.

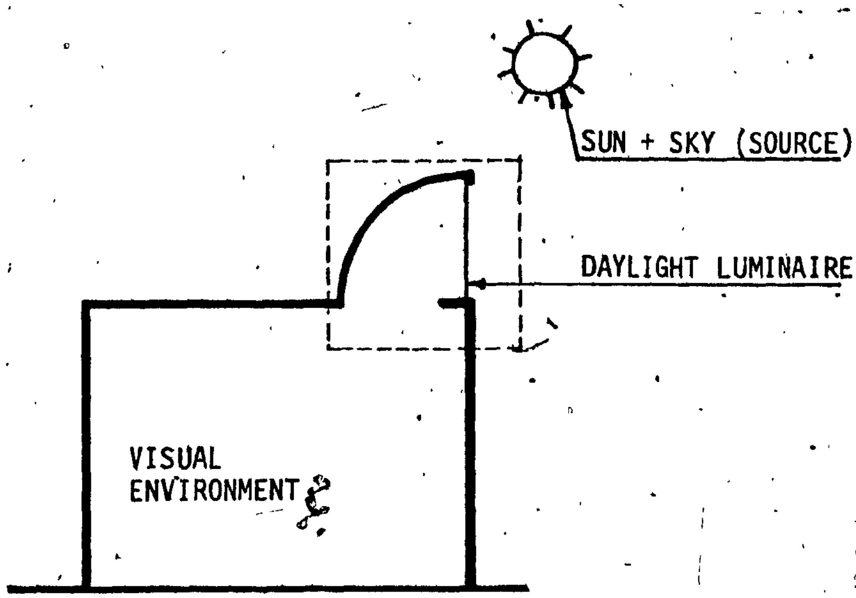



Plate (5.1) Source, Daylight Luminaire and Visual Environment

## 5.2 DAYLIGHTING LUMINAIRES

It was stated that daylight should be introduced in museums and art galleries. It should be brought to the viewing area from above, behind and each side of the viewer in varying proportions. It should be capable of being regulated in intensity and direction. The veiling glare, strong reflections and heating effect should be minimized. It should offer the flexibility which is required with the change of exhibitions. Light should offer all these possibilities if one is to believe that "the effectiveness of a museum is largely dependent on the contribution made by lighting" (17).

In daylighting design we refer to luminaires as a means to control, direct or redirect the natural light as desired. As light goes through this process, its characteristics are altered. In order to analyze these changes in detail, further investigations are required but at this stage we are interested in knowing the possible geometries for openings in museums. Parallels could be drawn between luminaires in artificial lighting and daylighting. The luminous intensity distribution represents the intensity of light of a luminaire in a particular direction and is used for the design of luminaires in artificial lighting. Similar concepts can be developed for daylight luminaires although as yet none are available.

The daylight luminaire has no defined luminous intensity distribution since it is so large and thus must be treated as a collection of radiative transfering surfaces. Contours of illuminance on a plane at a fixed geometry to the daylight luminaire could be constructed in order to give an indication of light distribution on the planes of the gallery.

## 5.3 LUMINAIRE TYPES

The luminaires in daylight can be divided into four categories: A. windows (side lighting), B. clerestory (side and top lighting), C. Sky light (top lighting ), D. Courtyard lighting.

A) A window is referred to as any luminaire that introduces light into the space from the sides and approximately at the viewers eye level. Windows can be introduced as a source of light or solely for contact with the exterior or for elevation designs, Plate (5.2a).

B) A clerestory is referred to as any luminaire that introduces light from the upper wall or vertical plane in the ceiling above the eye level of the viewer, Plate (5.2b).

C) A skylight or roof light is referred to as any luminaire that introduces light into the space from the slope or horizontal plane, Plate (5.2c).

D) Courtyard lighting is referred to as any luminaire that introduces light through a courtyard. Two kinds of spaces can receive light from a courtyard. One is the court itself if it is used as a gallery space which receives light from the top. The second kind space are the galleries on the perimeter of the court which receive light through vertical luminaires from the court, Plate (5.2d).

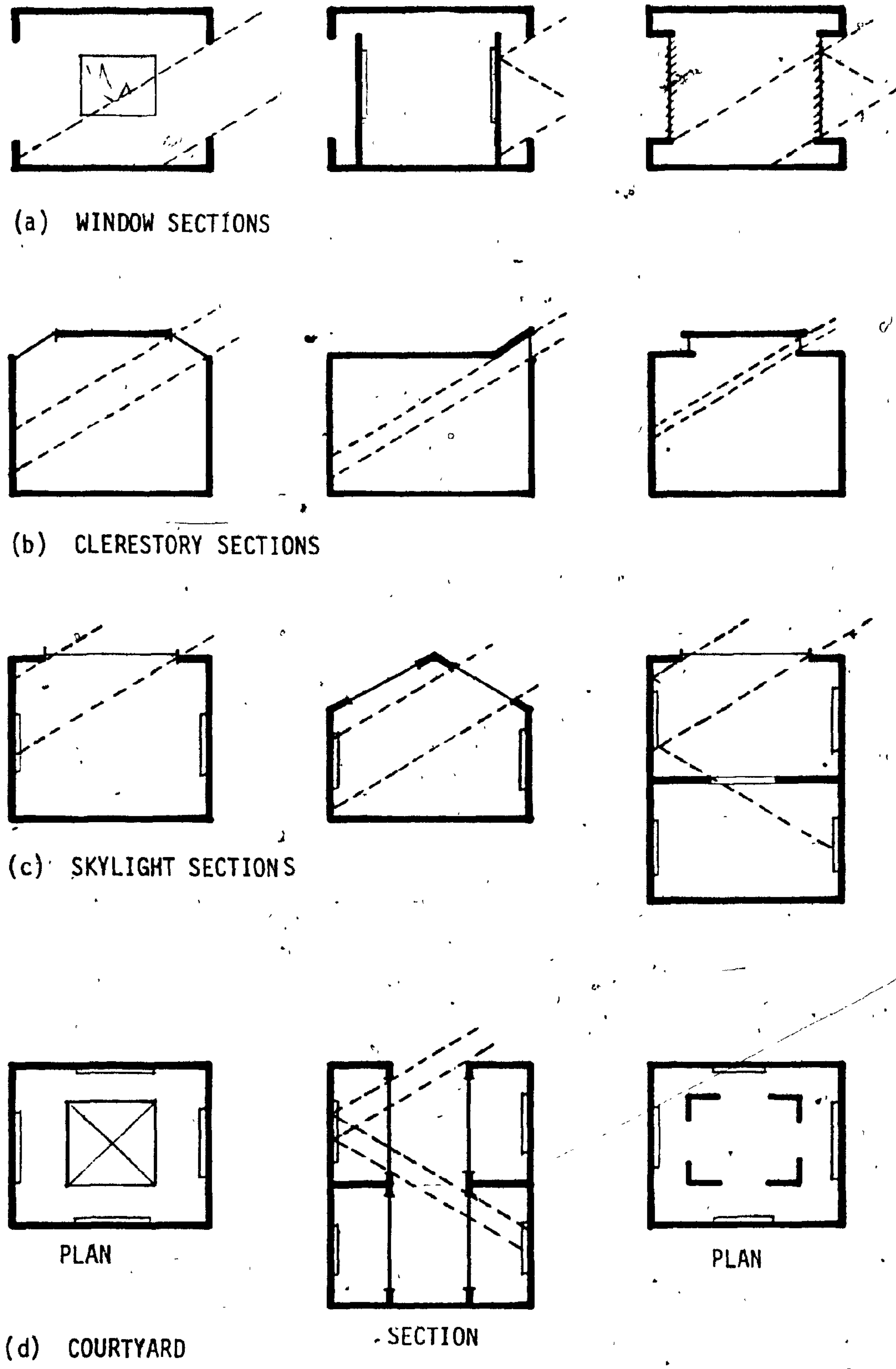



Plate (5.2), Window, side lighting, (b) Clerestory, (c) Skylights, (d) Courtyard lighting.

## 5.4 LUMINAIRE DESIGN

A slight alteration in luminaire design for artificial lighting in the lens quality, geometry and material of the reflector will vary the luminous intensity distribution. The same applies to the luminaire of a daylighting system. Besides the geometry, the material of finishes and hardware are important in the luminaire performance.

The choice of glass is very important. Here we are concerned only with the light transmitted through the glass but the choice should consider other factors such as energy gain. Louvers are used extensively, both in the exterior and interior of the glass. At the Yale Center for British Art the louvers are installed in the exterior over the sky light Plate (5.3), and at the Lehman Gallery Plate (5.4) the louvers are installed inside.

The choice of material, hardware and detailing are very important since they have a direct effect on how the luminaire will function. The weather, orientation and the geometry of the luminaire should be considered in designing the daylight luminaire. As W.M. Lam states: "If perception-based lighting is once again to assume its proper place as a form giver for architecture, it will not be because of the availability of cheaper glass, the introduction of more efficient light sources, or the generation of more sophisticated computer programs for calculating light levels..." (18). Although one cannot go this far and underplay the importance of hardware, the concept and the resulting quality should be decisive.

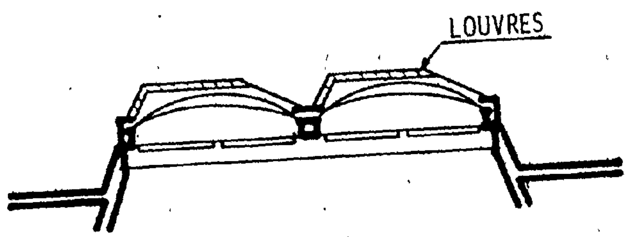



Plate (5.3), Louvers are installed on the roof. Yale Center for British Art.

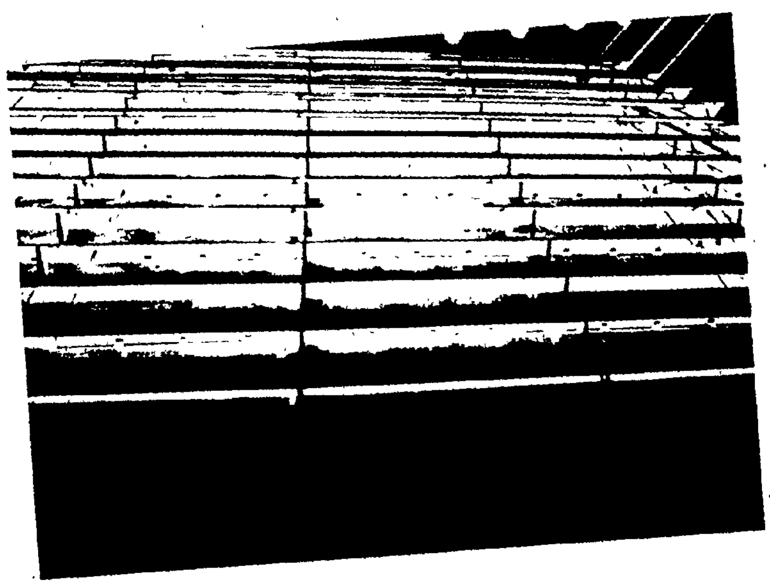


Plate (5.4), The Louver System is installed inside, Lehman Galleries.

### 5.4.1 EVALUATION SYSTEM OF DAYLIGHT LUMINAIRE DESIGN

A detailed evaluation system has to consider all the factors affecting the visual environment that have been discussed in the previous chapters. Model studies are required and a matrix of variables, ie. geometry, finishes, illuminance distribution, color, etc. should be set up and each concept evaluated. In order to get an approximate idea of how these concepts will function we limit ourselves in this study to the two most important factors: illuminance distribution and veiling glare since these two factors can be approximated by graphic means (see chapter 2 for discussions).

A. Illuminance Distribution

With respect to this factor the following points should be considered:

1 - Is light evenly distributed across the gallery?

2 - Do all planes receive even light?

3 - Are there dark planes?

4 - Are there dark corners?

5 - Are there very bright planes?

6 - Is light direct, partly direct or diffused?

Depending on the answers to the above questions one can appoint the following evaluation system:

DE Distribution is excellent. The ratio of illuminance on any plane is less than 20 to 10.

DG Distribution is good (acceptable).

DP Distribution on any plane is excessive.

B. Veiling Glare

Veiling glare can be detected graphically and the veiling glare zone can be located.

For this particular analysis the object is assumed to be specular or semispecular; thus the angle of incidence is equal to the angle of reflection. The effects from a specular surface are so strong that quantitative evaluations are of secondary importance. If the viewer sees the veiling image at all it will be a severe problem. Thus the analysis is a simple yes or no. No other model including ESI can account for qualitative effects due to the moving observer. A geometric rule of thumb can be used to locate the zone in which a source can be located. Two assumptions are made 1. A maximum of 30° general viewing angle is used. 2. The angle of incidence is equal to the angle of reflection Plate (5.5).

H = distance from eye level to the luminaire sill

w = observer's distance from the wall

W = distance of the luminaire sill to the exhibition wall.

D = observer's horizontal distance from luminaire

$\phi$ = viewing angle

It can be seen that

$$\tan \phi = \frac{r}{w} = \frac{R}{W+w}$$

and thus

$$W + w = \frac{\sqrt{H^2+D^2}}{\tan \phi} \quad \text{or} \quad w = \frac{\sqrt{H^2+D^2}}{\tan \phi} - W$$

If the one cone of vision is 30° from the horizontal

$$w = \sqrt{3}\sqrt{H^2 + D^2} - W$$

thus for a given luminaire height to room width or depth ratio one can assess the viewer positions that would have veiling glare. This allows one to determine permissible viewer locations, room proportions, object locations, or luminaire locations depending on what parameters are fixed. Note that the viewing angle is critical in controlling these relationships. More generally Plate 5.5 shows the whole room with the veiling glare ray intersecting the observers horizontal line of sight.

In general if the intersection occurs at the rear second half of the gallery from the exhibition wall, the glare problem is minimal (excellent); if it happens in the proximity of the center the glare problem exists but one can avoid it by moving forward in the gallery (good), and finally if the intersection happens close to the picture wall the glare zone is very large and the system is poor. This graphical evaluation only gives an approximate idea of how the concept will function, but in detail studies of other factors such as gallery and opening's dimensions should be altered and evaluated. To evaluate the following concepts one can establish this system:

**VE** Veiling glare absent

**VG** Veiling glare present in some locations

**VP** Veiling glare present in most locations

This method is used for a moving observer, other methods are used to locate the glare zone with respect to a fixed observer.

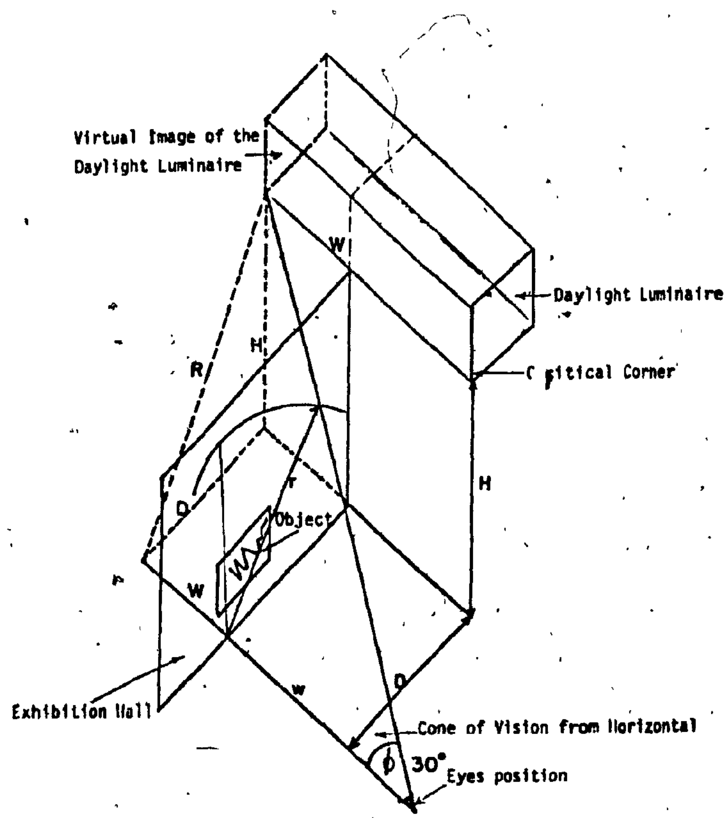
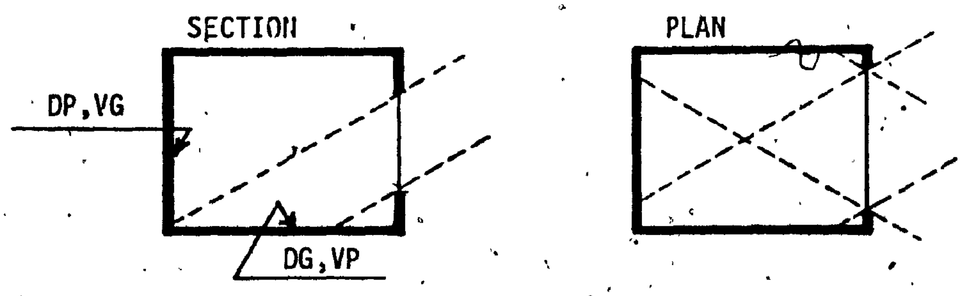



Plate (5.5), Graphical method to locate the glare zone and the H/W ratio

## 5.5 SIDELIGHTING - WINDOWS

The use of windows was very popular but it was replaced by skylights. One important concern was the growth of collections and the need for more wall space for exhibition. Windows are introduced in museums for two important reasons: 1) to create contact with the outside 2) to bring light into the gallery. Louis Kahn believed that "Natural light plays a vital part in illumination ... the visitor must be able to relate to nature momentarily ... to actually see at least a small slice of foliage, sky, sun, water. And the effects of change in weather, position of the sun, seasons, must penetrate the building and participate in illuminating both art and observer.. we are after a psychological effect through which the museum visitor feels that both he and the art he came to see are still part of the real, rotating, changeable world" (19). This fundamental need requires contact with the outside, but as a source of light windows are not useful unless a very effective control system is provided.

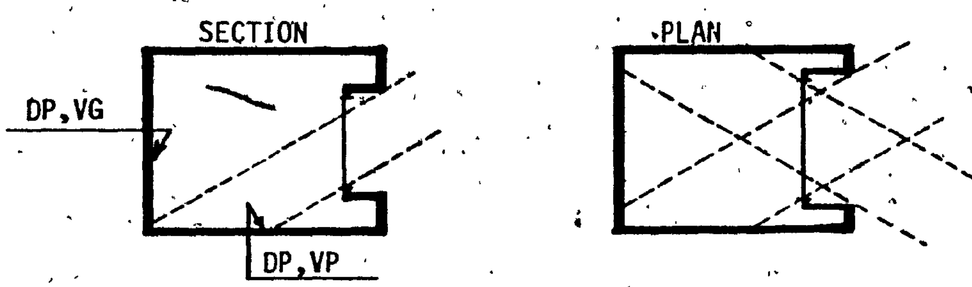
Windows can be designed in a variety of forms and geometry depending on orientation and function. If windows are introduced to create contact with the exterior they should be installed in nonexhibition areas such as corridors and other transient spaces. Seldom are they installed in galleries due to glare problems. The following are a list of possible window designs. These concepts are arranged based on the system that each is followed by an addition to the luminaire design. Starting with a plane window, other elements are added progressively.



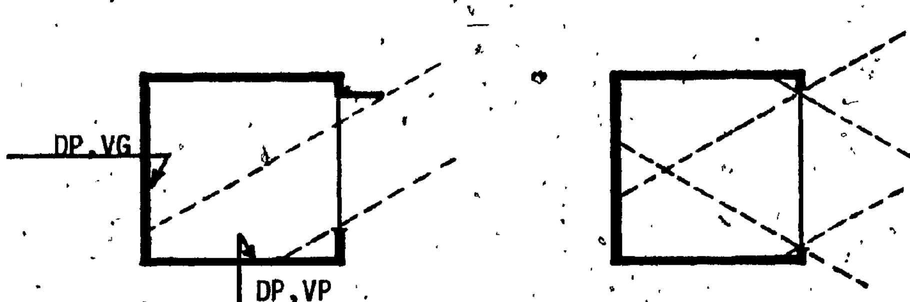

a) SIMPLE WINDOW

LEGEND

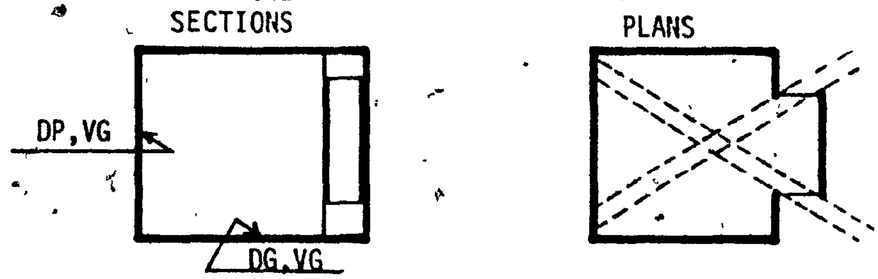
| | |
|---|---|
| DE | DISTRIBUTION IS EXCELLENT |
| DG | DISTRIBUTION IS ACCEPTABLE |
| DP | DISTRIBUTION IS POOR |
| VE | VEILING GLARE IS ABSENT |
| VG | VEILING GLARE IS PRESENT IN SOME LOCATIONS |
| VP | VEILING GLARE IS PRESENT |



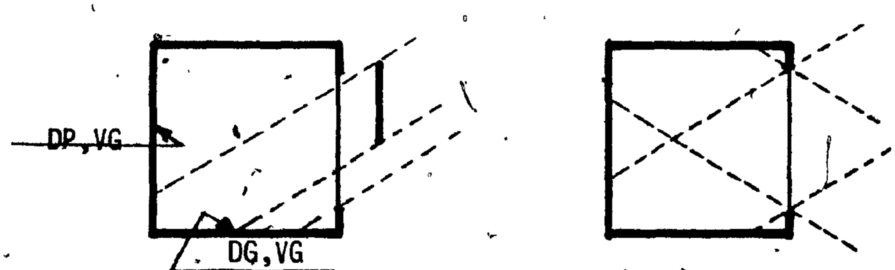

b) SET IN



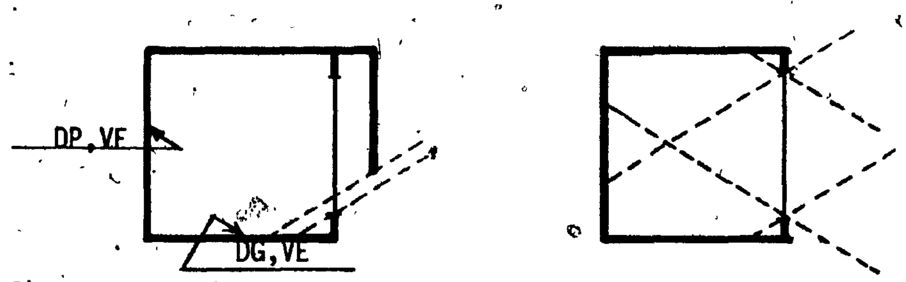

c) OVER HANG



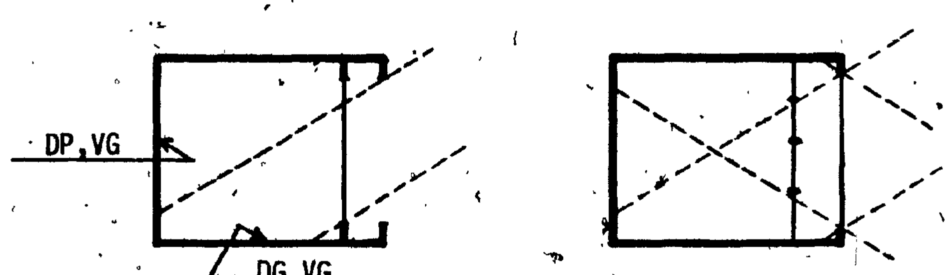

d) EXTENDED OUTWARD



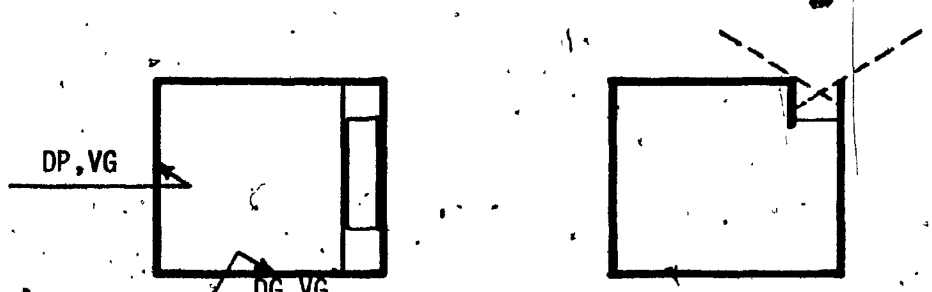

e) EXTERIOR PANELED




f) UPWARD REFLECTED LIGHT




g) PANELED INTERIOR




h) INDIRECT WALL WASHER

These basic concepts could be manipulated and adapted to individual schemes. The geometry employed in the overall design should provide for the designer the use of other variations.

The following advantages and disadvantages can be concluded:

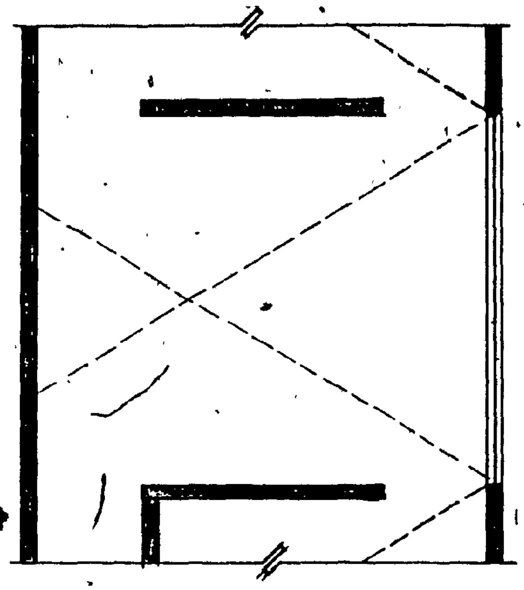
**a) Advantages:**

1. Provide contact with the exterior.
2. Can be a light source.
3. Effective in relating the museum to its surroundings.
4. Effective in elevation design.

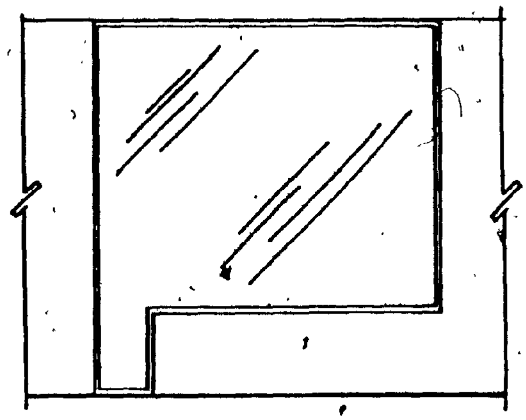
**b) Disadvantages:**

1. Takes away wall space.
2. Source of glare.
3. Creates high contrast with adjacent surfaces.
4. Imposing controls are in conflict with the above advantages i.e. blocking.
6. Source of heat, depending on orientation.
7. Causes problems of security.

The following are some existing examples of window lit spaces in museums illustrating the application of concepts to built designs. Based on the evaluation system one can say that concept (a) is the worst example and concept (e) is the best followed by (f). This is based on the opening design alone without any added control elements such as blinds.



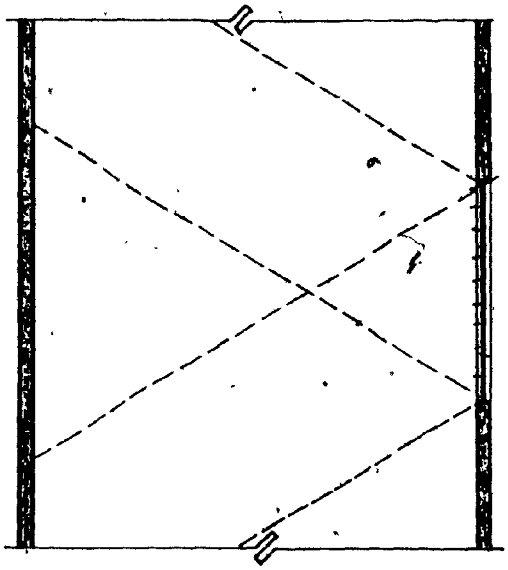
a) PLAN



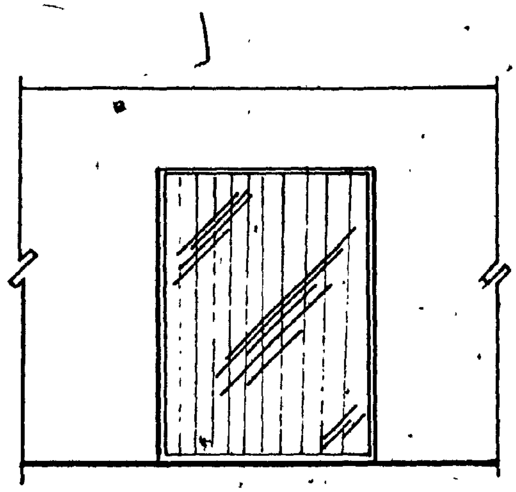
b) INTERIOR ELEVATION

c) GENERAL VIEW

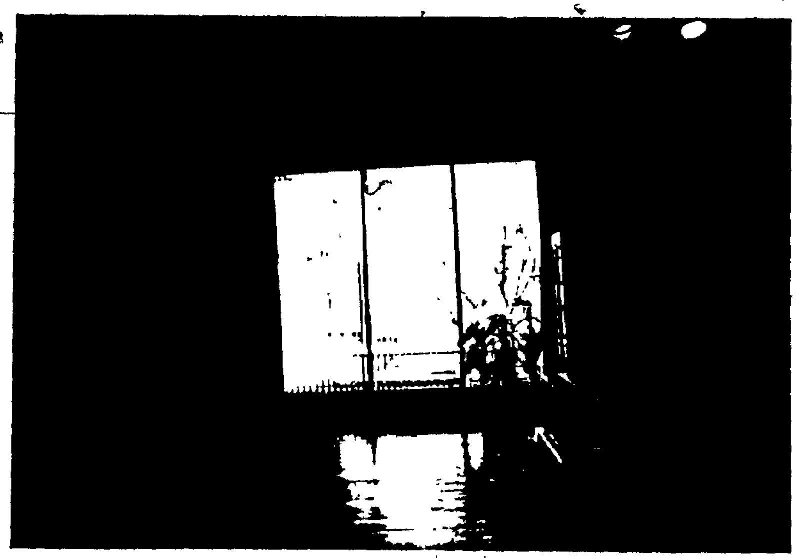
I. Johnson Museum
Concept (a) DP,VP



a) PLAN

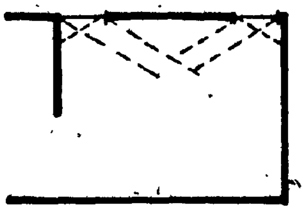


b) INTERIOR ELEVATION

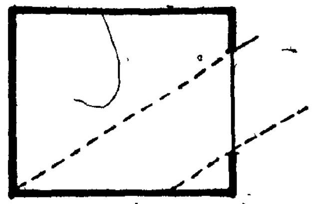


c) GENERAL VIEW

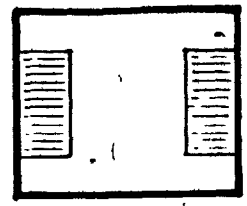
II. Montreal Museum of Fine Arts
Concept (a) DP, VP



a) PLAN



b) SECTION

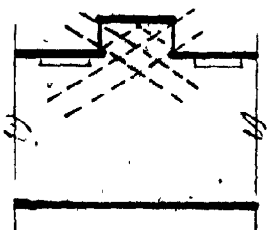


c) INT. ELEVATION

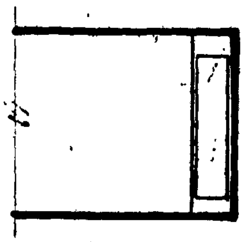
d) BLINDS INSTALLED

e) BLINDS REMOVED

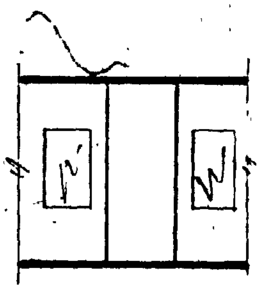
III. Yale Center for British Art
Concept (a) DG,VE



a) PLAN



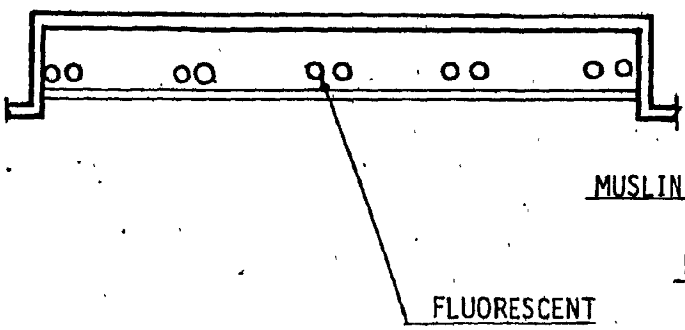
b) SECTION



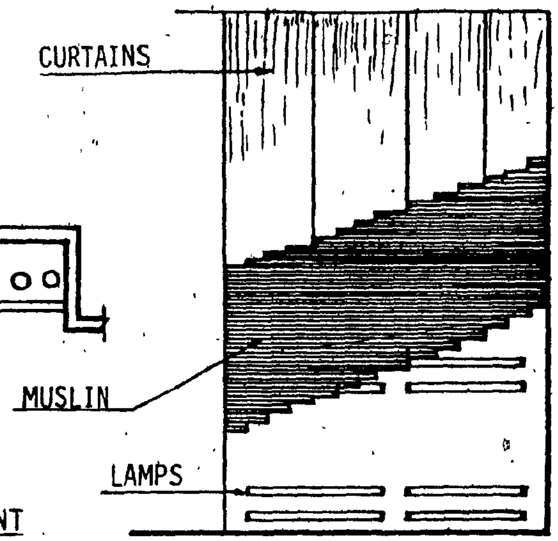
c) INT. ELEVATION

d) GENERAL VIEW

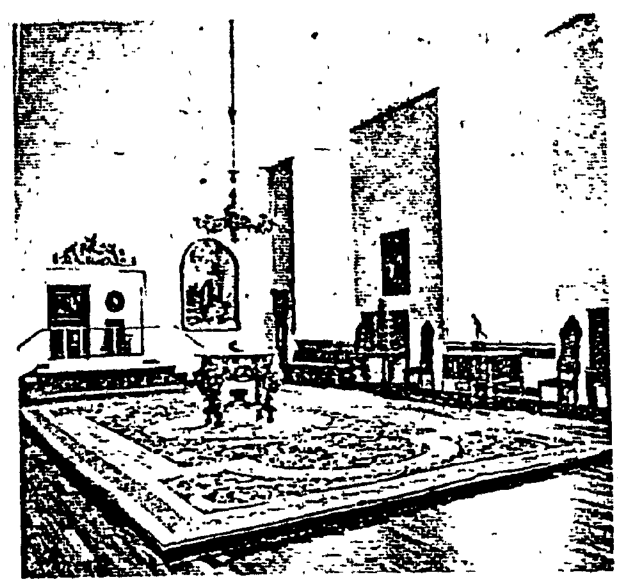
IV. Boston Museum of Fine Arts
Concept (d) DG,VG




a) PLAN

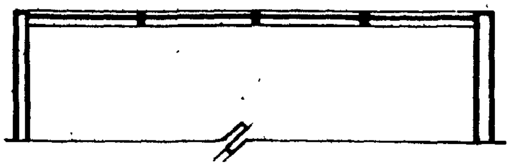



b) SECTIONAL ELEVATION

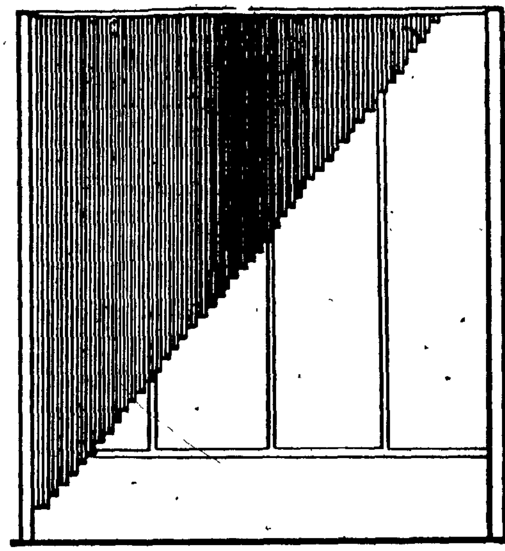


d) GENERAL VIEW

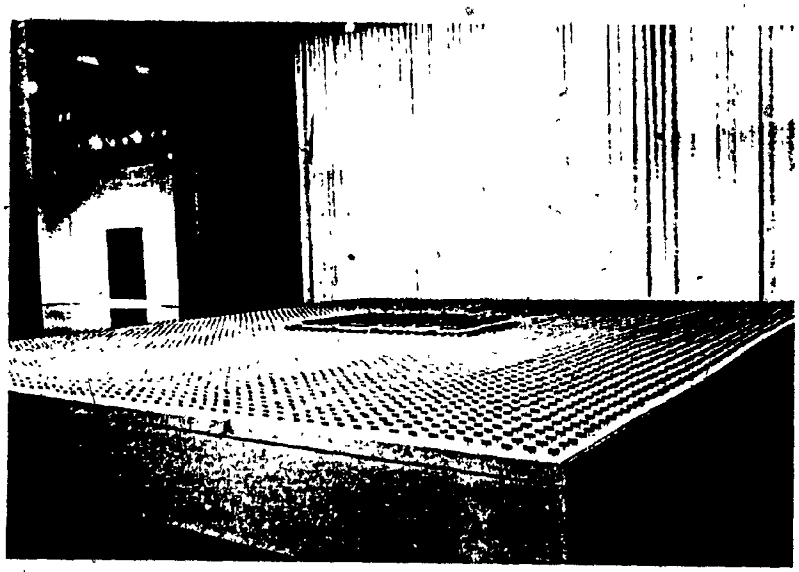
V. Artificial Window, Rijksmuseum
Concept (g) DG,VG



a) PLAN



b) ELEVATION



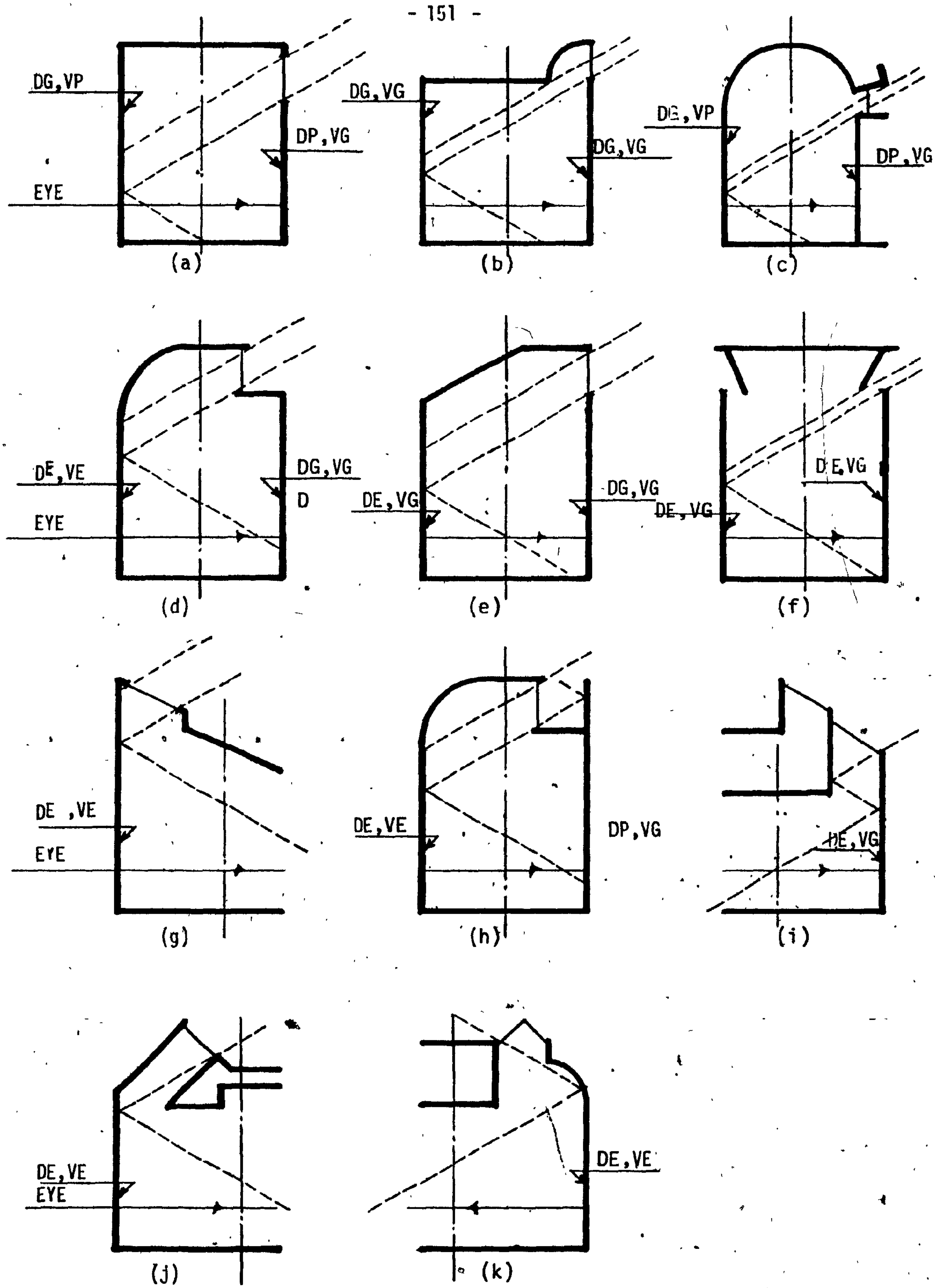
c) GENERAL VIEW

VI. Museum of Contemporary Art
Concept (a) DG,VG

## 5.6 CLERESTORY - LUMINAIRE

Clerestories are introduced to conserve wall space for exhibition purposes and to bring light in as far back as possible into the rooms. They do not provide direct contact with the outside in general but can give a view of the sky. The luminaire provides light diagonally which is very important for modeling as this angle of incidence is required for creating desired shadows and contrast. As windows, clerestories could become a source of glare if not properly designed, although little reflection is produced from the floor as is with window luminaires.

The following are some examples of clerestory luminaire designs. These concepts are arranged based on the geometry of the reflective planes, starting with the simple opening on the vertical plane leading to the opening on the roof beside the exhibition wall.


DG, VP
DP, VG
EYE
(a)
DG, VG
DG, VG
(b)
DG, VP
DP, VG
(c)
DE, VE
DG, VG
D
EYE
(d)
DE, VG
DG, VG
(e)
DE, VG
DE, VG
(f)
DE ,VE
EYE
(g)
DE, VE
DP, VG
(h)
DE, VG
(i)
DE, VE
EYE
(j)
DE, VE
(k)

We can conclude the following advantages and disadvantages of clerestory luminaires.

**a) Advantages:**

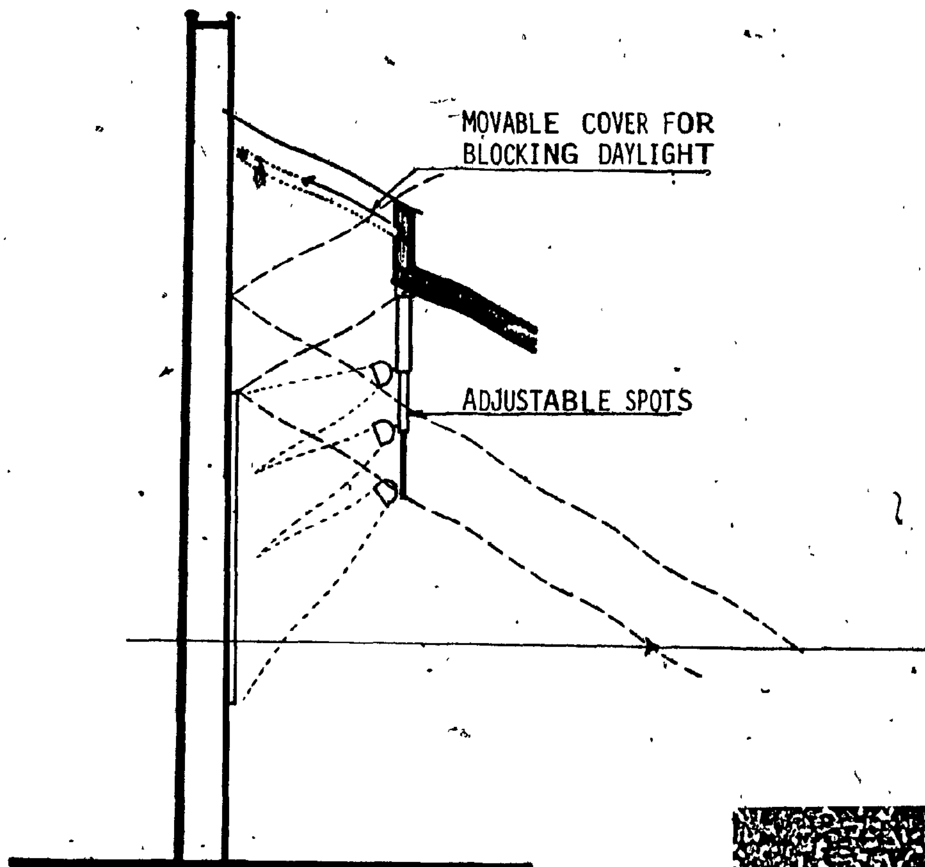
1. Provide contact with the outside.
2. Effective Luminaire (light source).
3. Effective in relating the museum to its surroundings.
4. Effective in elevation design.
5. Effective in modeling.
6. Effective in light distribution in the gallery.
7. Easy to control.

**b) Disadvantages:**

1. Source of glare.
2. Creates high contrast with adjacent surfaces.
3. Difficult to introduce in all 4 walls, if desired.

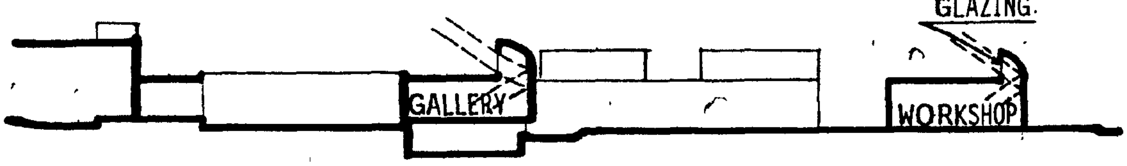
Based on the established evaluation system at the begining of this chapter one can conclude that concept (a) will pose the most problem and concept (k) followed by (i), (j) and (b) respectively would pose the least problems.

To illustrate the application of the foregoing concept we will study the following existing clerestory luminaires.



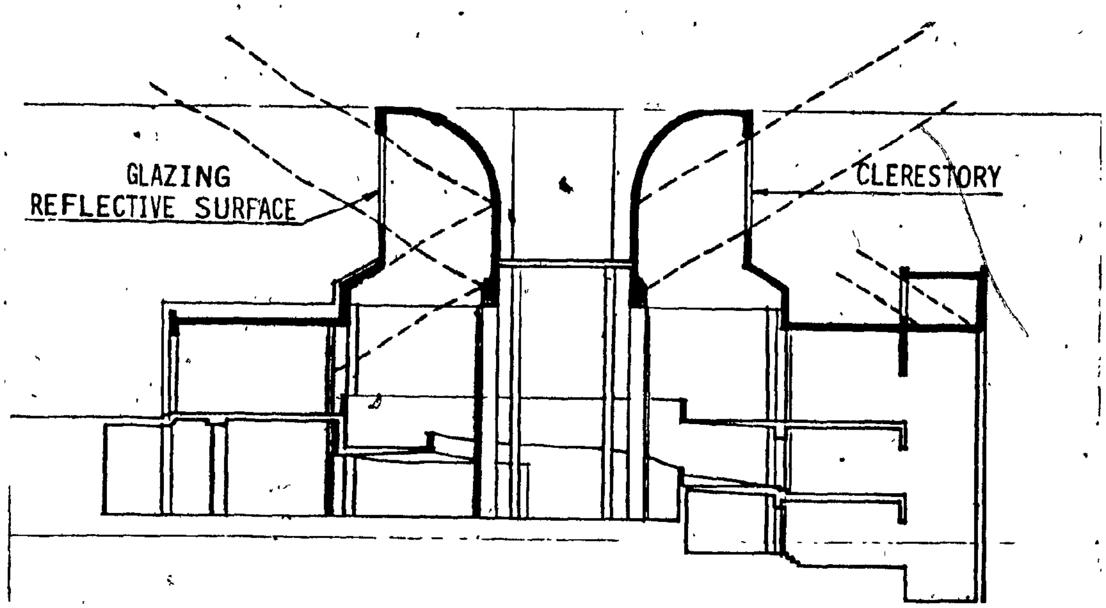

I. Arts Centre, St. Andrews University
Concept (g) DE, VE

a) GENERAL VIEW

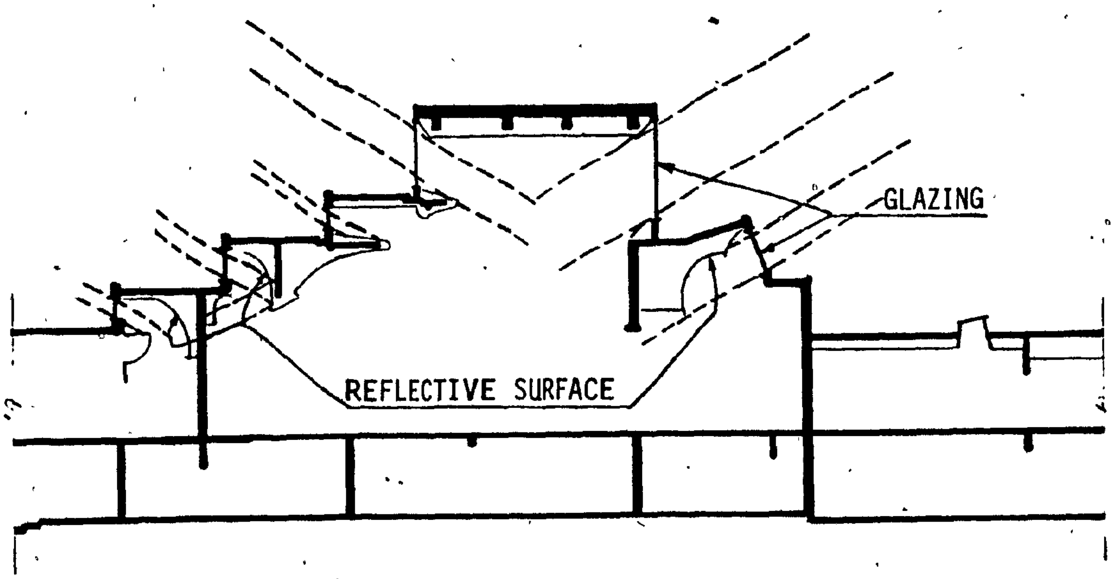



b) SECTION

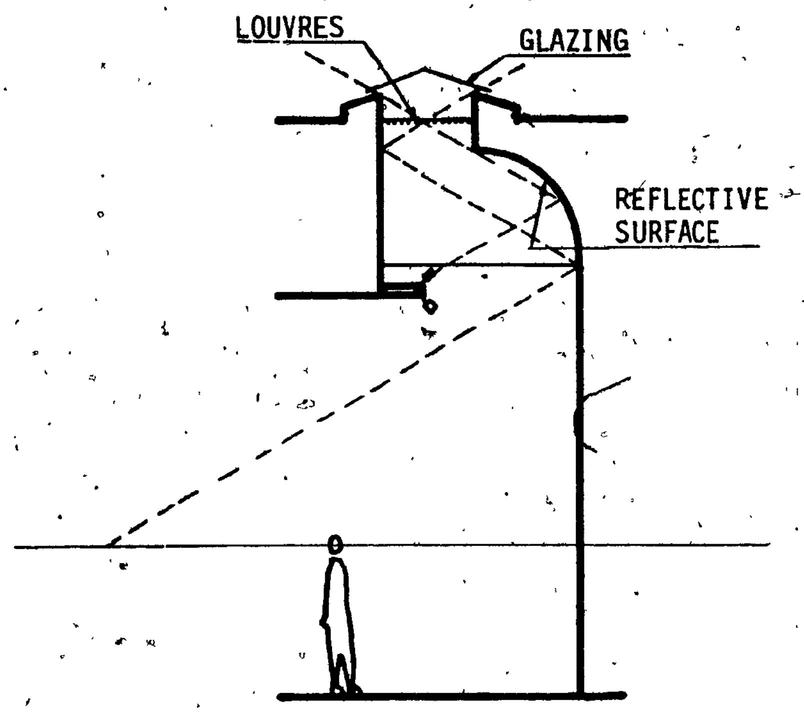
II. Huntington Museum, West Virginia
Concept (b) DE, VE




III. Tehran Museum of Contemporary Art
Concept (b) DE,VE




IV. North Jutland Fine Arts Museum, Aalborg
Concept (a,i) DE,VE

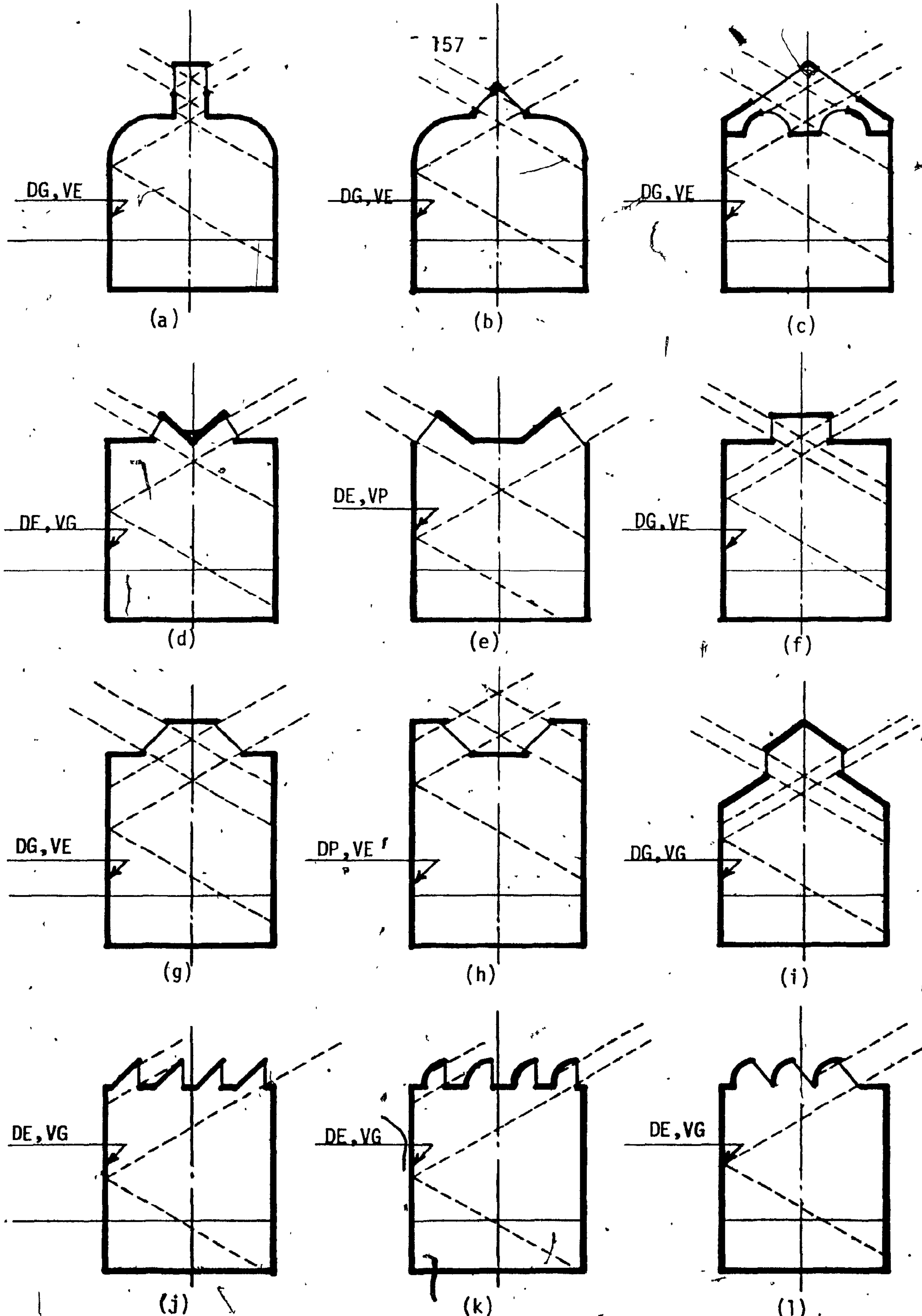


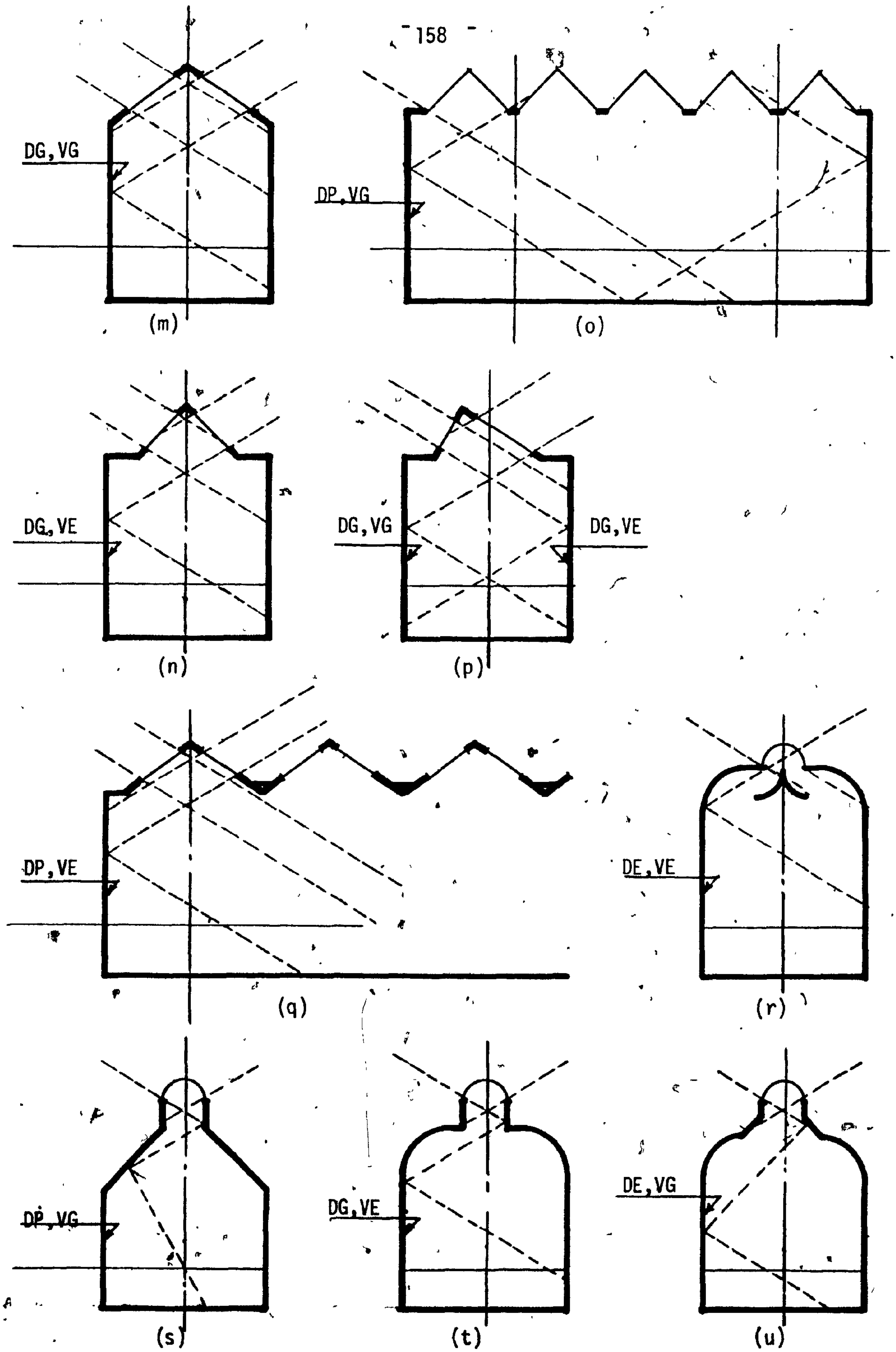

Dallas Museum of Fine Arts
Concept (k) DE,VE

## 5.7 TOP LIGHTING

This system of daylighting luminaire is most commonly used in museums. It provides ambient lighting as well as exhibition lighting. In a skylight design a very careful consideration must be given to the glare zone on the ceiling. It should be so designed that the light is directed on the walls and not on the floor in order to avoid reflections, and direct the light towards the task.

Overall skylights, partial skylight and repetitive clerestory lighting are used. The following are some examples of conceptual designs. These concepts are arranged based on the size and geometry of the skylight. Single openings concepts are followed by their repetitive design. The concepts which are similar with respect to the above criteria and the geometry of the reflective planes are considered for arrangement.


DG, VE
(a)
DG, VE
(b)
DG, VE
(c)
DF, VG
(d)
DE, VP
(e)
DG, VE
(f)
DG, VE
(g)
DP, VE
(h)
DG, VG
(i)
DE, VG
(j)
DE, VG
(k)
DE, VG
(l)


DG, VG
(m)
DP, VG
(o)
DG, VE
(n)
DG, VG
DG, VE
(p)
DP, VE
(q)
DE, VE
(r)
DP, VG
(s)
DG, VE
(t)
DE, VG
(u)

We can conclude the following advantages and disadvantages of top lighting luminaires:

**a) Advantages:**

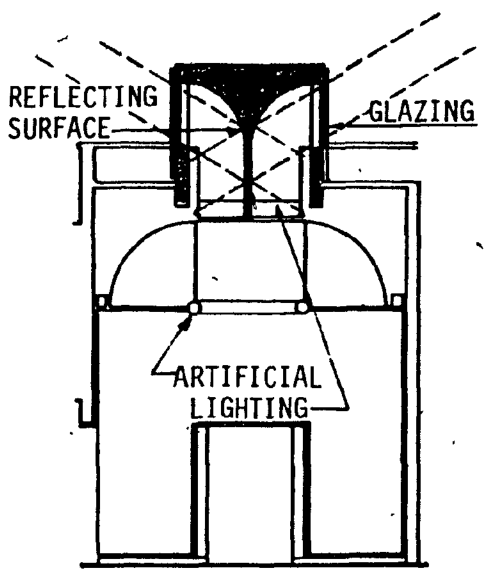
1. Provides psychological contact with the outside.
2. Is a luminaire (light source).
3. Effective in ambient lighting.
4. Effective in distributing light in the gallery.
5. Easy to control.
6. Effective in creating interest in the visual environment.
7. Effective in massing and geometry of the museum.
8. Creates interest in viewing the museum from above.

**b) Disadvantages:**

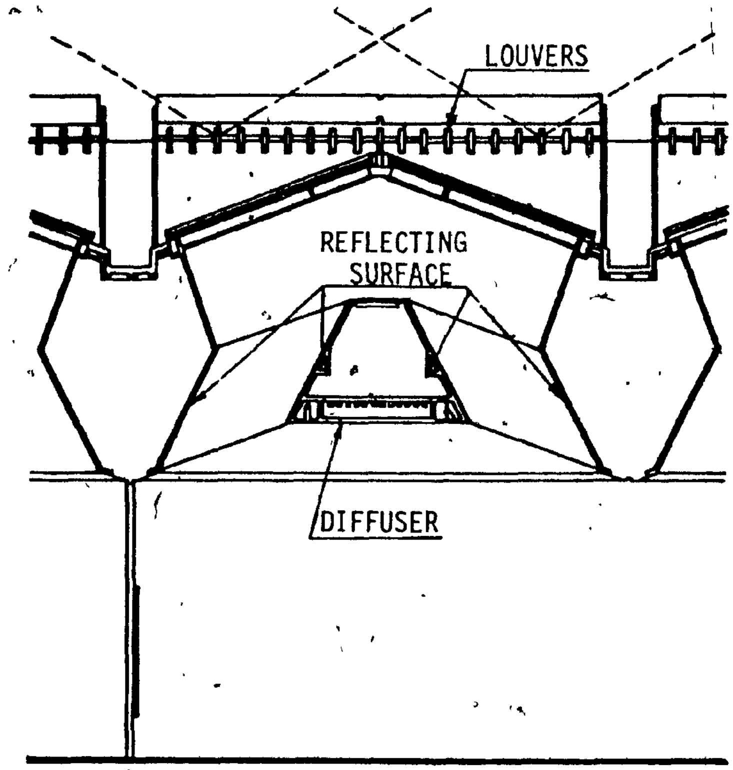
1. Not effective for modeling.
2. High level of control will eliminate advantages.
3. Lack of hardware, ie. louvres etc.
4. Source of heat loss and heat gain.

Based on the established evaluation system one can conclude that concepts (O) and (m) will have the most problems. Concepts (r), (u), and (k) will have the best performance.

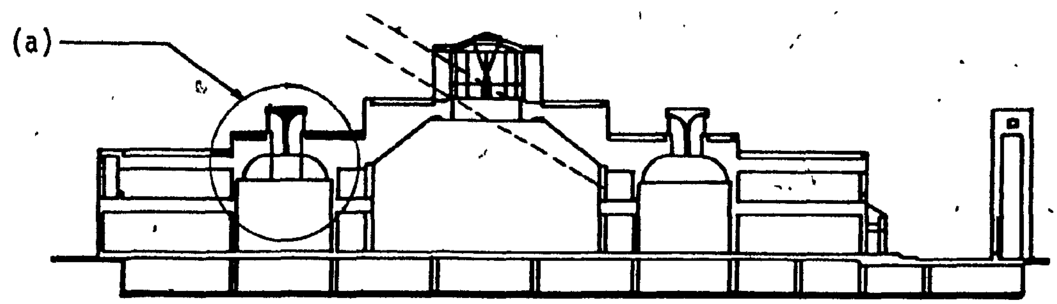
To illustrate the possibilities of top lit luminaires we'll study the following existing examples:



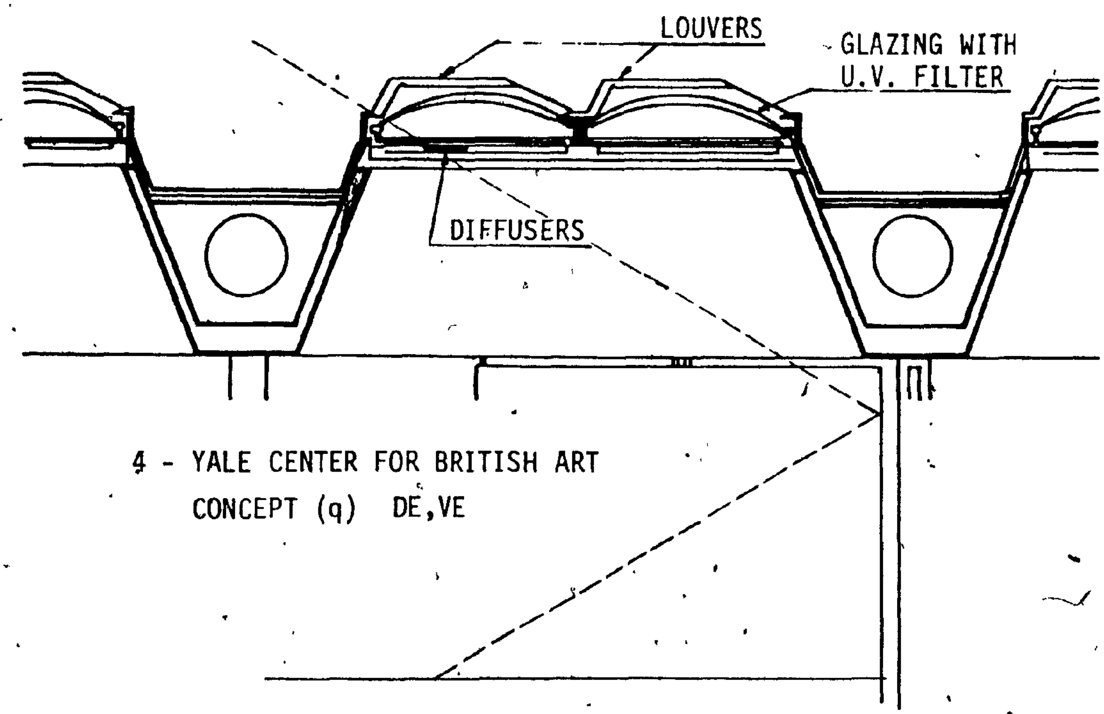

(a) SECTION DE,VE



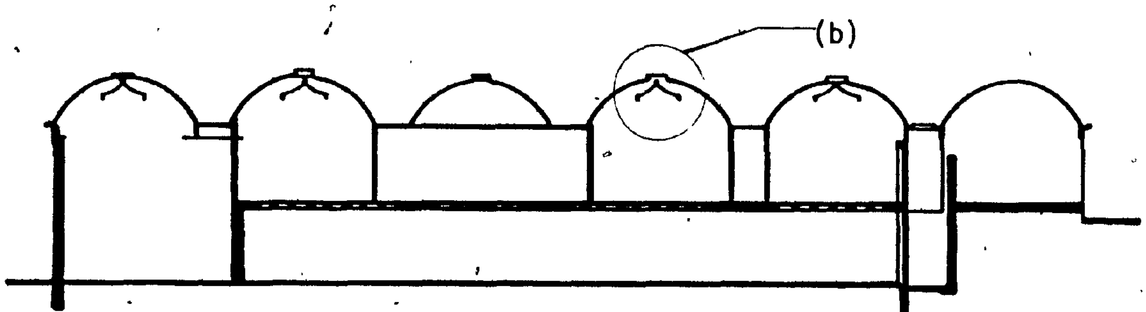

1 - EXTENSION TO THE TATE GALLERY
CONCEPT (b) DE,VE



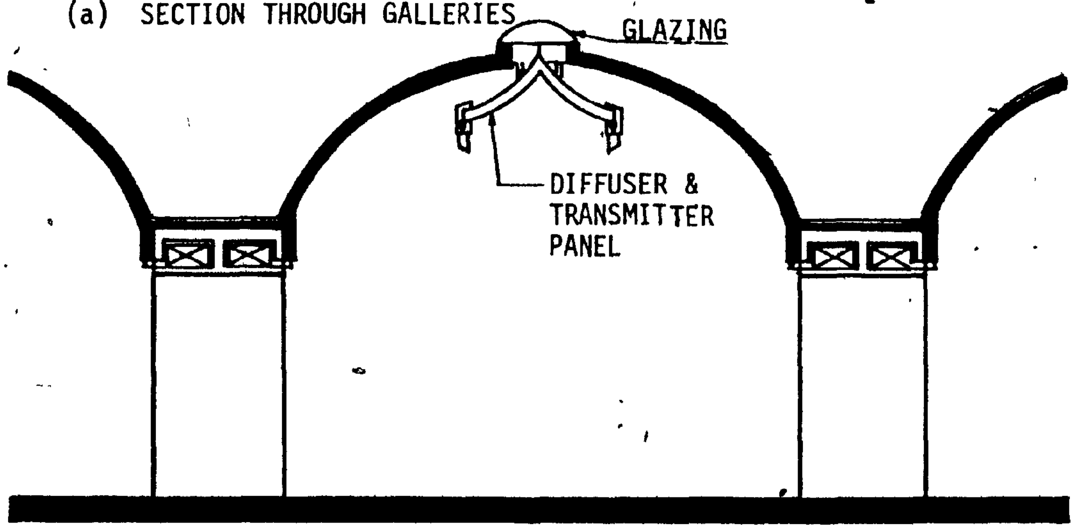

2 - HISTORIC AND FINE ARTS MUSEUM, ALASKA
CONCEPT (f) DE,VE




4 - YALE CENTER FOR BRITISH ART
CONCEPT (q) DE,VE

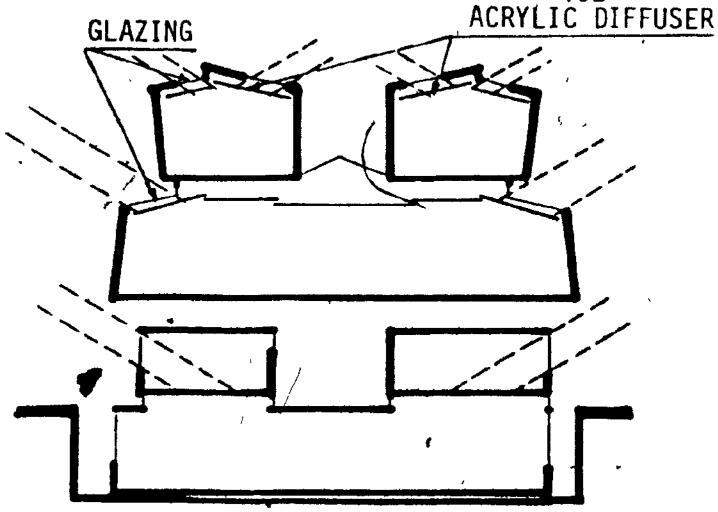



(a) SECTION THROUGH GALLERIES

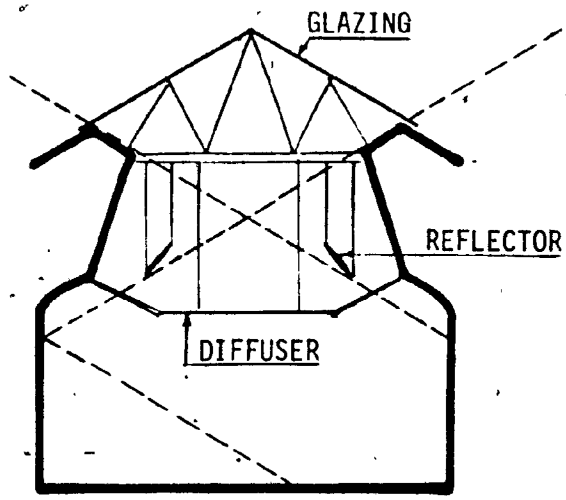



(b) DETAIL OF SKY LIGHT SYSTEM

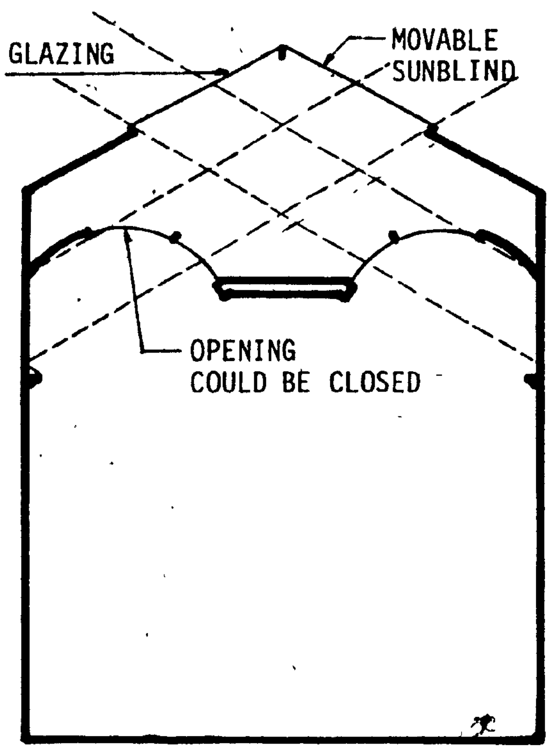
KIMBLE ART GALLERY, CONCEPT (r) DE,VE



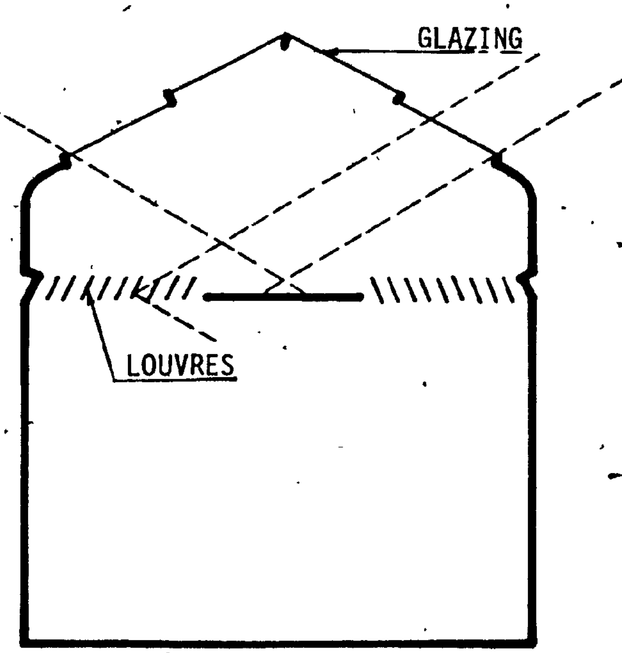

6. GALLERY OF MODERN ART, TURIN
CONCEPT (p) DE,VE



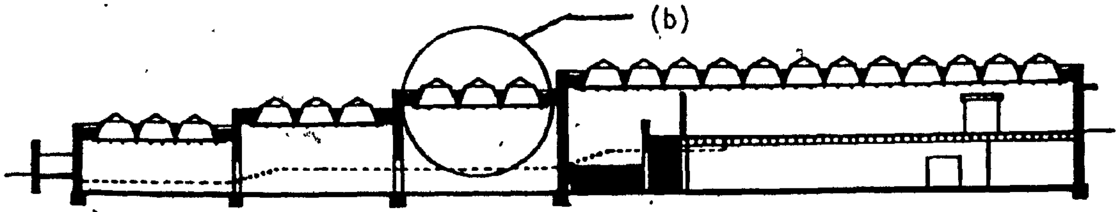

7. BIRMINGHAM CITY MUSEUM AND ART GALLERY
CONCEPT (h) DE,VG



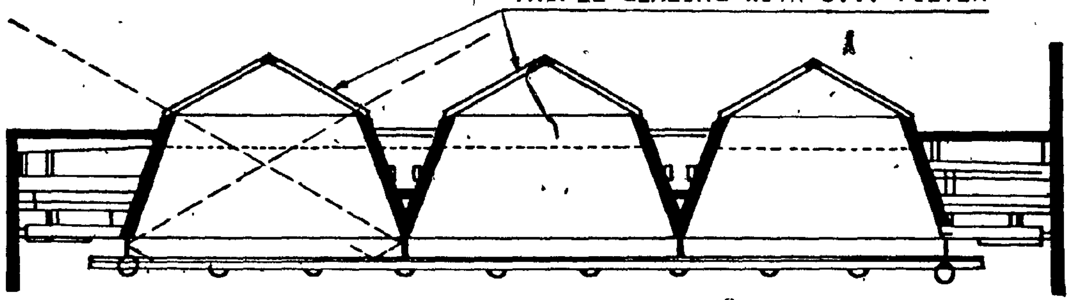

8. NATIONAL ART GALLERY, LONDON
CONCEPT (c) DG,VP




9. BOYMAS-VAN BEUNINGEN MUSEUM, ROTTERDAM
CONCEPT (c) DG,VG

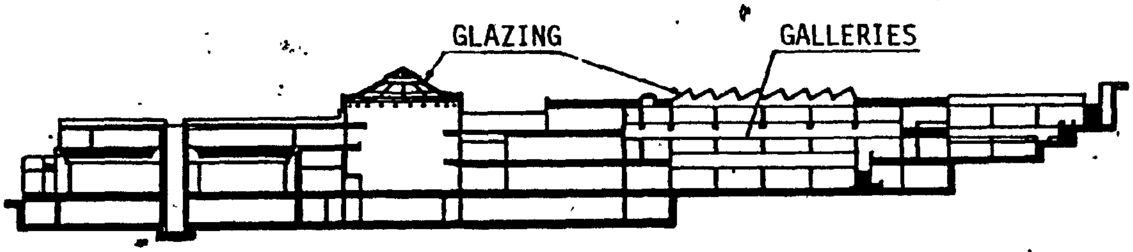



(a) SECTION THROUGH GALLERIES

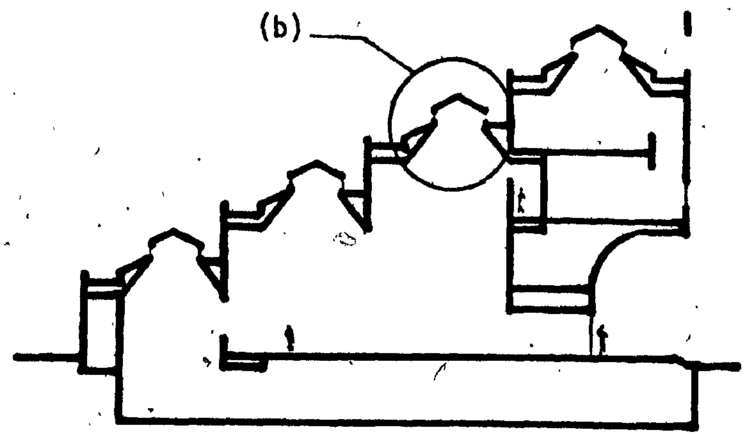



(b) SKYLIGHT DETAIL

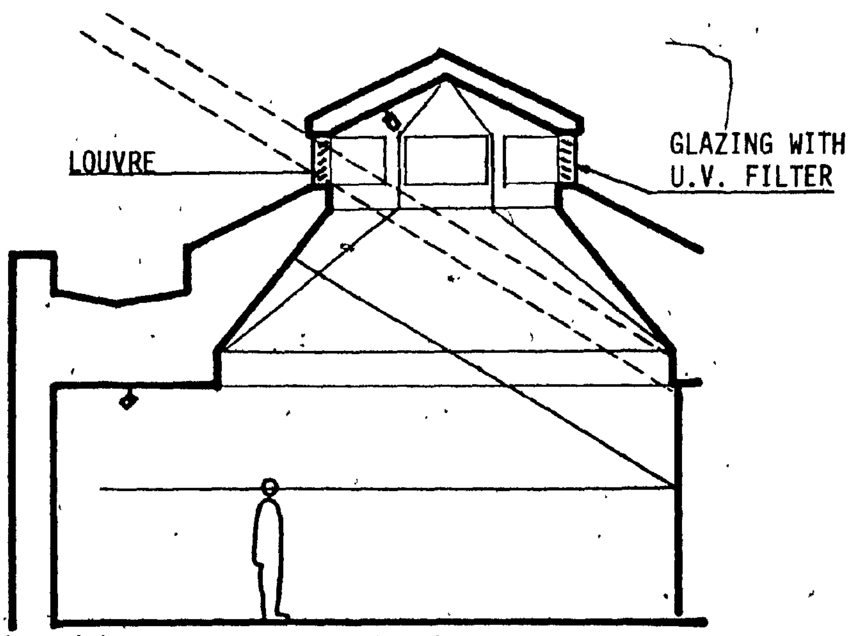
10. ADDITIONS TO LOUISIANA MUSEUM, DENMARK
CONCEPT (0) DE,VE




11. MUSEUM OF MODERN ART, KOREA
CONCEPT (j) DE,VG

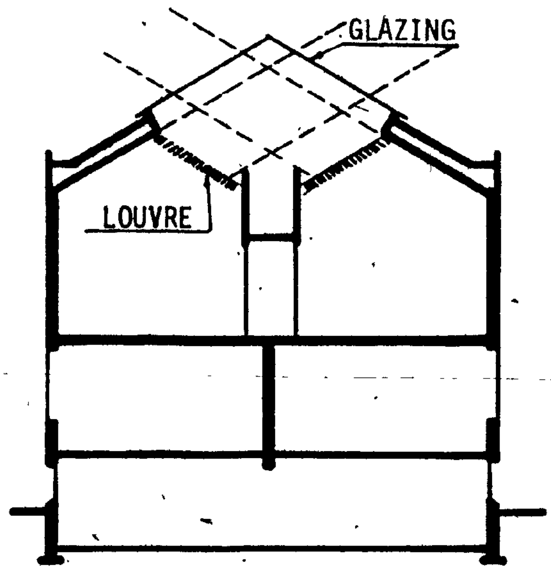



(a) SECTION THROUGH GALLERIES



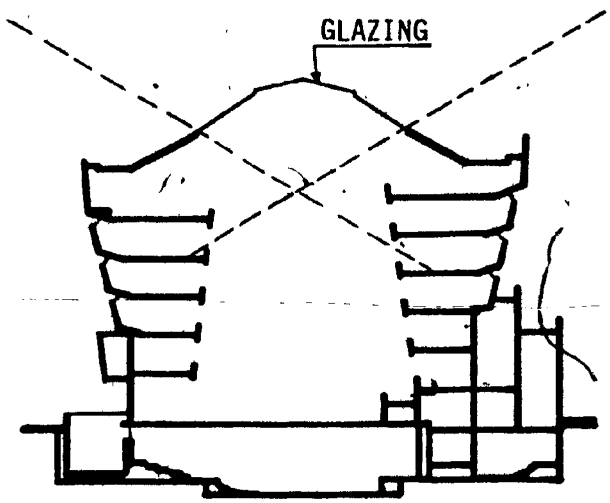

(b) ONE MODULE OF GALLERY

12. Portland Museum of Fine Arts
Concept (i). DE, VE



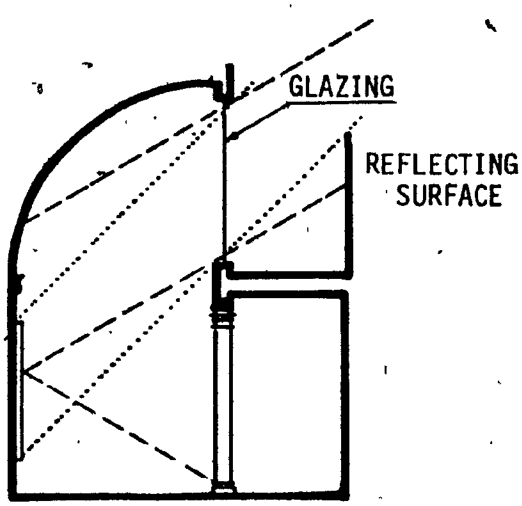

13. Municipal Museum, Linkoping, Sweden

Concept (m) DE,VP



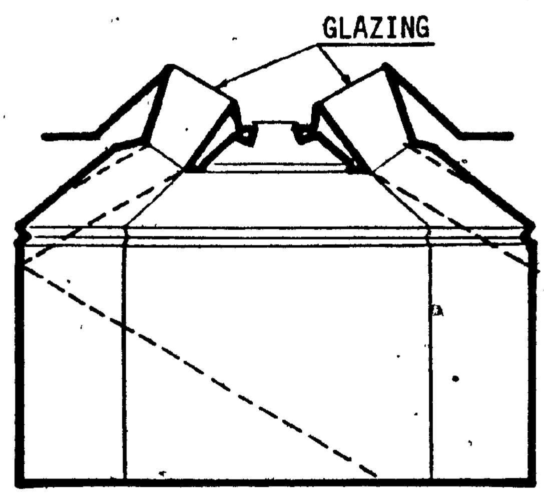

14. Guggenheim Museum, N.Y.C.

Concept (m) DP,VP



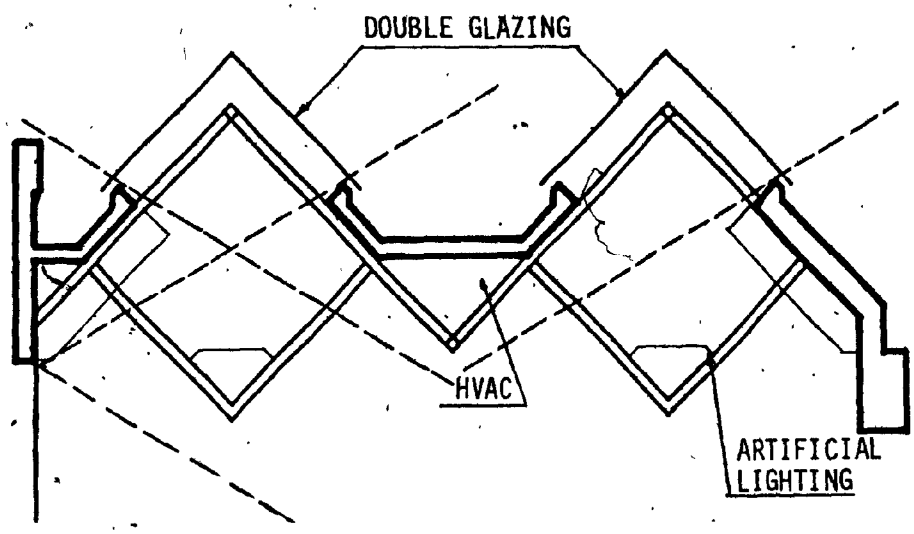

15. Duveen Gallery, Tate Gallery, London

Concept (b) DE,VP

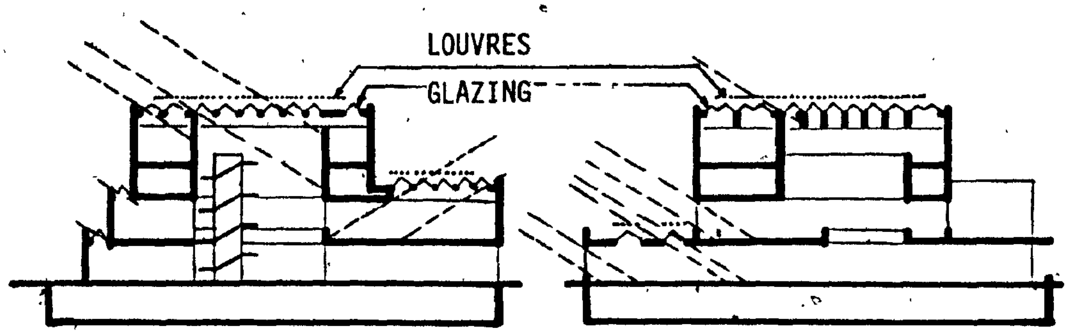



16. Fitzwilliam Museum, Cambridge, England

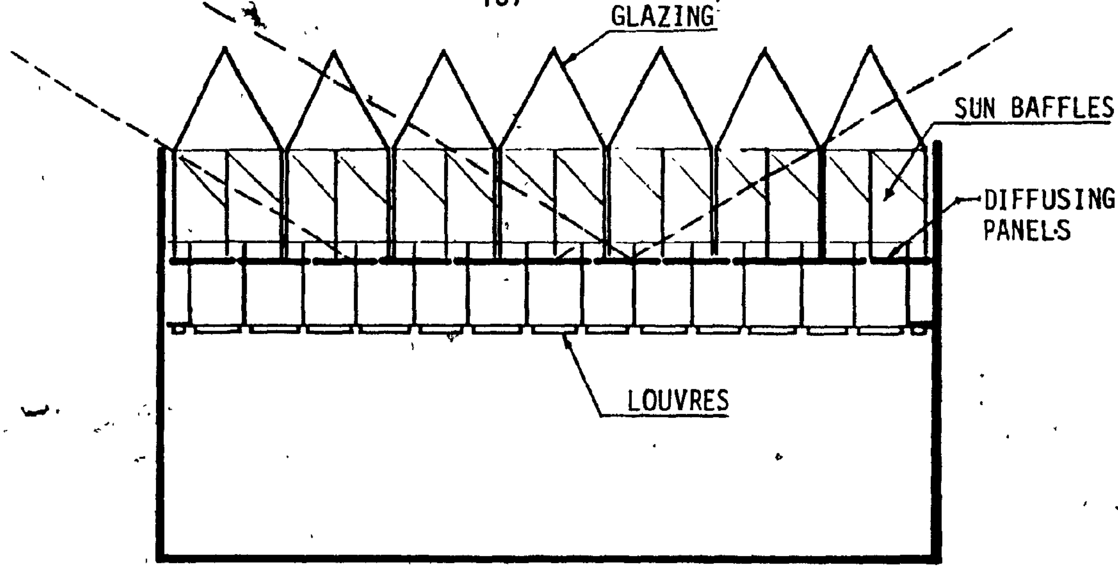
Concept (d) DG,VG



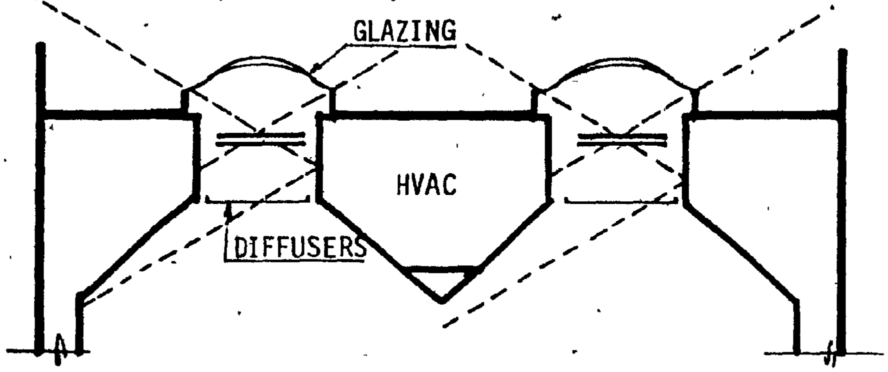

17. Extension to the Kunshalis Zurich
Concept (h) DG,VP



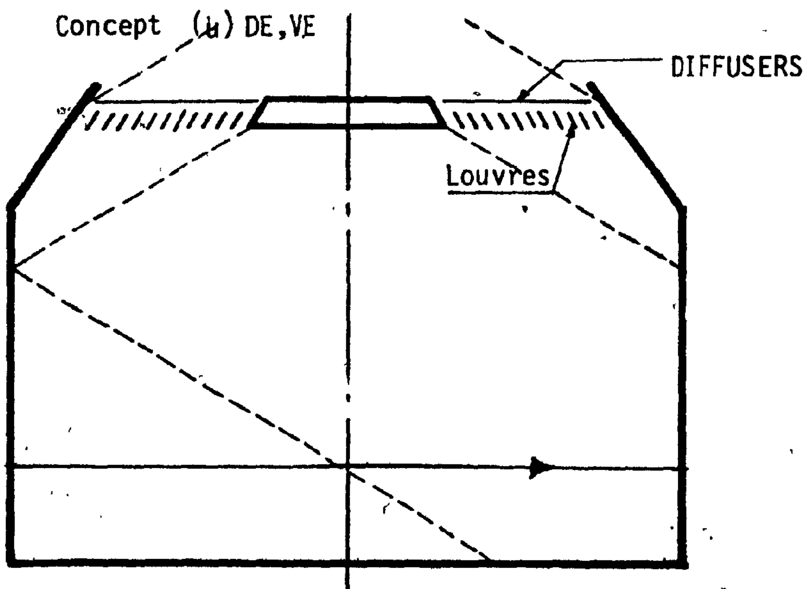

18. Vincent Van Goh Museum
Concept (o) DG,VG



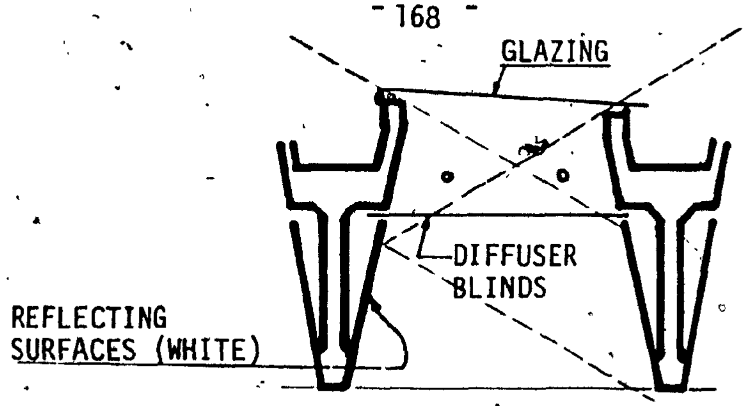

19. Hayward Art Gallery London.
Concept (o) DP,VG



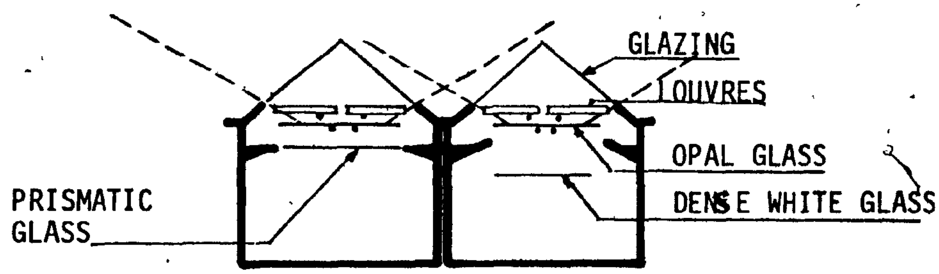

20. Boston Museum of Fine Arts
Concept (u) DE,VE



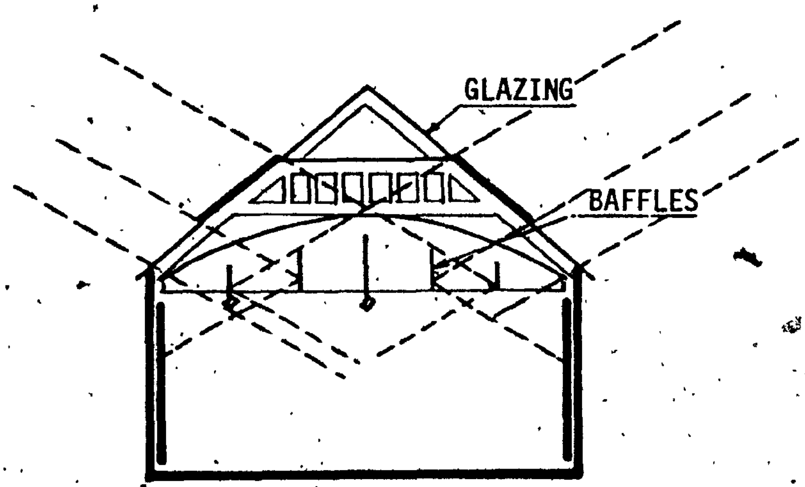

21. Boymans, Van Beuningen Museum, Rutterdam
Concept (n) DG,VG



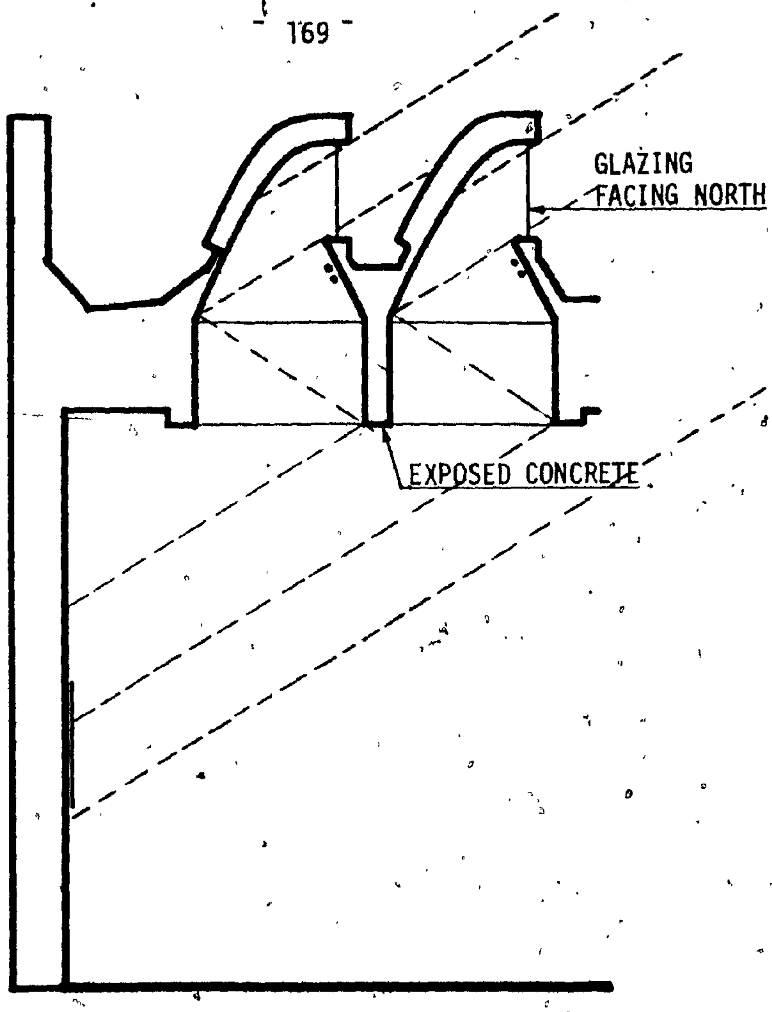

22. Commonwealth Institute, London
Concept (m) DE,VE



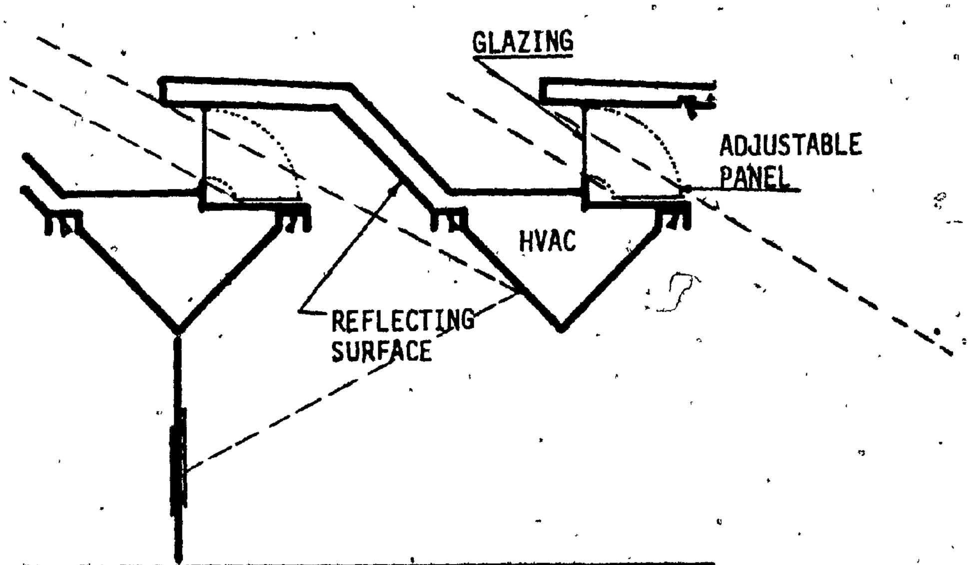

23. Haags Gemeentemuseum
Concept (m) DE,VE



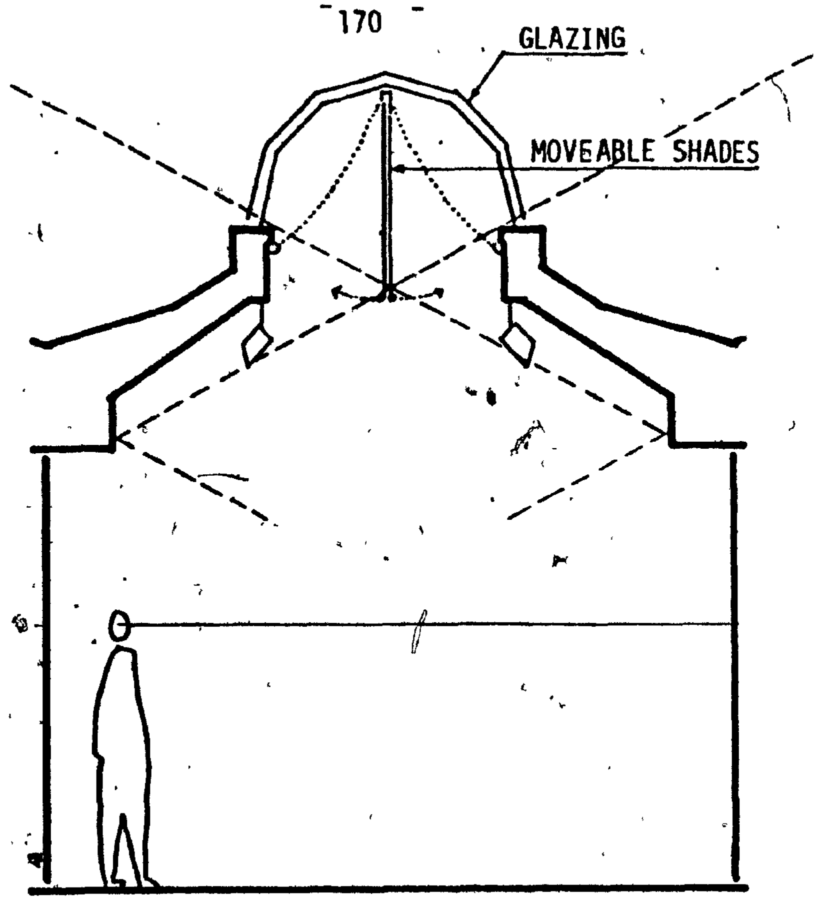

24. Central Art Gallery, Roochdale
Concept (m) DG,VE



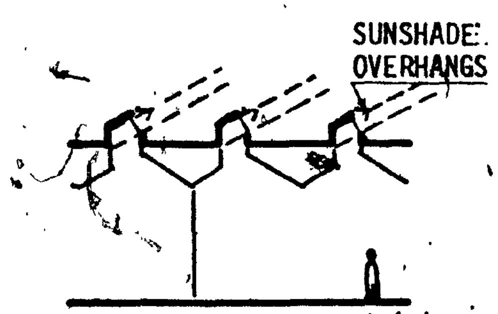

25. Israel Museum, Jerusalem
Concept (r) DG, VE



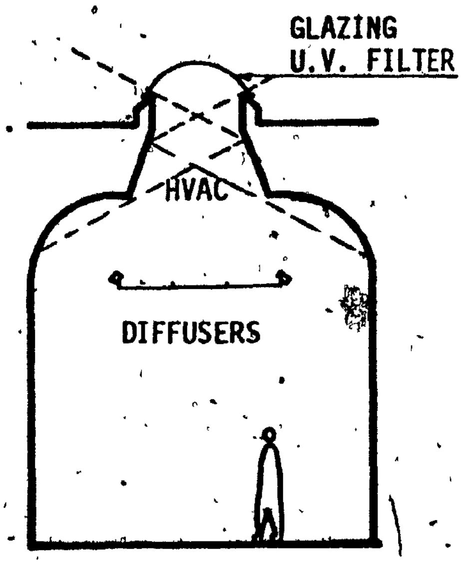

26. Trable Arts Center, Eastern Illinois University.
Concept (j) DE, VE



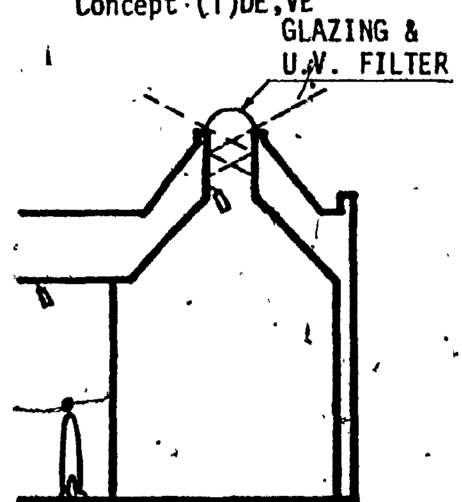

27. Mayer Art Gallery
Concept (s) DE,VG




a) SECTION, GALLERY (r)
Concept (1)DE,VE




28. The Speed Museum
Concept (t) DE,VE




29. (b) Section,perimeter gallery
Korea Museum of Modern Art
Concept (s) DG,VE

## 5.8 COURTYARD LIGHTING - LUMINAIRE

One could assume that courtyard lighting is a top lit space and the adjacent galleries are side lit spaces. The courtyard itself generally functions as an entry court or a sculpture court. The quality and quantity of light entering in the adjacent galleries is very different in comparison to windows opening to the outside. No barrier such as glazing exists in the vertical openings to the court. Shutters are used to control the level of illuminance entering the perimeter galleries but the filtering of U.V. should take place in the skylight of the court. Depending on the scale, rarely does a courtyard function as a satisfactory light source. Courtyards or atriums are mostly used for the creation of space and other activities.

Examples of design concepts are illustrated on page 133. The following are illustrations of existing museums with courtyard lighting.

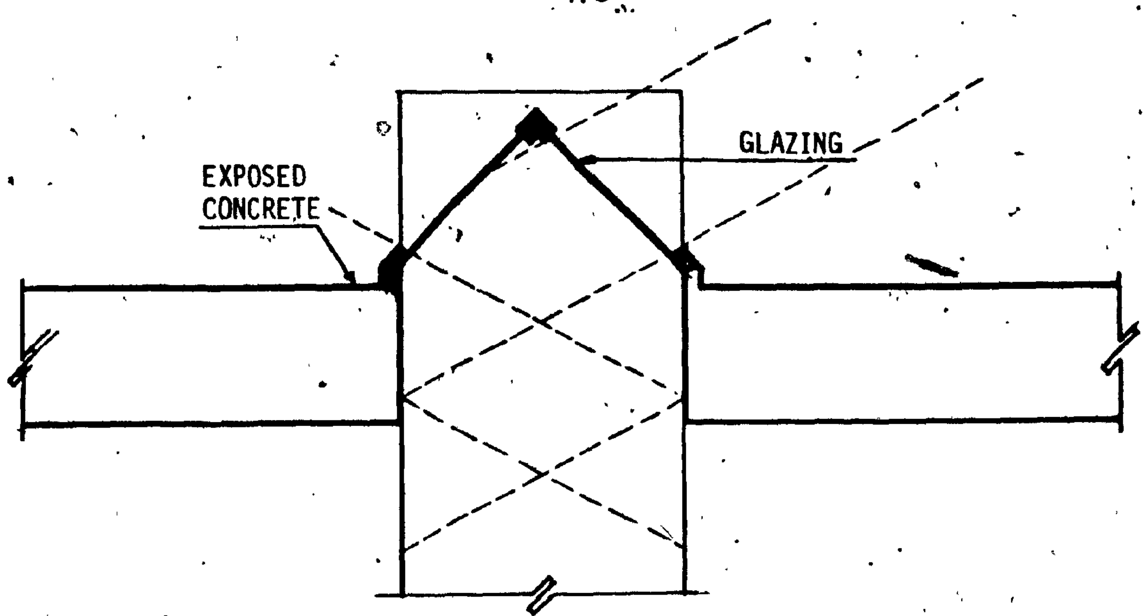
We can conclude the following advantages and disadvantages of courtyard lighting:

**a) Advantages:**

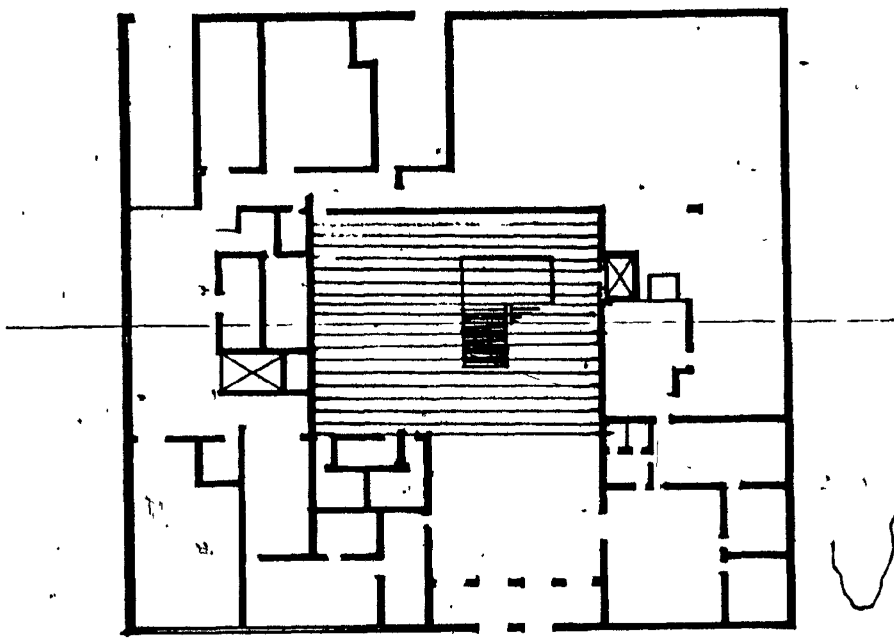
1. Provides limited contact with the outside.
2. Provides contact with the court spaces.
3. Effective in viewer orientation.
4. Could be a light source.

**b) Disadvantages:**

1. Takes away wall space.
2. Source of glare.
3. Creates high contrast with adjacent surfaces.
4. Not effective for modeling.
5. Difficult to control direct sun rays.
6. Source of heat loss and heat gain.
7. Problem with adaptation.




1. c, Detail of skylight and general view of the garden court.
DP, VP, Everson Museum, Syracuse, N.Y.



(a)

(b)

2. The entry court, Museum of Contemporary Art, Montreal
a. Floor plan indicating the court, b. The view of the skylight.

DG,VP

3. The view of the court at the Lehman Gallery, Metropolitan Museum of F.A., N.Y. DG,VP

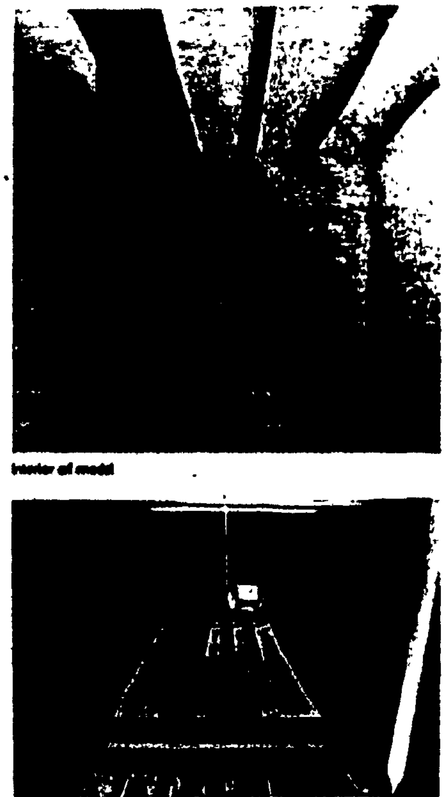
4. General view of the galleria (long court), at the Louvre Paris. DE,VE

## 5.9 DAYLIGHT DESIGN ANALYSIS TECHNIQUES

These are a short list of possibilities for introducing daylight in museums. There is a need to investigate these concepts and to find out how they would function in an actual building. For ongoing designs, however, one way to analyze the lighting performance is by the use of models. If possible full size mockups should be used. If these are not possible, scaled models should be employed. One of the characteristics of lighting is that, the quantity and quality of light is almost constant regardless of the scale of the model. Thus observations made through model studies can be applied directly to actual museums.

The museum lighting design is not only an analytical design process. To study the quality of lighting one must be able to see the effects and take measurements. The case studies are used as guidelines for similar designs.

The Portland Museum of Art is an example of the use of a scaled and full size model. The scaled model is used for preliminary investigation. Then the full size model is constructed on the site for a detailed investigation. Unfortunately only the level of illuminance (Lux) is measured and other factors that have been discussed throughout this study (U.V. for example) have been ignored. Nevertheless the process is valid if the transmissivities and reflectances of materials are the same as the real space and if room proportions are the same. Plate (5.5) illustrates a number of model studies in the visual environment design process.



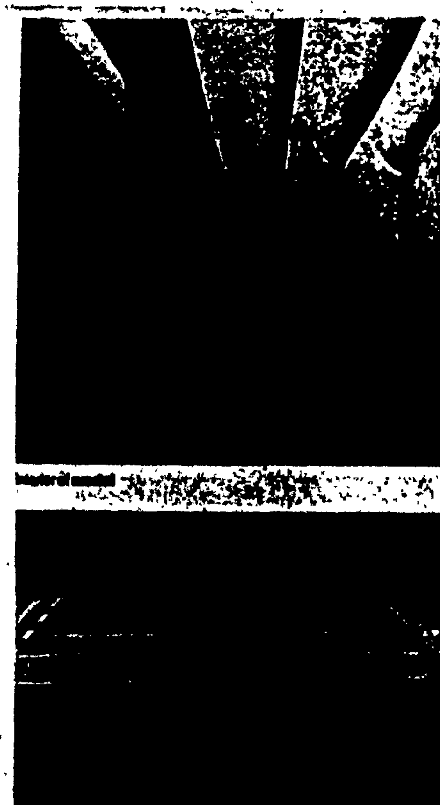


Plate (5.5,a), Two interior views and roof of models used for daylight studies, for Monchengladhach Museum.

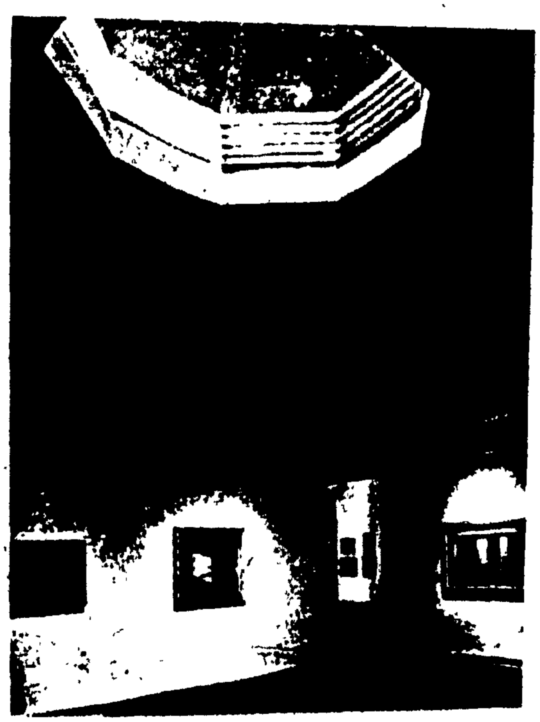


Plate (5.5,b), The view (above) of interior of model used for daylight analysis at Portland Museum. Below is the view of the actual gallery after opening.

Scaled models can be studied in artificial skies. The artificial sky provides the possibilities of simulating the exterior lighting conditions and taking measurements. Again it is used just for studying the illuminance and luminance levels. The model must be transferred to the exterior for site lighting constraints, glare and color rendering.

In addition to models, other techniques, such as computer programs are being developed and used. However, these programs compute only horizontal illuminance and do not determine glare, color rendering or visibility for vertical displays. The use of existing examples as analogies to be modified is one method used regularly during the design process. In Chapter 6 and 7 we will study a number of examples which have been documented.

## 5.10 CONCLUSION

By comparing the advantages and disadvantages of daylight luminaires we conclude that:

1. The geometry of openings is a very important factor in how the luminaire functions. Openings which see bright sky will cause veiling glare, and uneven illuminance distribution. Openings that cause light to be inter-reflected reduce veiling glare, give even illuminance and control UV damage.

2. Model studies, graphical studies, and case studies should be used to predict the performance of luminaires due to

the large number of different viewer/object/source relationships possible in a space. A statistical system approach needs to be developed to fully evaluate the visibility in the gallery space.

3. Controls should be designed as an integral part of the luminaire. Smaller source openings give smaller control surfaces and reduce costs. Glare control should also be provided.

4. All luminaire types must be used with limiting devices and controls. Daylight is admitted during viewing hours and should be blocked when the museum is closed.

5. Top lighting luminaires followed by clerestory luminaires have the most potential to limit veiling glare and control illuminance distribution without aid of complicated control devices.

6. The geometry of the viewer/object/source is the fundamental relationship that controls veiling glare, modeling and visibility.

## 5.11 FOOTNOTES CHAPTER V

17. J.B., Harris, Practical Aspects of Lighting as Related to Conservation, (paper to ICOm Conference in London, 1967), p. 133.

18. William M., Lam, Perception and Lighting, As Formgivers for Architecture, (McGraw-Hill, Inc., New York, 1977), p. 12.

19. Barbara, Weiss, American Museums, Three examples, (Lotus International, No. 34), P. 104.

# CHAPTER VI

# FIELD STUDIES

## 6.1 INTRODUCTION

It was necessary to visit some existing museums particularly museums which emphasize daylighting and see how these museums function with respect to lighting. A number of museums in the East Coast which are known for their designs were selected and visited.

Through the literature survey it was concluded that no comprehensive standards exist which consider all the factors affecting the daylit museums visual environment. Two choices were considered. One was to assume the existing standards for artificially lit museums and evaluate museum's daylighting based on these standards. This option was questionable with respect to some of the assumptions. The second option was to evaluate the theoretical conclusions reached from studies of Chapters 2-4 and see to what extent they are really applied to functioning museums. In order to undertake these studies it was necessary to visit a number of existing museums.

The choice of museums to be visited was based on the following factors:

1) The use of daylight as an exhibition lighting source and/or as a light source for other functons. One artificially lit museum (Montreal Museum of Fine Arts) was also investigated for comparison with daylit museums.

2) The Taxonomy of daylight luminaires. In Chapter 5 daylight luminaires were divided into four categories. General concepts and existing designs were evaluated. It was decided that in order to further analyze the four categories, museums which have used at least one kind of daylight luminaire should be investigated so that a more detailed comparison could be done. Unfortunately no clerestory lit museum was documented, due to the other conditions set for the choice of museums (Museums with clerestory luminaire are part of the case studies). One gallery which is best representative of daylit galleries in each museum was investigated and data was collected. Also each museum was documented as a whole for the study of other factors, such as planning which are included in the case studies.

3) Distance from Montreal and the budget. Due to budgetary constraints one cannot investigate any museum which is known for its daylight design. A list of museums in Europe and North America was prepared in consultation with experts in the field, but it was found unfeasible due to long travelling distance and budgetary reasons. Therefore museums in the proximity of Montreal were chosen. It was decided that some of the well known museums which were not visited, be included in the case studies for comparison with museums visited.

Clearly many more museums can be investigated, but the choices had to consider the above conditions and respond to the conclusions made through Chapters 2, 3 and 4.

The following museums were investigated:

1. Window Lit
   a. Johnson Museum, Cornell University, Ithaca, NY
   b. Museé d'Art Contemporain, Montreal
2. Sky Lit
   a. American Galleries, Metropolitain Museum, NYC
   b. Islamic Galleries " " "
3. Courtyard Lit
   a. Everson Museum, Syracuse, NY
   b. Lehman Galleries, Metropolitain Museum, NYC
4. Artificially lit
   a. Montreal Museum of Fine Arts, Montreal

## 6.2 METHODOLOGY AND INSTRUMENTATION

The aim of the field study was to collect information, data and documentation in the following areas:

1) The extent, type and nature of interior finishes.
2) The general lighting system.
3) Graphic documents such as plans, sections, etc.
4) Data on exterior conditions including daylight and sky conditions.
5) Data on interior lighting conditions: illuminance levels, U.V., U.V./lum and color temperature.
6) Color documentation.

7) Contrast documentation.

8) General observations.

9) Interviews with architects, lighting designers and curators.

Each step will be discussed individually with respect to methodology and instrumentation.

The Lighting Survey forms as used for offices and schools, were found inadequate for museums. Therefore a museum lighting study handbook was prepared and a special form for noting the data was drawn up. A copy of this handbook is included in Appendix (4).

### 6.2.1 GENERAL INFORMATION

This section recorded information regarding name, location, dimensions and interior surfaces. The interior surfaces were recorded with respect to material, texture, color and condition. Interior elements such as ceiling, skylight, walls, windows, floors, shades or blinds and the object's surfaces were recorded. This information was mostly collected by observation and photography.

## 6.3 DESCRIPTION OF GENERAL LIGHTING SYSTEM

This section recorded information regarding the lighting system such as daylight, artificial light, or the combination of the two. In a daylit museum the nature and number of luminaires (windows and skylights) were recorded. In artificial lighting the luminaires were recorded with respect to quantity, wattage, light source, distribution, description, spacing, mounting and conditions. A lot of information was obtained from museum and maintenance personnel.

## 6.4 GRAPHIC DOCUMENTATION

Plans, sections and the detail of skylights were gathered. Sketches of the gallery under study were drawn.

## 6.5 DATA ON EXTERIOR LIGHTING CONDITIONS

The weather conditions were recorded. The daylight level was recorded in synchronization with interior measurements in order to investigate the interior conditions with respect to exterior light level changes.

The following instruments were used:

A) Two light meters by Evans Electro Selenium, Model A. One was placed in the open and the second under a shade ring to assure that it would read the diffuse sky at all times. Since the direct light levels were above the sensitivity of the instruments, a neutral density grey filter was used with the cell exposed directly to the sun rays. Wratten gelatin filters, number 96 and number 60 (CAT. 149-6363) were used.

B) The Chart Recorder, Model 288 by Gulton Industries was used. The chart recorder was calibrated and amplified to record the readings every minute.

C) The Power Supply for the rechargeable portable package, was Model 3584 by System Research Corporation.

The instruments were packed for transport and shock resistance.

Plate 6.1, Set up of equipment, for exterior readings.

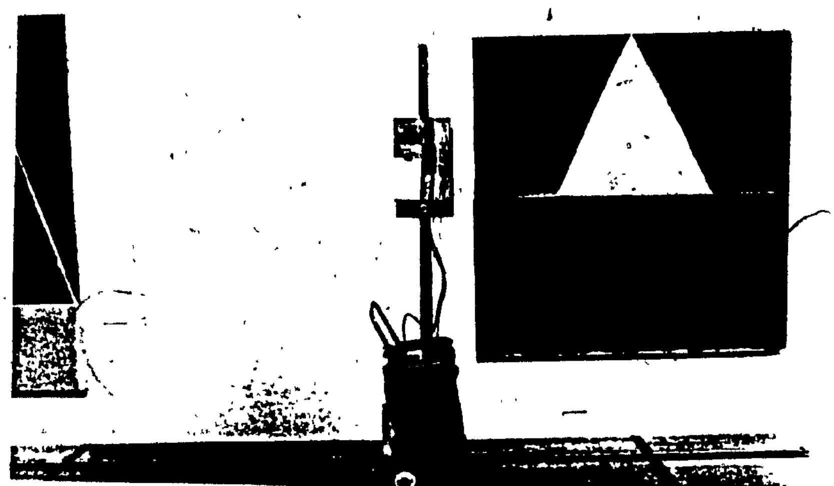


Plate 6.2, Set up of equipment, for interior readings.

The set up was placed in a convenient location; this caused a problem in some museums with respect to the public and security. Plate (6.1) illustrates the set up in the sculpture court of the Johnson Museum.

## 6.6 DATA ON INTERIOR LIGHTING CONDITIONS

The illuminance levels, U.V. content, U.V./lum and color temperatures were recorded. The following instruments* were used in this section.

A) Hagner Universal Photometer, Model S2, the cell is well filtered to the photometric CIE standard observer and Cosine corrected. Two readings were taken; one lower at $1^m$ level and one upper at $2^m$ level above the floor. It was calibrated prior to the measurements at the National Research Council, Physics Department.

B) Gamma Scientific, portable U.V. Monitor, Model 900 with Detector Head Model 820-17 (calibrated at the NRC Physics Department). (1)

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* These instruments were installed and arranged in order to be portable around the galleries for taking readings and also to be packed for long distance travel.

(1) These were on loan from the Canadian Conservation Institute (Ottawa).

C) Crawford Type 260 U.V. Monitor, EDR6 to measure U.V./lm (1).

In analyzing the data it was concluded that the Crawford monitor was very ineffective in measuring the U.V. content. As was explained in Chapter 4, one is able to calculate the U.V./lm through dividing the illuminance readings with Hagner by U.V. content readings with Gamma Scientific. It was concluded that the measured values of U.V./lm by the Crawford monitor were very erratic. This can be illustrated by plotting the measured values and the derived values. There is no correspondence between the two sets of data as seen in Plates (6.3 a,b,).

This can be due to

1. The SPD response of the U.V. Monitor
2. The SPD response of the lux Monitor
3. The method of calculation used in the Crawford Minitor for obtaining UV/lm.

This monitor is evaluated against the Hagner photometer and the Gamma Scientific UV radiometer, both of which were accurately calibrated in the same NRC lab.

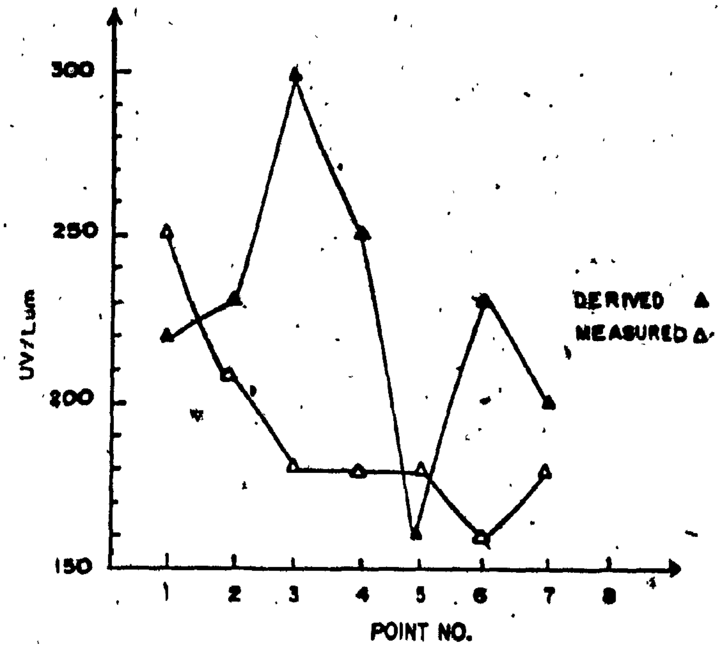



Plate (6.3,a) - The UV/lm measured and calculated in the Johnson Museum.

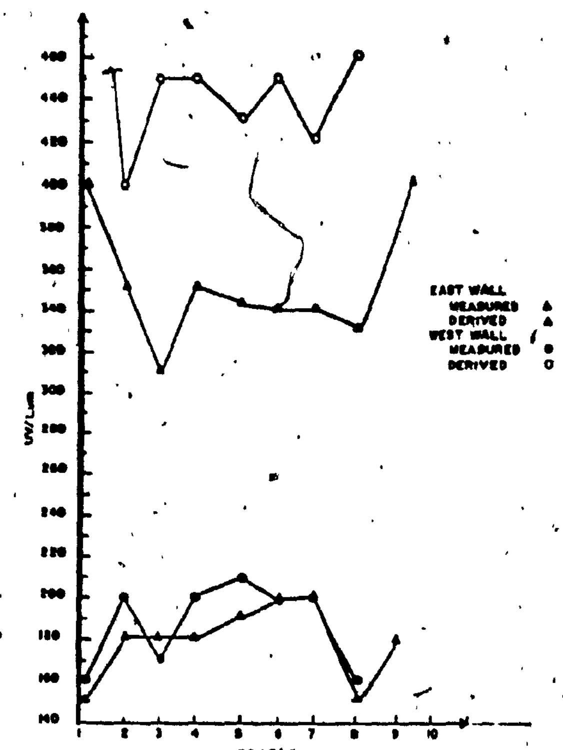



Plate (6.3,b) - The UV/lm measured and calculated in the American Gallery.

D) Color temperature meter Gossen Sixticolor Serial # 668837.

The readings were made at each station point with a support that placed each instrument in the correct vertical location perpendicular to the wall. Five readings were then made in quick succession during 1 minute and the time was noted. These readings were 2 illuminance levels at 1 m and 2 m, UV at 1.6 m, color temperature at 1.6 m and UV/lumn at 1.6 m hight.

In this section the speed was crucial since the ideal situation was to be able to record the space in one instant before the daylighting changed. In fact readings were quite stable in time for constant sky conditions. The instruments were set up in such a manner that one person was able to perform the experiment.

## 6.7 COLOR DOCUMENTATION AND PHOTOGRAPHY

In order to perform a color study of the spaces with respect to the works of art, qualities of finishes and luminaires, it was realized at an early stage that one should have a spectrophotometer. Due to cost it was impossible to obtain this equipment.

One of the aims of the study was to determine how to make a quick comprehensive field measurement. Photography is commonly used by lighting engineers to record spatial conditions and the lighting effects on surfaces. It is well known that color photographs do not record images as the eye sees them [138]; however they do accentuate differences, expecially the SPD of sources.

A tripod mounted 35 mm camera was loaded with Ektachrome B 160 ASA professional film from one batch lot. The camera was fitted with a 20 mm lens giving almost a 90° angle of view. Thus 4 photos of each room were usually sufficient to record the effects. Two slides were taken, one with a blue 80-B Wratten filter and one without. The 80-B filter corrects indoor type B film for 6500 °K daylight. A standard Kodak color test strip was placed in the scene along with a 6 panel grey scale. Knowing the SPD response of the filter, one could theoretically determine the color shifts in the space across the color test strip. However, it was apparent on return from the field visits that the test strip was too small in the film to be of use to detect color shifts quantitatively. The two filters however were useful to visually detect rather sudden changes in the SPD of the source as seen in the slides. Dramatic shifts were observed in the American Wing of the Metropolitan Museum and in the Johnson Museum.

It was determined that only a 4" x 5" camera would have been feasible for the color study. Such a camera would not be permitted by curators since it could make unauthorized photos of the original works of art. It's bulk and expense would prohibit its use in any event.

## 6.8 GENERAL OBSERVATIONS

In this section the general conditions, qualities and subjective evaluation of the gallery were recorded. General factors such as glare conditions, control means, shadows and visual comfort were recorded.

## 6.9 INTERVIEWS

Before departure a questionnaire and request for an interview was sent to architects, curators and lighting designers of the museums. A number of responses were received and meetings were held to discuss the questions.

It was found out that each stage of the study undertaken could have been a detailed and extensive study on its own. However, since no study of this kind had been performed before, this study could serve as a means of integrating each substudy. It was also found out that one could have studied each museum throughout the year with respect to one or more of the above factors. However the more comprehensive nature of the survey would have been sacrificed and the costs and time required would have increased enormously.

## 6.10 DATA ANALYSIS

The following is a presentation and analysis of each museum. The museums are arranged with respect to their lighting system as was discussed in Chapter 5. A table of comparison for all museums is drawn up for quick reference Table (6.1). This comparison reveals that:

1. Large variation of illuminance exists, from 32 lux to 1330 lux (41.5 times).

2. All museums exceed recommended levels of illuminance (Chapters 2, 4).

3. The average illuminance values (lux) for all museums are:

| Min. | Avg. | Max. |
|---|---|---|
| 198 | 327 | 504 |

Thus the relevance of recommended levels to actual practice is seriously questioned. Are all these museums risking their collections? At the very least more rigorous research into deterioration and recommended levels are required.

4. A very large variation in UV content exists. From 4 mW/m$^2$ to 260 mW/m$^2$ (65 times). The UV content (mw/m$^2$) for all museums are averaged:

| Min. | Avg. | Max. |
|---|---|---|
| 56 | 69 | 85 |

Almost all museums exceed the minimum recommended UV levels (See Chapter 4 and the comments in # 3 above).

5. Variations in UV/lm are large but not as great as illuminance levels. 50 UV/lum to 400 U.V./lum (8 times).

In many galleries, the light contained above the minimum recommended level of UV. The average UV content (U.V./lm) for all museums are

| Min. | Avg. | Max. |
|---|---|---|
| 85 | 110 | 115 |

6. Only one gallery meets the recommended color temperature. The average color temperatures are:

| Min. | Avg. | Max. |
|---|---|---|
| 2950 | 3330 | 4130 |

7. The C.T. values suggest that the color response of the visual environment may not be optimum since there is a dominant red region.

## SUMMARY OF DATA FOR ALL GALLERIES DOCUMENTED

| NO. | Component Light / Gallery Documented | Illuminance (Lux) Min. | Avg. | Max. | U.V. (mw/m²) Min. | Avg. | Max. | C.T. °K Min. | Avg. | Max. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | Johnson Museum, Cornell | * 325 | * 750 | * 1330 | * 160 | * 200 | * 260 | ** 3000 | 4200 | 8000 |
| 2. | Museé D'art Contemporain Montréal | * 210 | * 285 | * 400 | 4 | * 17 | * 19 | ** 2800 | ** 3000 | ** 3400 |
| 3. | American Galleries, Metropolitan | * 280 | * 400 | * 600 | * 160 | * 180 | * 200 | ** 3100 | ** 3200 | 3700 |
| 4. | Islamic Galleries, Metropolitan | * 150 | * 210 | * 300 | * 36 | * 39 | * 46 | ** 3000 | 3700 | 4200 |
| 5. | Everson Museum, Syracuse | * 32 | * 95 | * 260 | * 14 | * 17 | * 32 | ** 2800 | ** 2900 | ** 3000 |
| 6. | Lehman Galleries, Metropolitan | * 250 | * 350 | * 400 | * 16 | * 21 | * 32 | ** 3000 | ** 3200 | 3500 |
| 7. | Montreal Museum of Fine Arts | 140 | * 205 | * 240 | 7 | * 9 | * 12 | ** 3000 | ** 3100 | ** 3100 |

* Exceeds recommended level
** Below recommended level

Plate (6.1), Summary of Data, taken in galleries.
Note the number of readings exceeding the recommended level.

**LEGEND**

| | | | |
|---|---|---|---|
| 1. Excellent | ○ | 12. Changeable | CH |
| 2. Satisfactory | ⊗ | 13. Fluorescent Lamps | FL |
| 3. Poor | ◒ | 14. Incandescent Lamps | IC |
| 4. No | ● | 15. Track Lighting | TL |
| 5. Yes | □ | 16. Spot Lighting | SL |
| 6. Modular/Column | MC | 17. Direct | D |
| 7. Modular/Partition | MP | 18. Diffused | DF |
| 8. Modular/Open | MO | 19. No Information | NI |
| 9. Free Planning | FP | | |
| 10. Fixed | FI | | |
| 11. Moveable | M | | |

## 6.11 WINDOW LIT GALLERIES

Two window lit galleries which represent the two extremes of daylight luminaire performance were chosen. The first is the Johnson museum which has a large window lit gallery facing North at three stories above the ground and the second is the Museé D'Art Contemporain, where windows are a secondary light source for exhibitions.

A. Johnson Museum

Gallery 14.a of this museum has windows in three walls; but the window which covers the North wall is the prime source of light. This window does not have any overhang, blinds or obstruction although other openings affect the overall lighting condition of the gallery. It was found out that the window luminaire has the following characteristics:

1. It is a source of high veiling glare.
2. It causes large contrast variations.
3. It has a poor illuminance distribution.
4. It has high color temperature variations.
5. It provides good contact with the outside which relates the museum to its surroundings.

The window luminaire of this gallery in relation to advantages and disadvantages of side lighting luminaires, discussed in Chapter 5, shows the following common characteristics:

1. It provides contact with the exterior

2. It is a light source.
3. It is effective in relating the museum to its surroundings.
4. It is effective in elevation design.
5. It takes away exhibition spaces.
6. It is a source of glare.
7. It creates high contrast.

It differs with respect to:

1. It is not a source of heat, to cause deterioration, due to its orientation.
2. It does not cause security problems, since it is located on the 3rd floor.
3. No controls are provided.
4. It has windows in three walls.
5. UV filters are not installed.
6. No transition from light to dark is provided.

B. Museé D'Art Contemporain

Gallery II of this museum has two sidelighting luminaires which have indirect contact with the outside. Each opening is located in one wall and controlled. Therefore these windows do not exactly act as a source of task lighting, but they affect the ambient lighting. It was found that the windows have the following characteristics:

1. They are a source of contrast.
2. They are a source of discomfort glare.

3. They do not have any apparent effect on the illuminance distribution.
4. They do not effect the color temperature.
5. They create contact with the outside.
6. They do not affect the museum's relationship with its surroundings.

The Window Luminaire of this gallery in relation to advantages and disadvantages of side lighting luminaires, discussed in Chapter 5, shows the following characteristics of plane windows:

1. It provides contact with the exterior.
2. It is a source of glare.
3. It takes away exhibition space.
4. It creates contrast.
5. The controls are in conflict with the advantages.

It differs in that:

1. It reflects the light many times. Therefore the highly diffused light is not effective in modeling.
2. It is not a source of heat, since it has an indirect relation to the exterior.
3. It does not cause security problems.
4. The openings are located in two walls.
5. No transition from light to dark is provided.

## DATA SHEET

### FIELD STUDY (6.12.1)

**A. GENERAL**

1. Museum Name: Herbert F. Johnson Museum of Art
2. Location: Cornell University, Ithaca, New York
3. Architect: I.M.Pei and Associates
4. Lighting Designer: Edison Price & Assoc.
5. Date of Completion: 1970
6. Collections: Oil paintings, Oriental Art, Sculpture
7. Space Description: See Plate (6.12.5)

**B. GALLERY DOCUMENTED**

1. Gallery Name Location: 14 a. 2nd Floor (Plate 6.12.4)
2. Date of Visit: September 1982
3. Weather Condition: Clear, sunny, patches of moving cloud
4. Time of Measurements: 11.00 A.M. to 11:30 A.M.
5. Solar Altitude Angle: Start: 48.0 Finish: 50.0
6. Azimuth Angle: Start: 23.0 Finish: 12.00

## DATA SHEET

### TABLE OF FINDINGS

| NO. | SYSTEM | FACTORS | |
|---|---|---|---|
| 1. | HVAC | Exposed Ducts | ● |
| | | Integrated W/Structure | ● |
| | | Integrated W/Lighting | ● |
| 2. | DAY LIGHT | Top Lighting | ● |
| | | Side Lighting | ◒ |
| | | Court Lighting | ● |
| | | Clerestory | ● |
| | | Diffusing System | ● |
| | | U.V. Control | ● |
| | | Glare Control | ● |
| | | Contrast | ⊗ |
| | | Color Rendering | ○ |
| | | Interaction W/Artificial | ◒ |
| | | Interaction W.Structure | ◒ |
| | | Heating Effect | ○ |

| NO. | SYSTEM | FACTORS | |
|---|---|---|---|
| 3. | INTERIOR | Wall system | FI |
| | | Ceiling System | FI |
| | | Finishes | FI |
| 4. | EXHIBITION | 2-D Paintings | □ |
| | | 2-D Paper | ● |
| | | 3-D Sculpture | ● |
| | | Case Exhibition | ● |
| | | Tapestry | ● |
| | | Wall Mounted | □ |
| | | Free Standing | ● |
| 5. | ARTIFICIAL | Luminaire Type | IC |
| | | U.V. Control | ● |
| | | Modeling | ◒ |
| | | Color Rendering | ⊗ |
| | | Color Temperature | ⊗ |
| | | Interaction W. Daylight | ● |
| | | Interaction W Structure | ● |
| | | Heating Effect | ◒ |
| | | Contrast | ○ |

**DATA SHEET**

**SUMMARY OF MEASURED DATA (6.12.3)**

| COMPONENT OF LIGHT | Min. | Avg. | Max. |
|---|---|---|---|
| Illuminance (Lux) | * 325 | * 750 | * 1330 |
| U.V. ($mw/m^2$) | * 160 | * 200 | * 260 |
| U.V./lm (Crawford) | * 190 | * 288 | * 400 |
| Colour Temp. (°K) | * 3000 | 4200 | * 8000 |

* Exceeds Recommended Level
** Below Recommended Level

1. The illuminance levels exceed the recommended levels.
2. The illuminance levels are higher near the north window and fall off, away from the window.
3. The variation in illuminance levels throughout the year as described in 6.19 is expected to be from -20% to +227%. Thus the average and worst case values in Plate 6.12.8 would be 260 lux to 1064 lux. Lower points illuminance levels are higher than upper points which are due to the direction of daylight from the window.

4. Daylight has caused color temperatures above the recommended range near the window due to the adjacent clear sky source. Other room surfaces have acceptable color temperatures.
5. Veiling glare is a problem due to the window. Several paintings were impossible to see, Plate 2.17.
6. The cloth panel background provided acceptable required contrast for the work of art.
7. This room while very pleasant as a rest area with magnificent views, was the worst gallery space visited due to the high UV levels, excessive and omnipresent veiling glare from windows (Chapter 5). There was no transition to an adjacent interior low level gallery for works on paper. There was a noticable change in color temperature of the sources at the entrance to the interior gallery.
8. The modeling direction was so strong as indicated in Plate 6.12.8, that the texture and finish of the paintings near the window at positions 1-2 East and 7-8 West would appear unnatural.

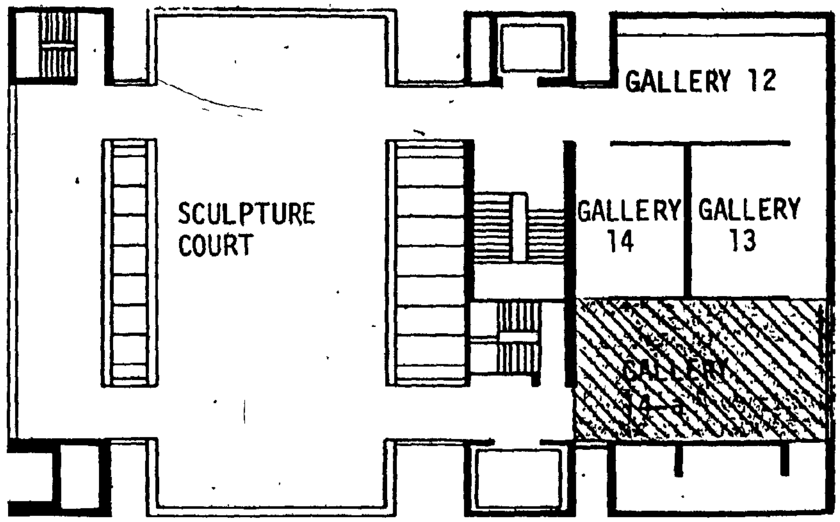



Plate 6.12.4, Second floor plan, Gallery studied is shaded.

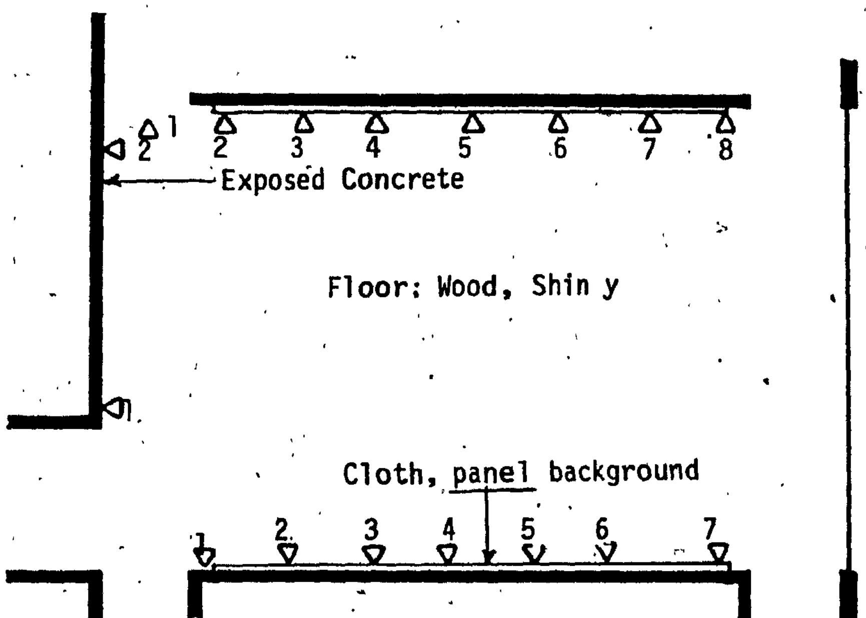



Plate 6.12.5, Floor plan, Gallery 14-a.

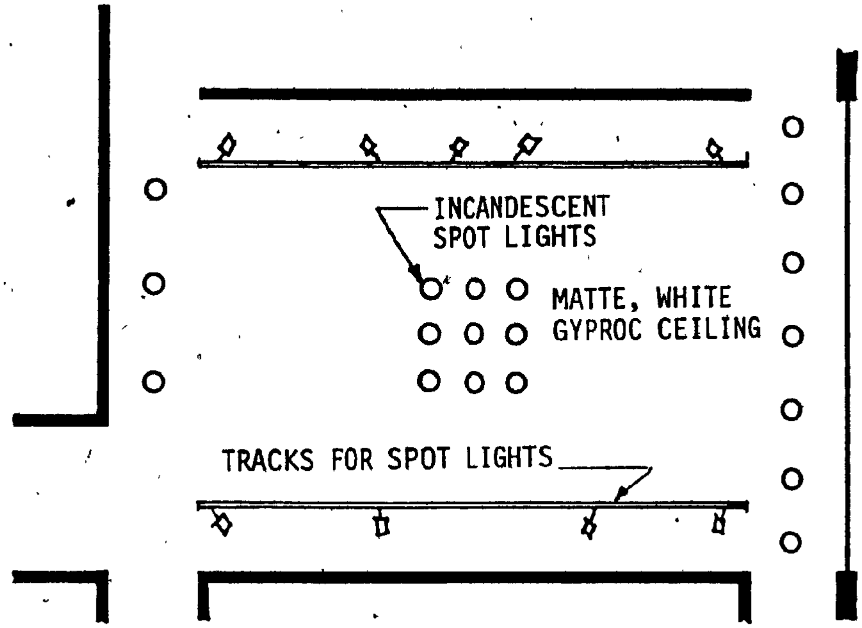



Plate 6.12.6, Reflected ceiling plan, Gallery 14-a.

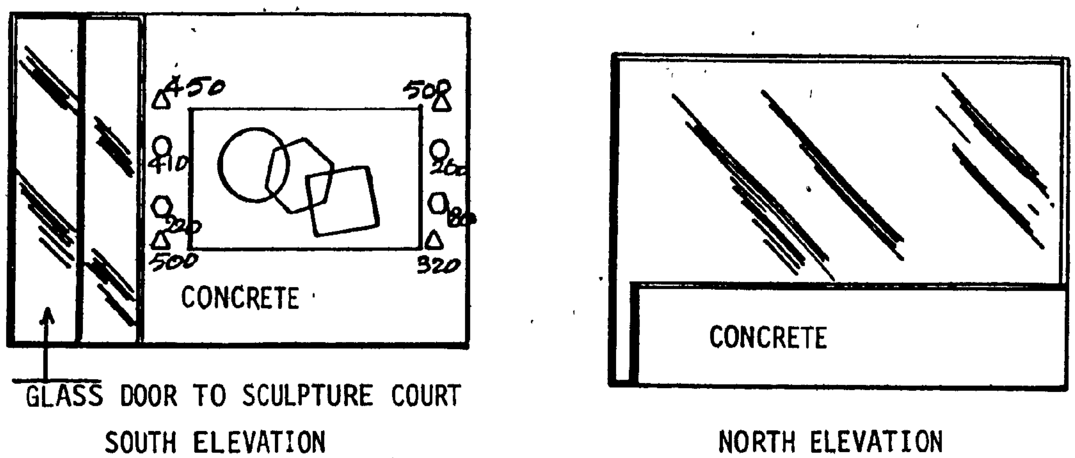



Plate 6.12.7, South and North Interior Elevations.

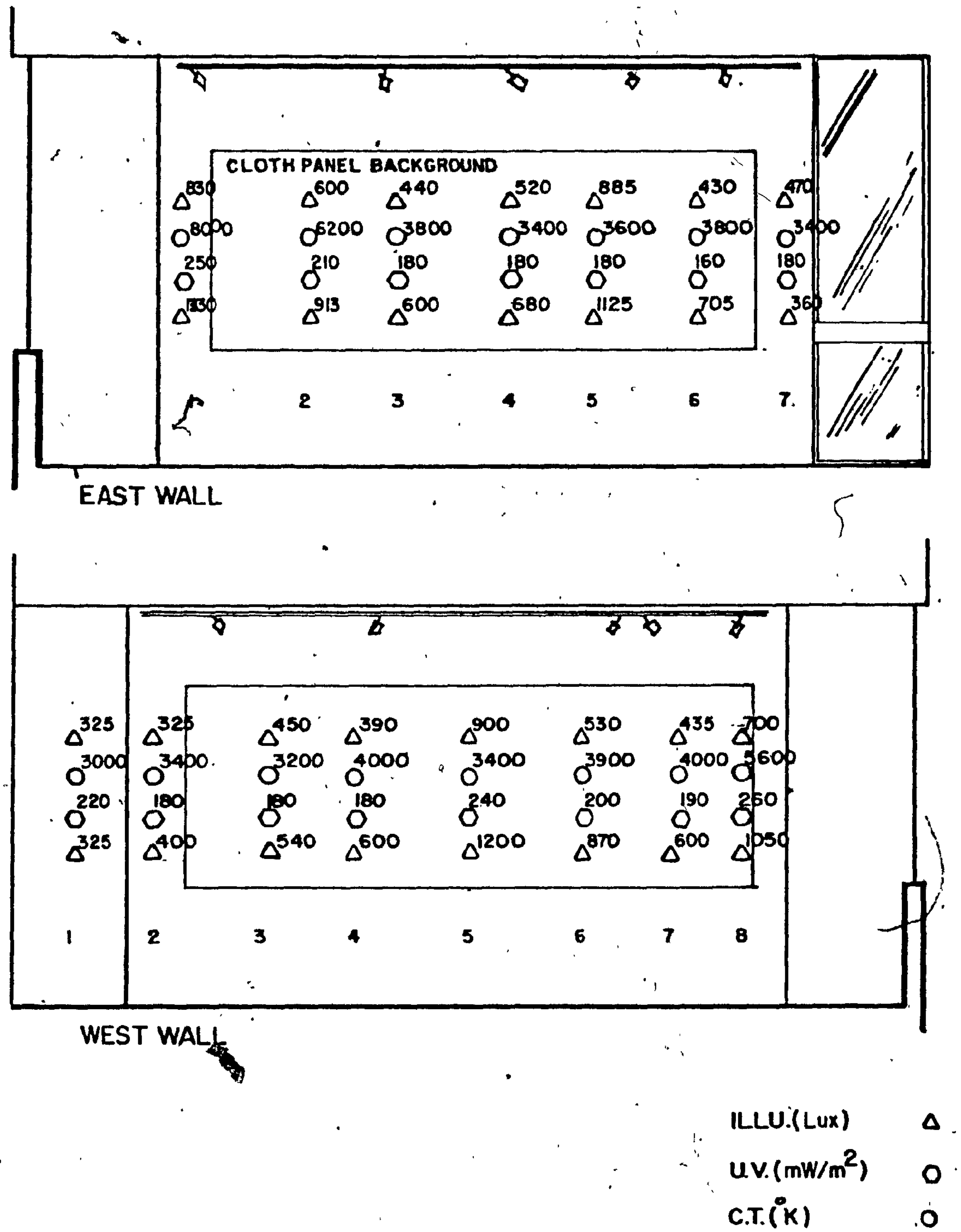



Plate 6.12.8, East and west wall interior elevation

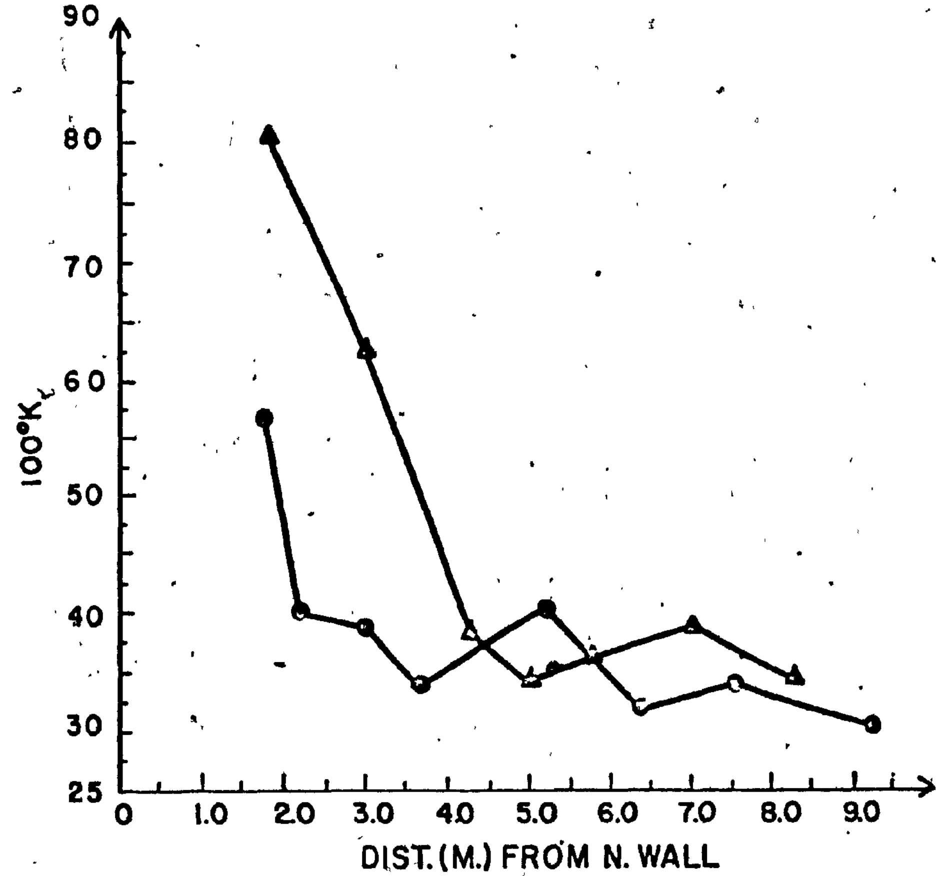



Plate 6.12.9, Color Temperature

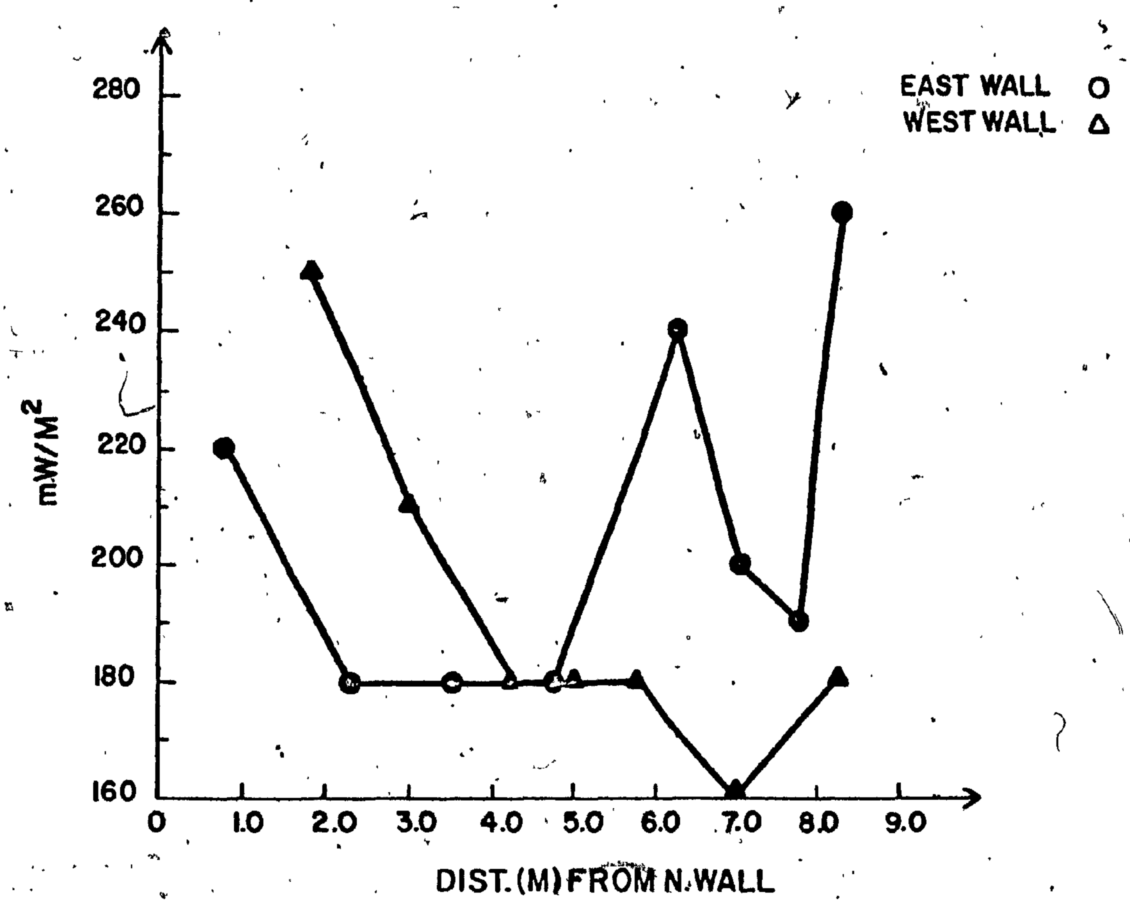



Plate 6.12.10, UV Content

## DATA SHEET

### FIELD STUDY (6.13)

**A. GENERAL**

1. Museum Name: Musée D'art Contemporain
2. Location: Montreal, Que.
3. Architect: G. Gauthier, J. Bland Assoc.
4. Lighting Designer: NI
5. Date of Completion: 1969
6. Collections: Painting, Sculpture
7. Space Description: See Plate (6.13.5)

**B. GALLERY DOCUMENTED**

1. Gallery Name Location: Gallery II, second floor
2. Date of Visit: November, 1982
3. Weather Condition: Overcast
4. Time of Measurements: 11.30 A.M. to 12 noon
5. Solar Altitude Angle: Start: 41.0 Finish: 42.5
6. Azimuth Angle: Start: 10 Finish: 0.0

## DATA SHEET

### TABLE OF FINDINGS

| NO. | SYSTEM | FACTORS | |
|---|---|---|---|
| 1. | HVAC | Exposed Ducts | ● |
| | | Integrated W/Structure | ⊗ |
| | | Integrated W/Lighting | ⊗ |
| 2. | DAY LIGHT | Top Lighting | ● |
| | | Side Lighting | □ |
| | | Court Lighting | □ |
| | | Clerestory | ● |
| | | Diffusing System | ⊗ |
| | | U.V. Control | ● |
| | | Glare Control | ⊗ |
| | | Contrast | ⊗ |
| | | Color Rendering | ⊗ |
| | | Interaction W/Artificial | ◒ |
| | | Interaction W.Structure | ◒ |
| | | Heating Effect | ● |

| NO. | SYSTEM | FACTORS | |
|---|---|---|---|
| 3. | INTERIOR | Wall system | FI |
| | | Ceiling System | FI |
| | | Finishes | FI |
| 4. | EXHIBITION | 2-D Paintings | □ |
| | | 2-D Paper | ● |
| | | 3-D Sculpture | ● |
| | | Case Exhibition | ● |
| | | Tapestry | ● |
| | | Wall Mounted | □ |
| | | Free Standing | ● |
| 5. | ARTIFICIAL | Luminaire Type | IC |
| | | U.V. Control | ● |
| | | Modeling | ⊗ |
| | | Color Rendering | ⊗ |
| | | Color Temperature | ⊗ |
| | | Interaction W. Daylight | ◒ |
| | | Interaction W Structure | ◒ |
| | | Heating Effect | ◒ |
| | | Contrast | ⊗ |

## DATA SHEET (6.13.3)

## SUMMARY OF MEASURED DATA

| COMPONENT OF LIGHT | Min. | Avg. | Max. |
|---|---|---|---|
| Illuminance (Lux) | * 210 | * 285 | * 400 |
| U.V. (mw/m$^2$) | 4 | * 17 | * 19 |
| U.V./lm (Crawford) | 50 | 60 | 75 |
| Colour Temp. (°K) | ** 2800 | ** 3000 | ** 3400 |

* Exceeds Recommended Level
** Below Recommended Level

1. Illuminance levels exceed the recommended levels.
2. Color temperatures are below the recommended levels and are constant.
3. Veiling glare does not cause problems due to
   a. High ceiling light
   b. Lack of specular reflective surfaces
4. The U.V. content is higher than recommended levels but the values are not too high in comparison with other galleries documented. Note that the daylight is reflected several times from room surfaces before it reaches the paintings. At each reflection a high percentage of the UV is removed (See chapter 4).
5. The UV content drops as one moves away from the opening.

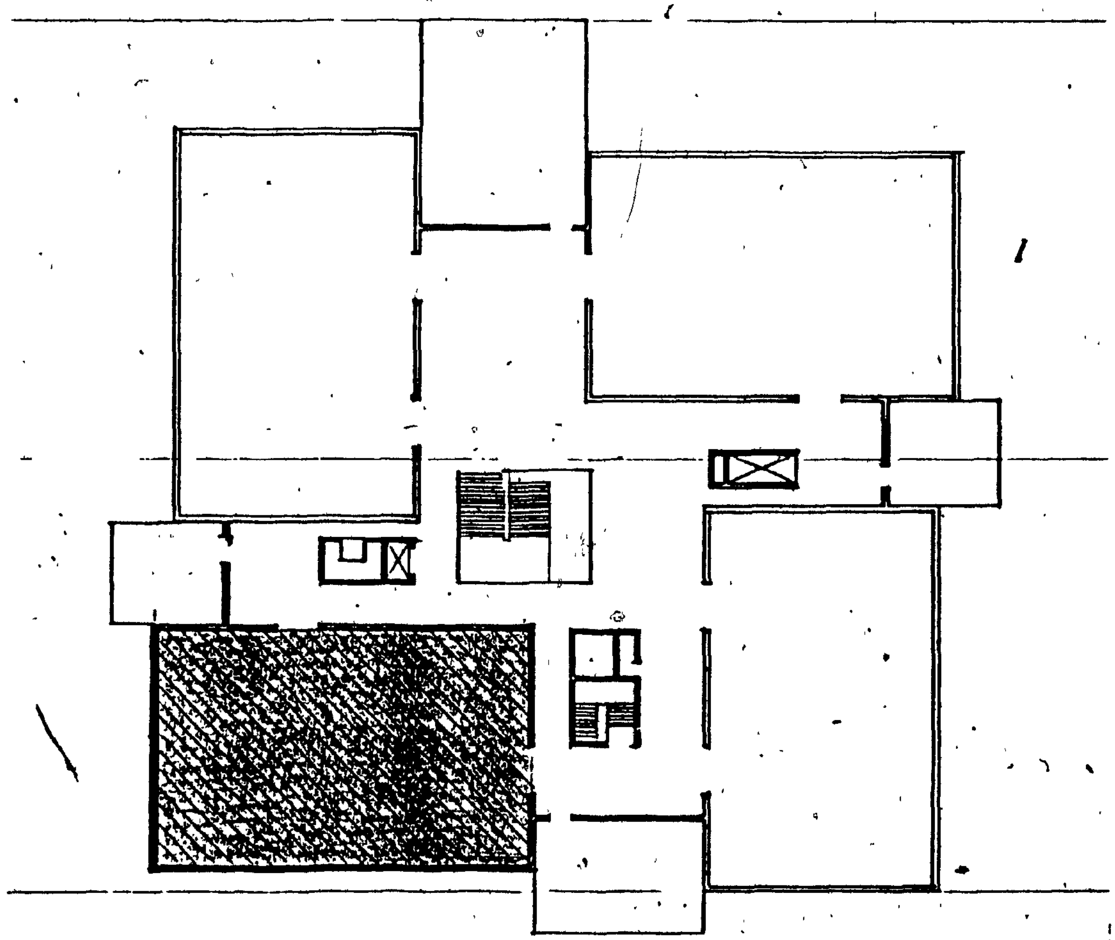


Plate 6.13.4, Second floor plan of the gallery, Gallery 11, is shaded.

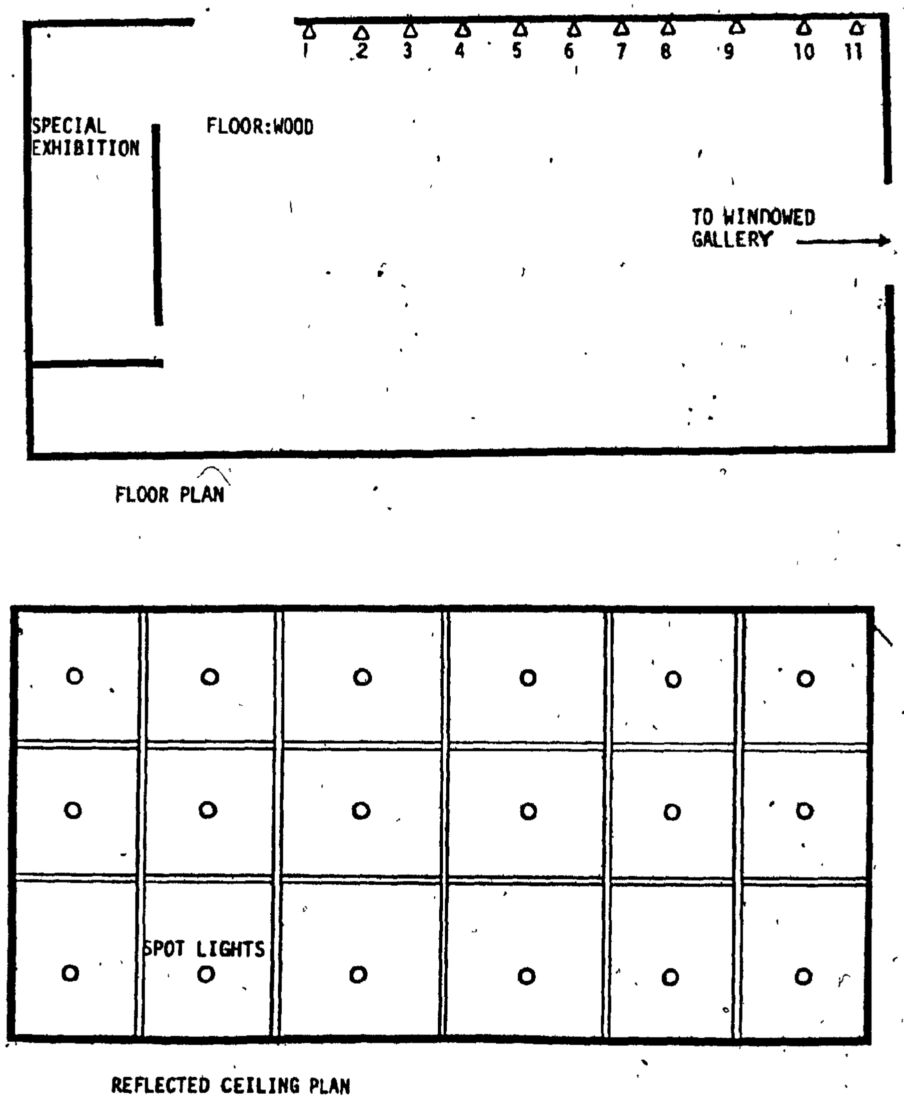
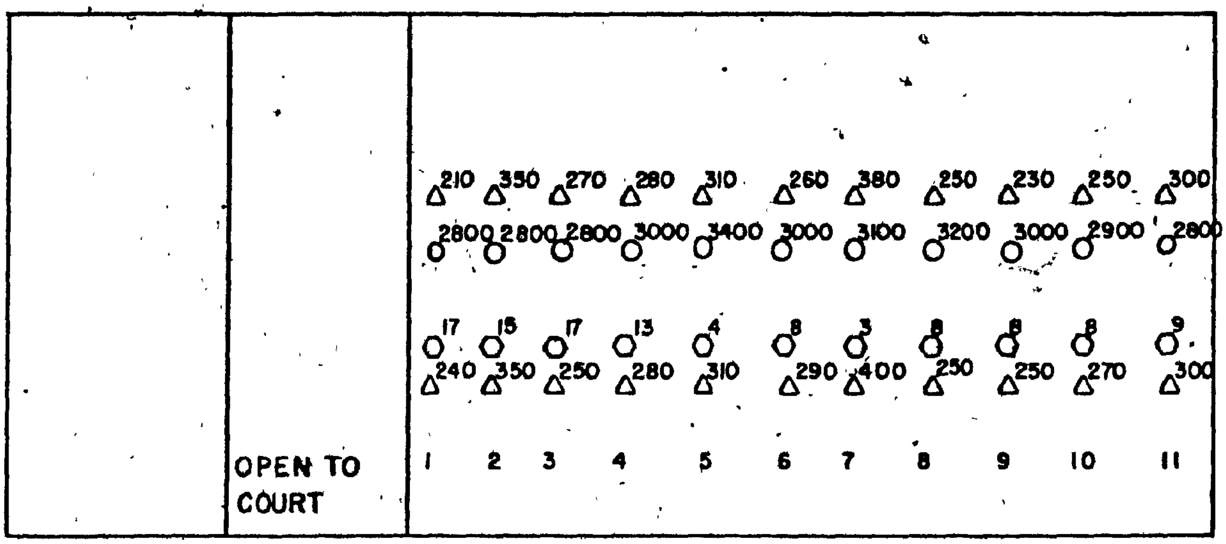



Plate 6.13.5, Floor plan & reflected ceiling plan of gallery 11.




NORTH WALL

Plate 6.13.6, Interior elevation

ILLU. (Lux) △

U.V. (mW/m²) O

C.T. (°K) O

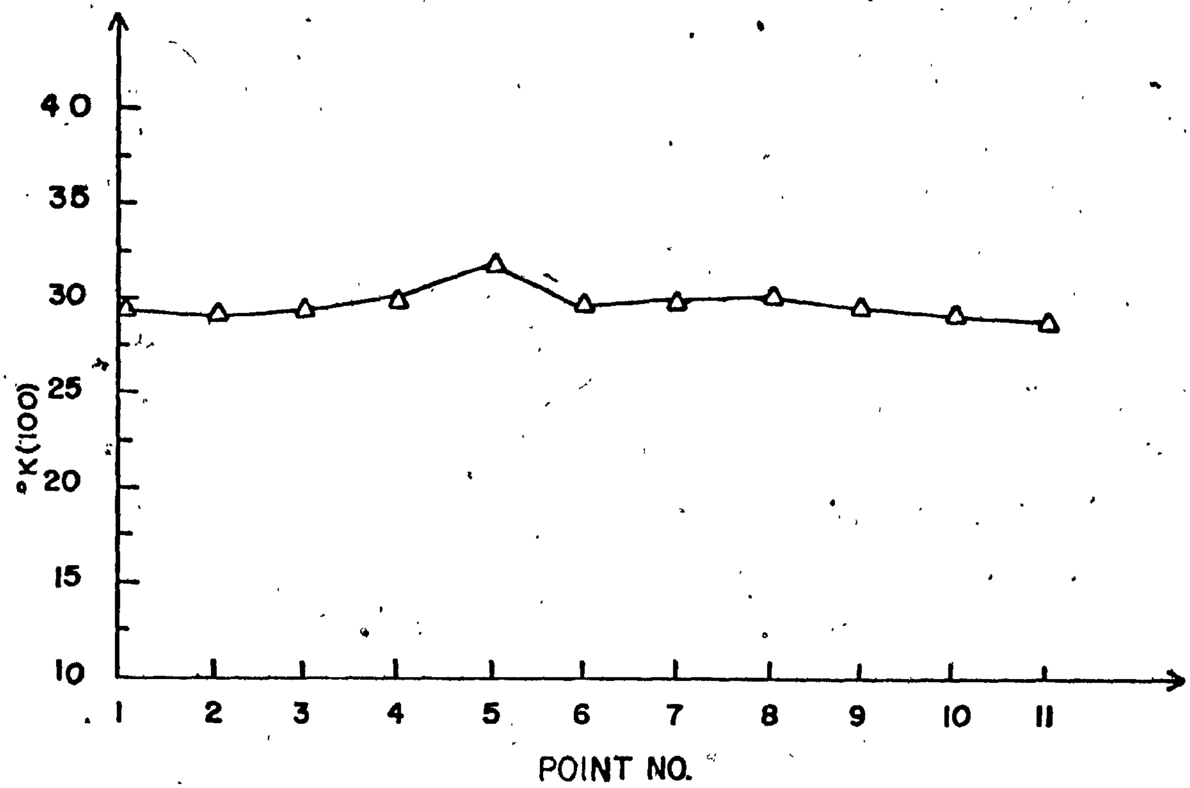



Plate 6.13.7, Graph of Color Temperature

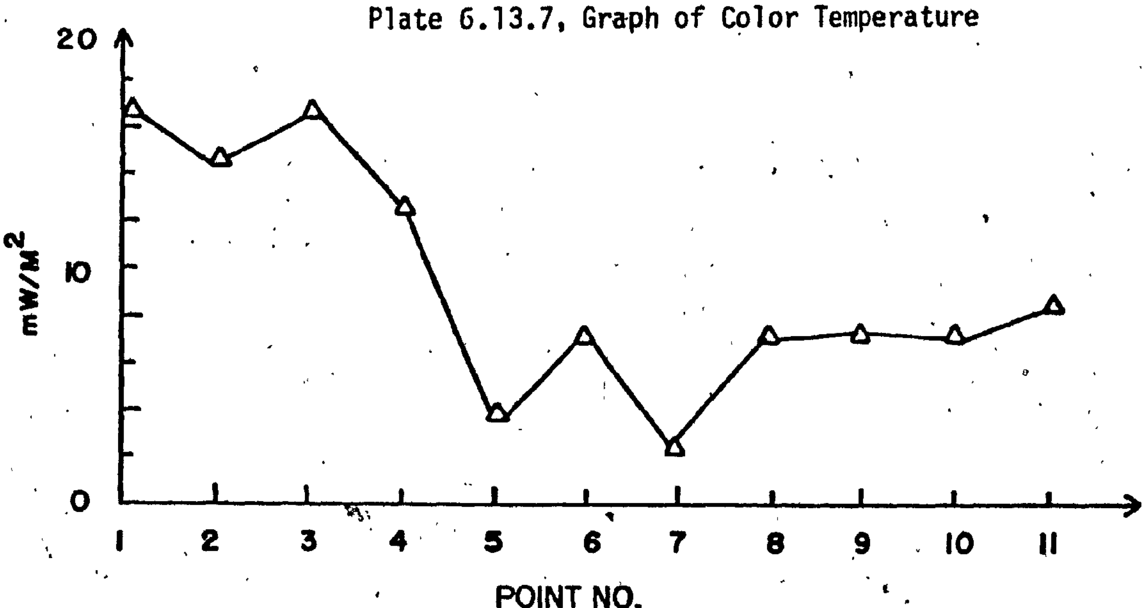



Plate 6.13.8, Graph of UV Content

## 6.14 TOP LIT GALLERIES

Two Top Lit galleries were investigated. Although both are similar with respect to daylight luminaire, they differ in performance. First the American Galleries which are covered with sky light and the galleries are flooded with daylight. In the second, the Islamic galleries, a small white washed skylight is located in the middle of the ceiling and illuminance levels are much lower than expected. These two galleries were chosen in order to illustrate the extreme possibilities, in terms of illuminance levels, color temperature and the variation of objects on display. In the American galleries oil paintings are exhibited which belong to the 2nd group, whereas sensitive objects of the 3rd group are shown in the Islamic galleries.

### A. American Galleries

Gallery 218 of these galleries is illuminated through a skylight and laylight system. Daylight is diffused and transmitted through the laylight system which creates an even lighting condition. Incandescent spot lights are used for modeling.

The skylight system of this gallery has the following characteristics:

1. It creates flat lighting in the gallery.
2. It is not effective with respect to modeling.
3. It causes color temperatures to stay constant.
4. It provides limited contact with the outside.
5. It does not cause problems with glare.

The skylight system used in gallery 218, shows the following common characteristics with Top Lighting daylight luminaires as was discussed in Chapter 5.

1. It provides contact with the outside.
2. It is an exhibition light source.
3. It is effective in providing ambient lighting.
4. It is effective in creating interest in the visual environment.
5. It is a source of heat gain on clear summer days.

The skylight system differs in that:

1. It is not effective in illuminance distribution.
2. It does not provide any contrast.
3. It is not easy to control.

B. Islamic Galleries

Gallery 7 of these galleries is illuminated by a white washed skylight system. Incandescent spots are used for task lighting and modeling. Fluorescent lights are used for showcase lighting, which contribute to the ambient lighting. The objects on display are of the sensitive group and illuminance levels are recommended to be less than 50 lux. Therefore the glazing of the skylight is white washed in order to reduce the intensity of daylight, and also being located in a very high ceiling causes further reduction of illuminance levels.

The skylight of this gallery has the following characteristics.

1. It provides ambient lighting.
2. It is effective in modeling.
3. It provides some contact with the outside.
4. It is effective in illuminance distribution and creation of contrast.
5. It does not cause any glare problem.

The skylight system used in gallery 7, shows the following common characteristics of Top Lighting daylight luminaire.

1. It provides contact with the outside.
2. It is an exhibition light source.
3. It is effective in distributing light in the gallery.
4. It is effective in creating interest in the visual environment.
5. It provides flexibility for illuminance control.
6. It provides for ambient lighting.

The skylight system differs in that:

1. It is highly controlled.
2. It does not provide for modeling due to high levels of controls.
3. It is used for task lighting.

## DATA SHEET

## FIELD STUDY (6.14.1)

### A. GENERAL

1. Museum Name: American Wing Metropolitan Museum of Fine Arts
2. Location: New York City
3. Architect: Kevin Roche John Dinkeloo and Associates
4. Lighting Designer: NI
5. Date of Completion: 1974
6. Collections: Oil Paintings
7. Space Description: See Plate (6.14.5)

### B. GALLERY DOCUMENTED

1. Gallery Name Location: Gallery 218
2. Date of Visit: September, 1982
3. Weather Condition: Clear, Sunny
4. Time of Measurements: 10.00 A.M. to 10.30 A.M.
5. Solar Altitude Angle: Start: 41.0 Finish: 45.0
6. Azimuth Angle: Start: 42.0 Finish: 33.0

## DATA SHEET

## TABLE OF FINDINGS

| NO. | SYSTEM | FACTORS | |
|---|---|---|---|
| 1. | HVAC | Exposed Ducts | ● |
| | | Integrated W/Structure | ● |
| | | Integrated W/Lighting | ⊗ |
| 2. | DAY LIGHT | Top Lighting | ⊗ |
| | | Side Lighting | ● |
| | | Court Lighting | ● |
| | | Clerestory | ● |
| | | Diffusing System | ○ |
| | | U.V. Control | ⊗ |
| | | Glare Control | ⊗ |
| | | Contrast | ⊗ |
| | | Color Rendering | ◒ |
| | | Interaction W/Artificial | ○ |
| | | Interaction W.Structure | ○ |
| | | Heating Effect | ◒ |

| NO. | SYSTEM | FACTORS | |
|---|---|---|---|
| 3. | INTERIOR | Wall system | FI |
| | | Ceiling System | FI |
| | | Finishes | FI |
| 4. | EXHIBITION | 2-D Paintings | □ |
| | | 2-D Paper | ● |
| | | 3-D Sculpture | ● |
| | | Case Exhibition | ● |
| | | Tapestry | ● |
| | | Wall Mounted | ○ |
| | | Free Standing | ● |
| 5. | ARTIFICIAL | Luminaire Type | IC |
| | | U.V. Control | ● |
| | | Modeling | ⊗ |
| | | Color Rendering | ◓ |
| | | Color Temperature | ◓ |
| | | Interaction W. Daylight | ⊗ |
| | | Interaction W Structure | ● |
| | | Heating Effect | ◓ |
| | | Contrast | ⊗ |

## DATA SHEET

## SUMMARY OF MEASURED DATA

| COMPONENT OF LIGHT | Min. | Avg. | Max. |
|---|---|---|---|
| Illuminance (Lux) | * 280 | * 400 | * 600 |
| U.V. (mw/$m^2$) | * 160 | * 180 | * 200 |
| U.V./lm (Crawford) | * 100 | * 150 | * 200 |
| Colour Temp. (°K) | ** 3100 | ** 3200 | ** 3700 |

* Exceeds Recommended Level
** Below Recommended Level

1. Illuminance levels are above the recomended levels.
2. Color temperature values are almost constant and below the recommended levels. This is partly due to the mixture of sources and partly due to the reflections from the shiny wood floor (yellow color) and the filter affect of the laylight.
3. The U.V. content is very high.
4. Glare does not exist since light is diffused.
5. The luminous ceiling has caused monotony and lack of contrast and modeling.

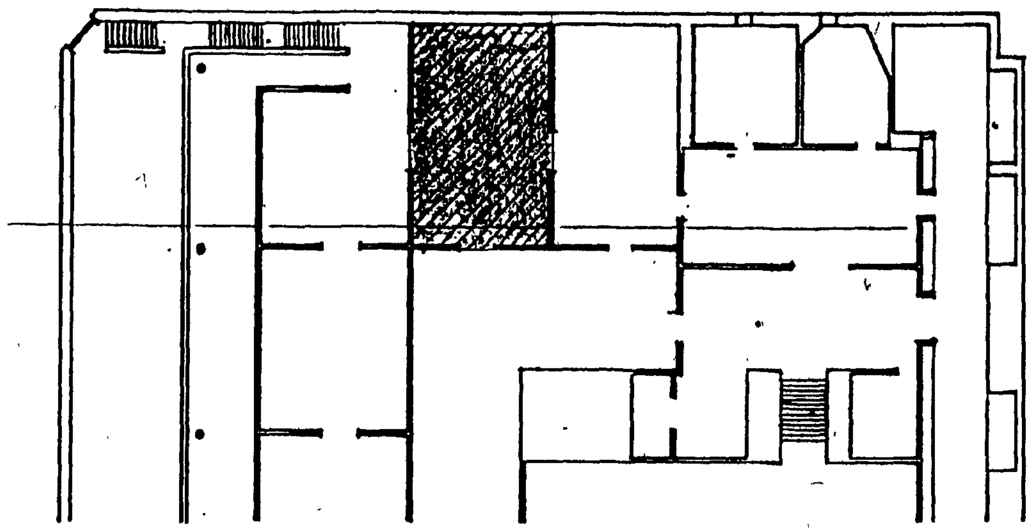


Plate 6.14.4, The second floor plan, gallery 218 is shaded.

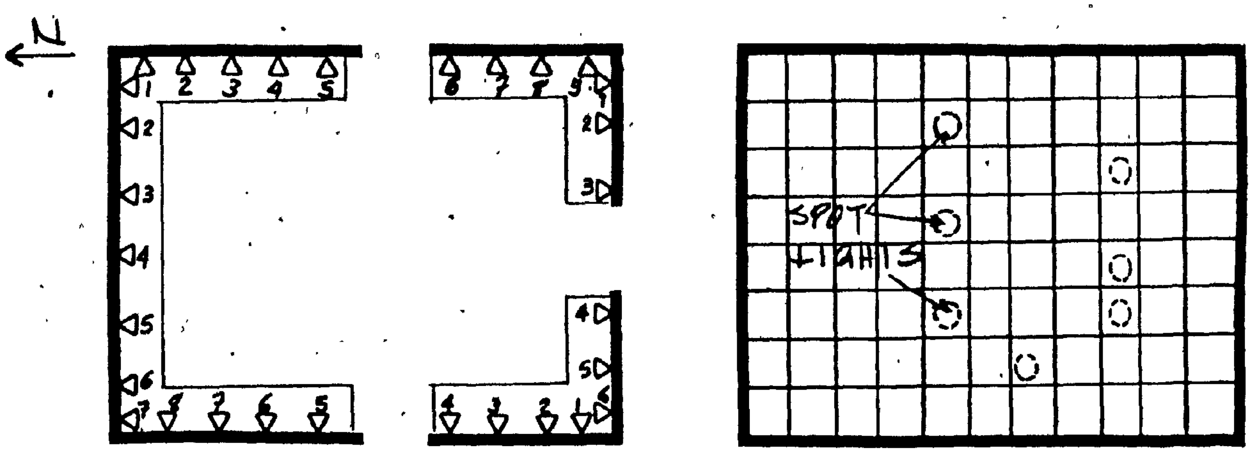
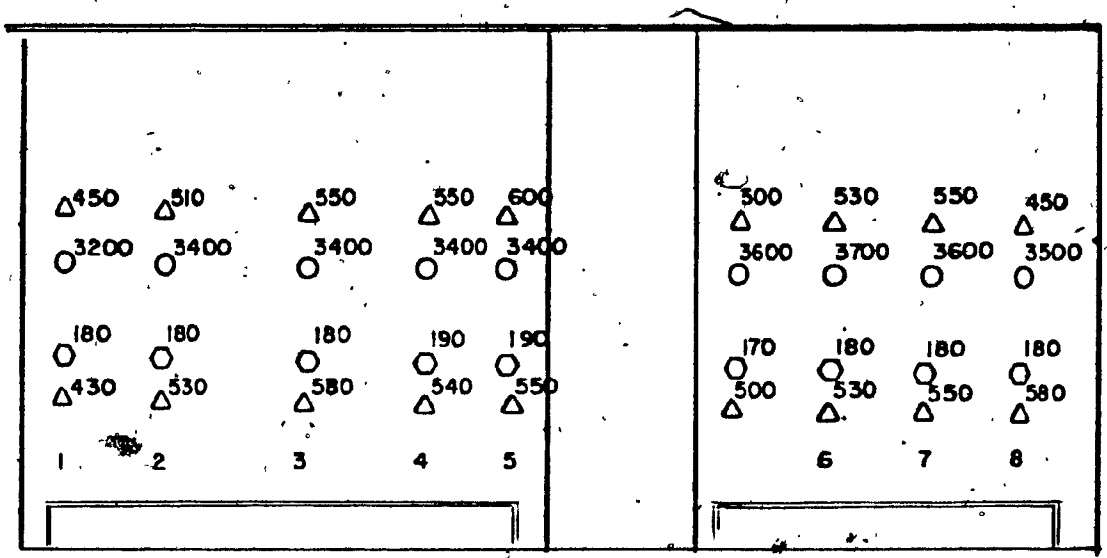
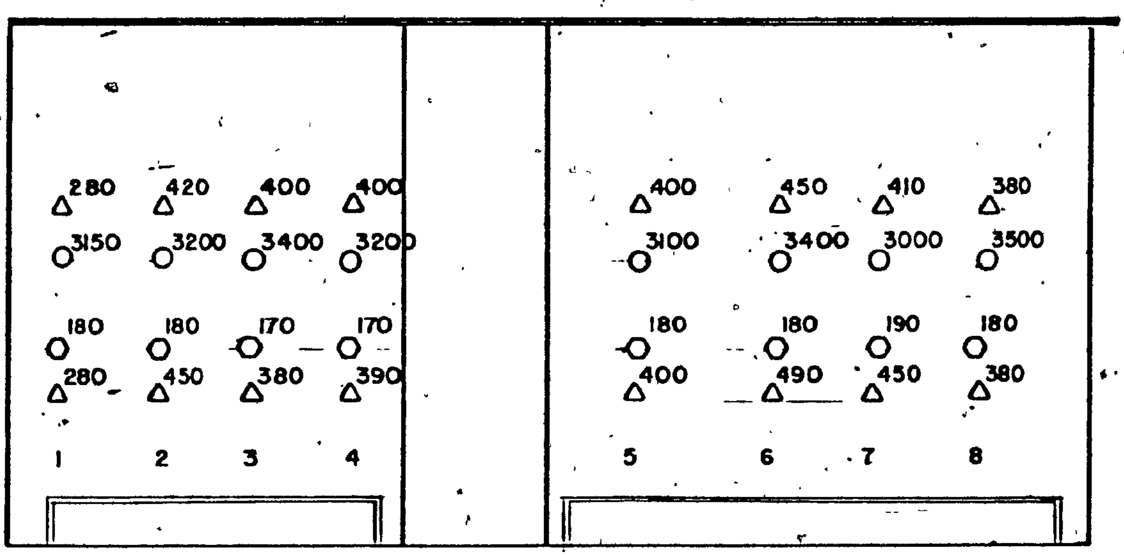



Plate 6.14.5, Floor plan and reflected ceiling plan of gallery 218.




EAST WALL

ILLU.(Lux) △
U.V.(mW/m²) O
C.T.(°K) O




WEST WALL

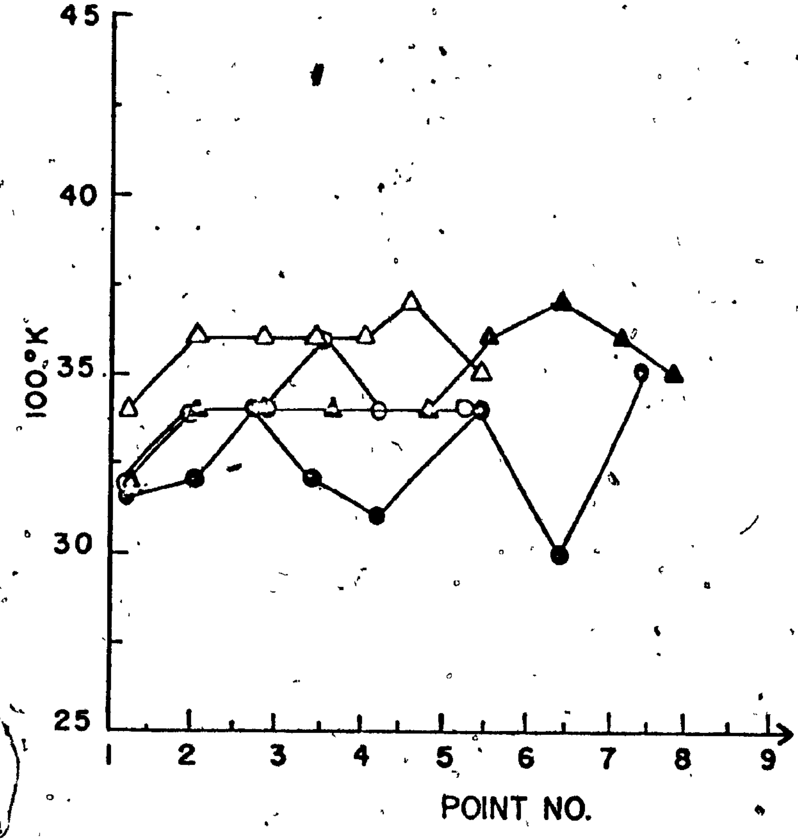



Plate 6.14.7, Color Temperature

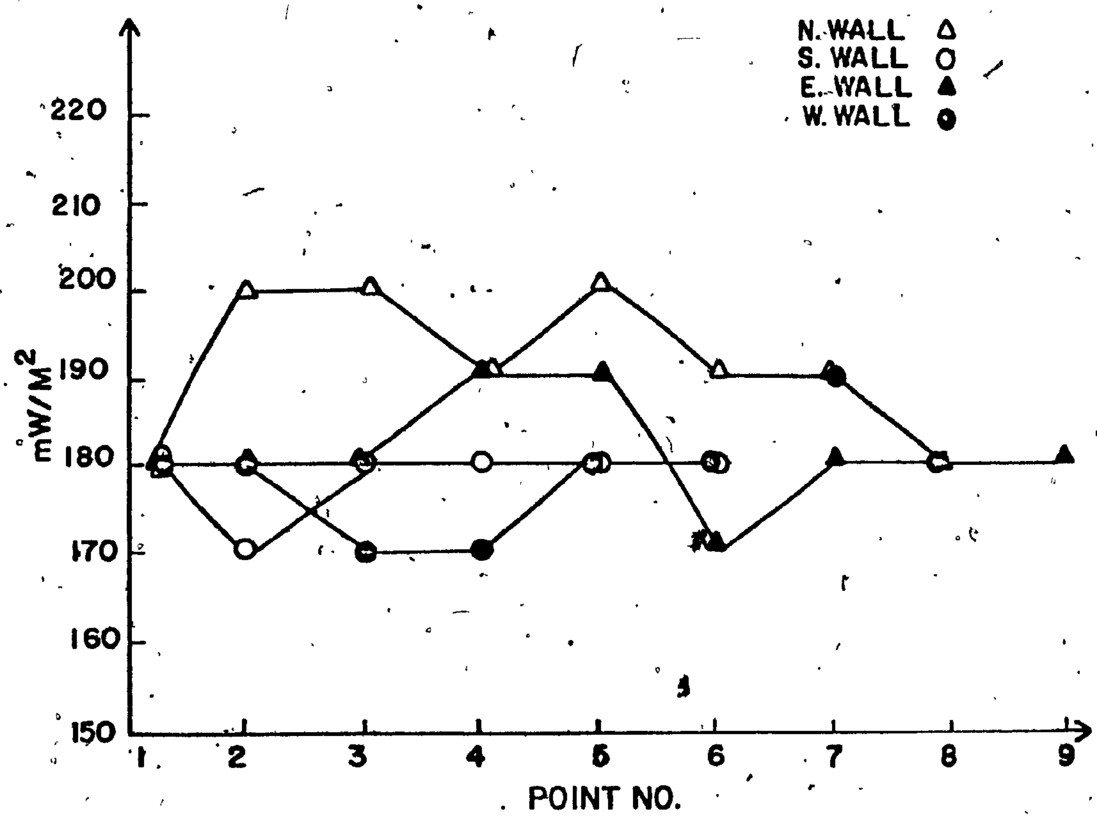



Plate 6.14.8. UV Content

# DATA SHEET

## FIELD STUDY (6.15)

A. **GENERAL**

1. Museum Name: Islamic Galleries, Metropolitan Museum of Fine Arts
2. Location: New York City
3. Architect: Kevin Roche John Dinkeloo and Associates
4. Lighting Designer: NI
5. Date of Completion: 1983
6. Collections: Carpets, Manuscripts, Works on paper, Sculptures
7. Space Description: See Plate (6.15.4)

B. **GALLERY DOCUMENTED**

1. Gallery Name Location: Gallery 7
2. Date of Visit: September, 1982
3. Weather Condition: Clear, Sunny
4. Time of Measurements: 9.00 A.M. to 9.30 A.M.
5. Solar Altitude Angle: Start: 33.0 Finish: 37.5
6. Azimuth Angle: Start: 57.0 Finish: 51.0

## DATA SHEET

## TABLE OF FINDINGS

| NO. | SYSTEM | FACTORS | |
|---|---|---|---|
| 1. | HVAC | Exposed Ducts | ● |
| | | Integrated W/Structure | ● |
| | | Integrated W/Lighting | ● |
| 2. | DAY LIGHT | Top Lighting | ○ |
| | | Side Lighting | ● |
| | | Court Lighting | ● |
| | | Clerestory | ● |
| | | Diffusing System | ○ |
| | | U.V. Control | ○ |
| | | Glare Control | ○ |
| | | Contrast | ○ |
| | | Color Rendering | ○ |
| | | Interaction W/Artificial | ○ |
| | | Interaction W.Structure | ⊗ |
| | | Heating Effect | ○ |

| NO. | SYSTEM | FACTORS | |
|---|---|---|---|
| 3. | INTERIOR | Wall system | CH |
| | | Ceiling System | FI |
| | | Finishes | CH |
| 4. | EXHIBITION | 2-D Paintings | □ |
| | | 2-D Paper | □ |
| | | 3-D Sculpture | □ |
| | | Case Exhibition | □ |
| | | Tapestry | □ |
| | | Wall Mounted | □ |
| | | Free Standing | ● |
| 5. | ARTIFICIAL | Luminaire Type | FL |
| | | U.V. Control | ● |
| | | Modeling | ⊗ |
| | | Color Rendering | ⊗ |
| | | Color Temperature | ⊗ |
| | | Interaction W. Daylight | ○ |
| | | Interaction W Structure | ⊗ |
| | | Heating Effect | ⊗ |
| | | Contrast | ○ |

## DATA SHEET (6.15.3)

## SUMMARY OF MEASURED DATA

| COMPONENT OF LIGHT | Min. | Avg. | Max. |
|---|---|---|---|
| Illuminance (Lux) | * 150 | * 210 | * 300 |
| U.V. ($mw/m^2$) | * 36 | * 39 | * 46 |
| U.V./lm (Crawford) | 50 | 50 | 50 |
| Colour Temp. (°K) | ** 3000 | ** 3700 | 4200 |

* Exceeds Recommended Level
** Below Recommended Level

1. Illuminance levels are higher than recommended levels but they are below the suggested levels by this study.
2. Upper values are generally high, which are due to the directions of spots in track lighting.
3. Color temperature levels are below the recommended levels.
4. Ambient lighting is produced by white washed skylights and fluorescent lighting of showcases.
5. The high level of U.V. content is generally due to the ambient lighting.

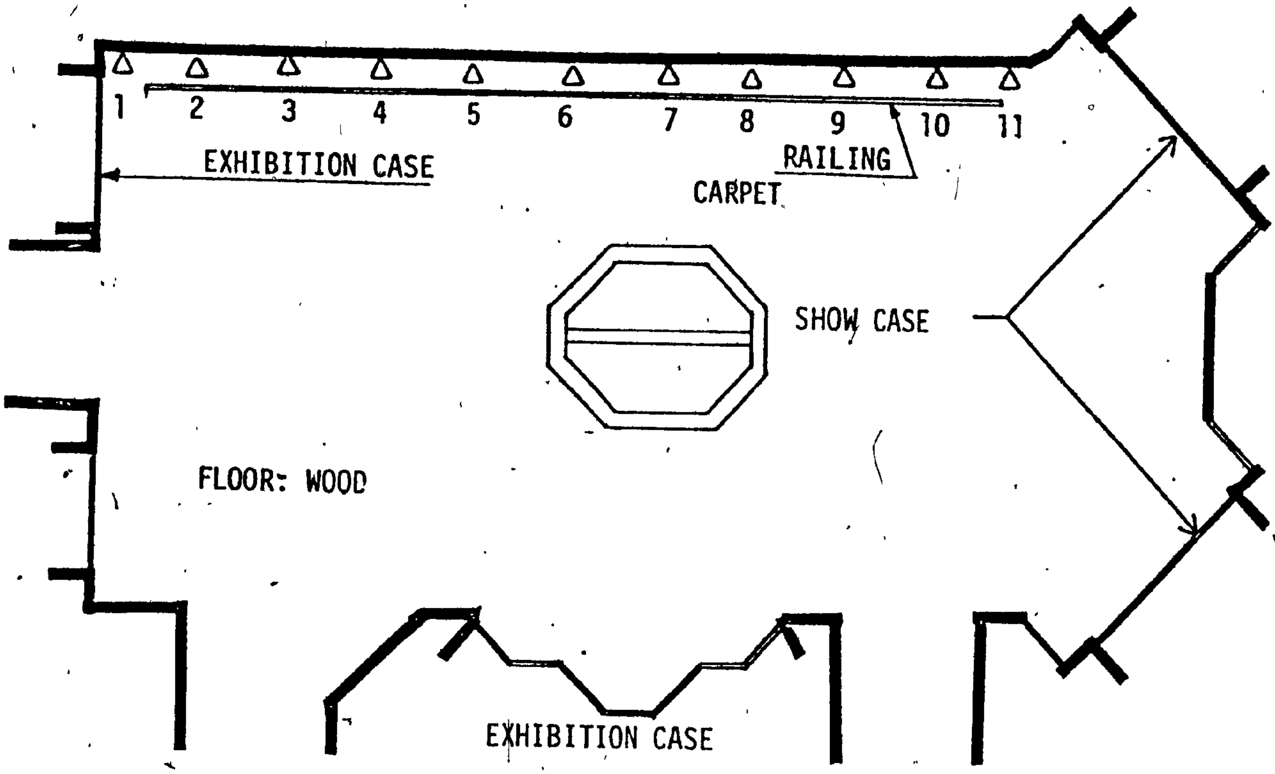



Plate 6.15.4, Floor Plan of Gallery 7

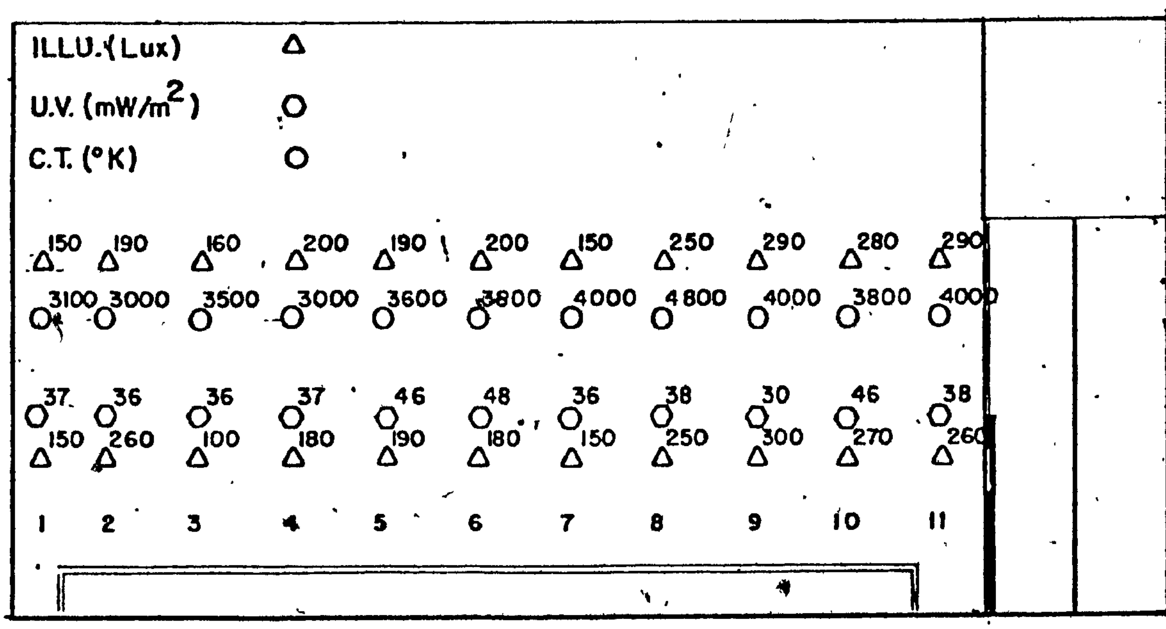



Plate 6.15.5, East wall Elevation

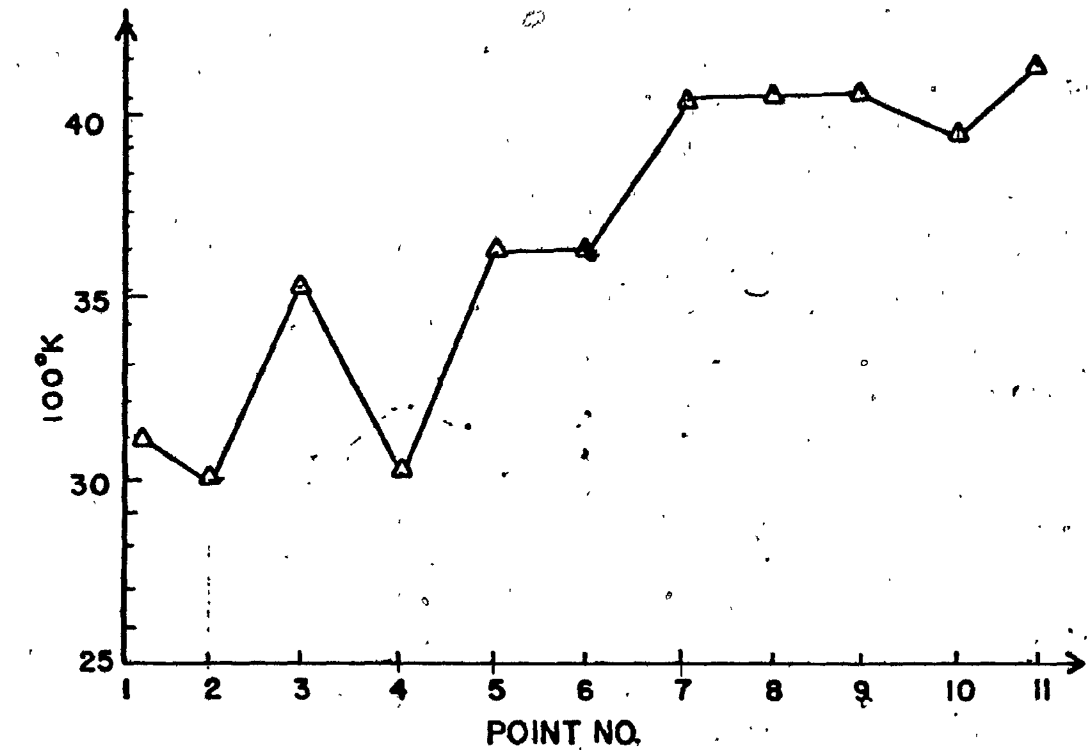



Plate 6.15.6, Color Temperature

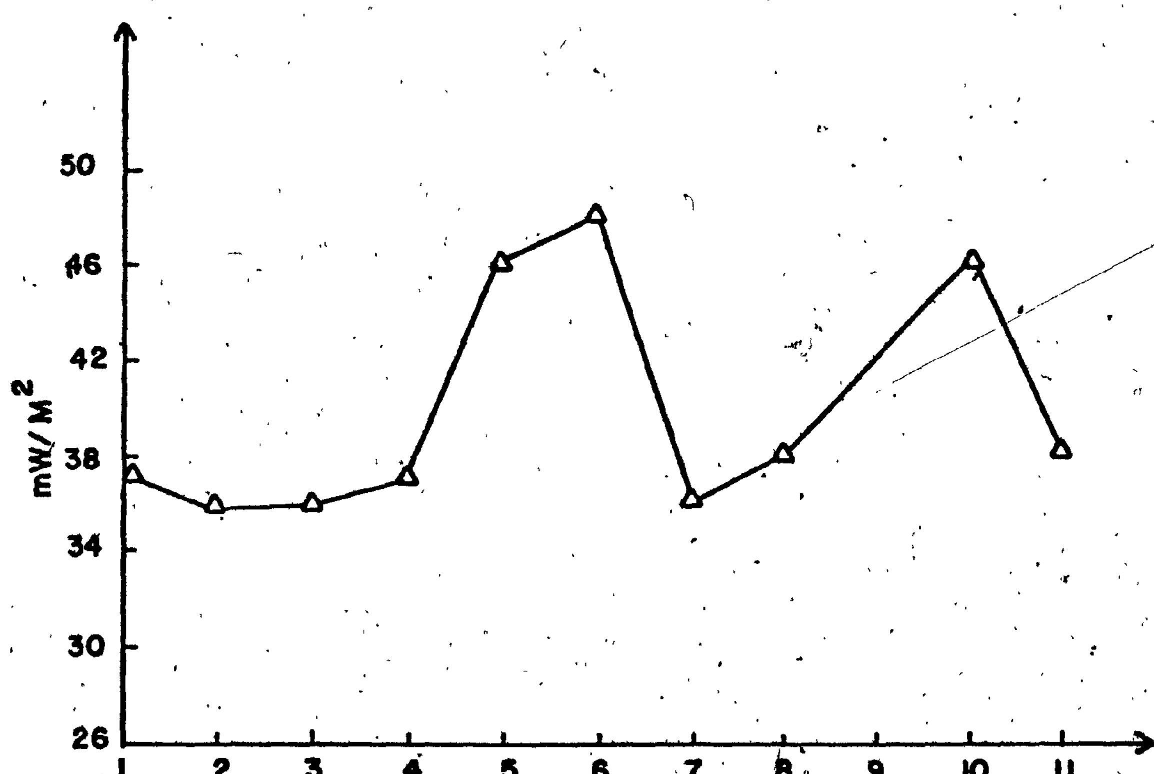



Plate 6.15.7, UV Content

## 6.16 COURTYARD LIT GALLERIES

Two Courtyard Lit galleries were investigated: 1. Gallery C of the Everson Museum which has openings into the sculpture court. The courtyard is lit by large windows and clerestory luminaires. Therefore the light entering the galleries is limited. 2. Gallery 3 of the Lehman galleries which has large openings into the court. The courtyard is covered by a pyramid shape skylight. These two galleries were chosen in order to illustrate the extreme possibilities in courtyard daylight luminaires, in terms of illuminance levels, color temperature, and the relationship between the gallery and the courtyard.

### A. Everson Museum

Gallery C is illuminated through openings into the court and incandescent spots on tracks. One of the openings has an indirect relationship with the courtyard and the other two are directly related to the court. The courtyard lighting of this gallery has the following characteristics:

1. It is effective in providing ambient lighting.
2. The openings cause discomfort glare and high contrast.
3. It provides limited contact with the exterior through the courtyard.
4. It is not effective for modeling.

The courtyard lighting system used in gallery C, shows the following common characteristics with Courtyard lighting luminaire as was discussed in Chapter 5.

1. It provides limited contact with the outside.
2. It provides contact with the court space.
3. It is effective in viewer's orientation.
4. It is an ambient light source.
5. It does not take away too much wall space from the exhibition.
6. It causes problems with adaptation.

The courtyard luminaire differs in that:

1. It is a source of glare.
2. It causes high contrast with adjacent walls.
3. It is not a source of heat gain.

B. Lehman Galleries

Gallery 3 of the Lehman galleries is illuminated through large openings into the courtyard. The courtyard is fully skylit. The openings are controlled by a manual louver system. A special geometrical planning is used which allows daylight into the gallery from 40° angle planes on the plan, see drawing (6.17.4). The courtyard lighting of this gallery has the following characteristics:

1. It is effective in providing task lighing.
2. It is effective in providing ambient lighting.
3. It provides contact with the exterior.
4. It provides contact with the court space.
5. It is effective in illuminance distribution.

6. It is not a source of glare.
7. It does not cause any high contrast.

The Courtyard lighting system used in gallery 3, shows the following common characteristics of courtyard lighting luminaire as was discussed in Chapter 5.

1. It provides contact with the outside.
2. It provides contact with the court space.
3. It is effective in viewer orientation.
4. It is a source of exhibition light.
5. It is a source of ambient light.
6. It does not cuase any glare problem.
7. It does not cause any high contrast.
8. It takes away wall space.
9. It is effective in modeling.

The courtyard luminaire differs in that:

1. It is difficult to control the direct sun rays.
2. It has to depend on staff for manual louver controls.
3. It is a source of heat gain.

# DATA SHEET

## FIELD STUDY (6.16.1)

### A. GENERAL

1. Museum Name: Everson Museum
2. Location: Syracuse, New York
3. Architect: I.M. Pei and Assoc.
4. Lighting Designer: Edison Price & Assoc.
5. Date of Completion: 1969
6. Collections: Paintings, Sculptures
7. Space Description: See Plate (6.16.5)

### B. GALLERY DOCUMENTED

1. Gallery Name Location: Gallery C, second floor
2. Date of Visit: September, 1982
3. Weather Condition: Overcast
4. Time of Measurements: 10.00 A.M. to 11.00 A.M.
5. Solar Altitude Angle: Start: 46.0 Finish: 52.0
6. Azimuth Angle: Start: 45.0 Finish: 24.0

## DATA SHEET

### TABLE OF FINDINGS

| NO. | SYSTEM | FACTORS | |
|---|---|---|---|
| 1. | HVAC | Exposed Ducts | ● |
| | | Integrated W/Structure | ⊗ |
| | | Integrated W/Lighting | ◒ |
| 2. | DAY LIGHT | Top Lighting | ● |
| | | Side Lighting | ● |
| | | Court Lighting | □ |
| | | Clerestory | ● |
| | | Diffusing System | ● |
| | | U.V. Control | ● |
| | | Glare Control | ● |
| | | Contrast | ⊗ |
| | | Color Rendering | ⊗ |
| | | Interaction W/Artificial | ◒ |
| | | Interaction W.Structure | ● |
| | | Heating Effect | ● |

| NO. | SYSTEM | FACTORS | |
|---|---|---|---|
| 3. | INTERIOR | Wall system | FI |
| | | Ceiling System | FI |
| | | Finishes | FI |
| 4. | EXHIBITION | 2-D Paintings | □ |
| | | 2-D Paper | ● |
| | | 3-D Sculpture | □ |
| | | Case Exhibition | ● |
| | | Tapestry | ● |
| | | Wall Mounted | □ |
| | | Free Standing | ○ |
| 5. | ARTIFICIAL | Luminaire Type | IC |
| | | U.V. Control | ● |
| | | Modeling | ◒ |
| | | Color Rendering | ◒ |
| | | Color Temperature | ◒ |
| | | Interaction W. Daylight | ◒ |
| | | Interaction W Structure | ◒ |
| | | Heating Effect | ◒ |
| | | Contrast | ◒ |

## DATA SHEET (6.16.3)

### SUMMARY OF MEASURED DATA

| COMPONENT OF LIGHT | Min. | Avg. | Max. |
|---|---|---|---|
| Illuminance (Lux) | 32 | 95 | * 260 |
| U.V. (mW/m$^2$) | * 14 | * 17 | * 32 |
| U.V./lm (Crawford) | 45 | 60 | * 100 |
| Colour Temp. (°K) | ** 2800 | ** 2900 | ** 3000 |

* Exceeds Recommended Level
** Below Recommended level

1. Average illuminance levels are below the recommended levels.
2. The variations between upper and lower readings are due to the direction of the artificial lighting.
3. There is a sharp increase at certain points which is due to the scalloping.
4. Color temperature readings are constant across the wall.
5. The openings to the court only affect the contrast, but have no effect on illuminance levels and color temperature.

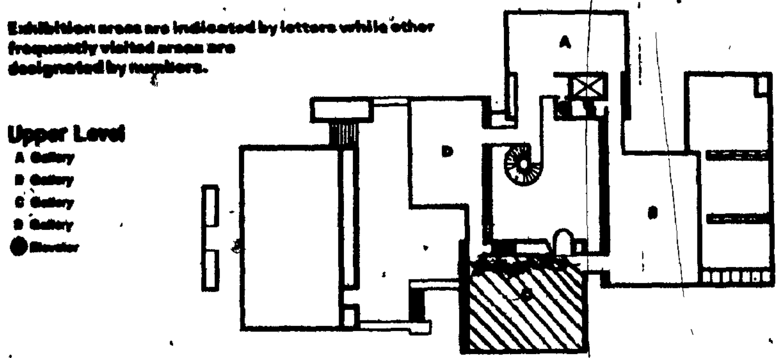



Plate 6.16.4, Second floor plan, gallery (C) is shaded.

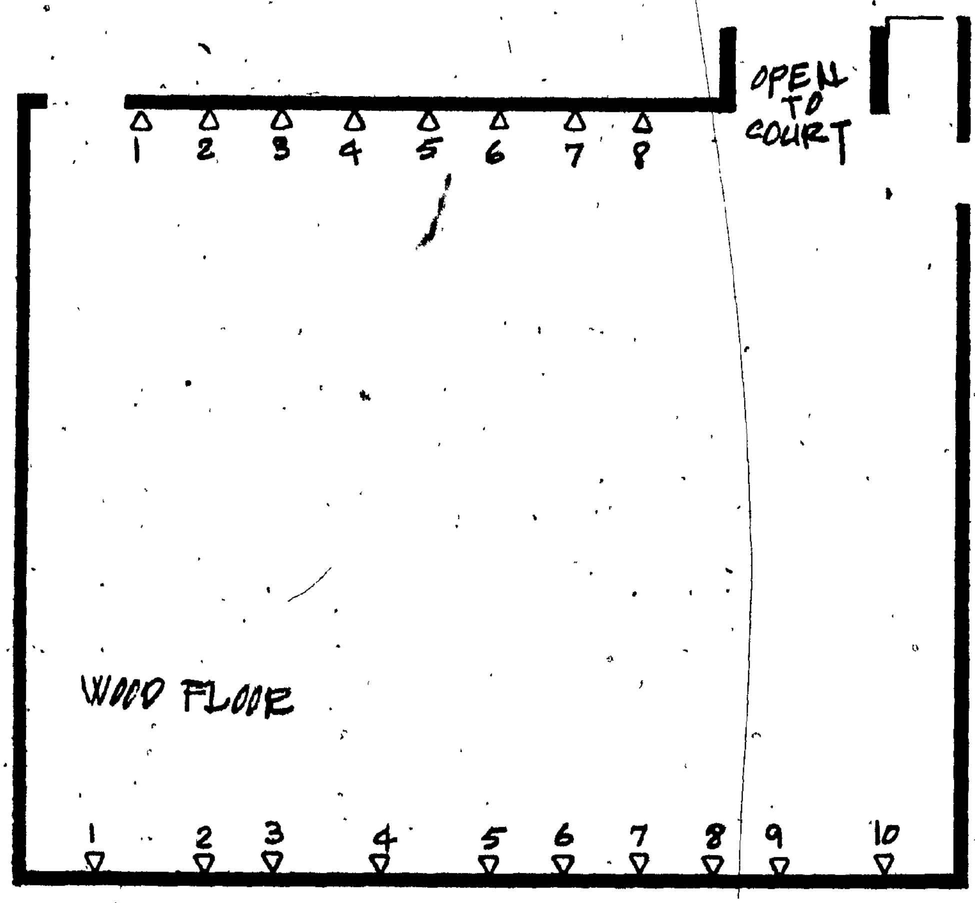



Plate 6.16.5, Floor plan of gallery (C).

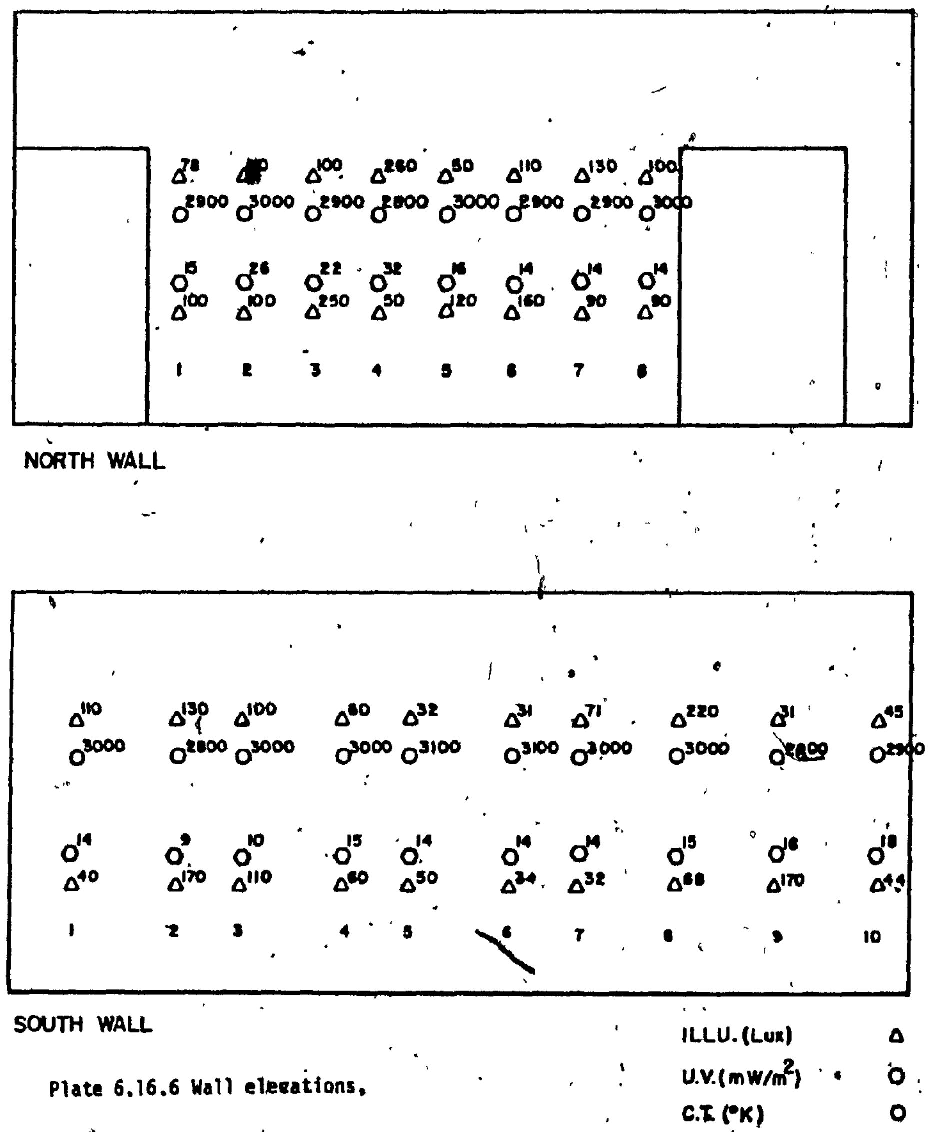



Plate 6.16.6 Wall elevations.

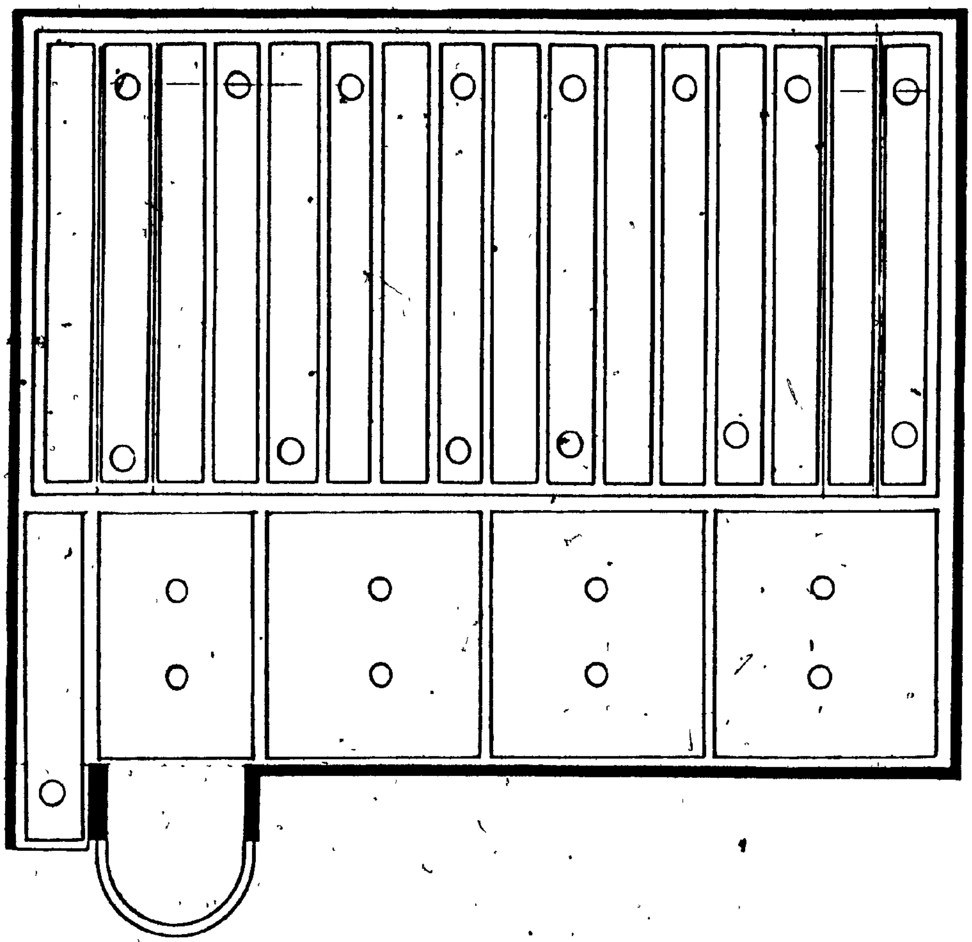


Plate 6.16.7, Reflected ceiling plan of gallery (C).

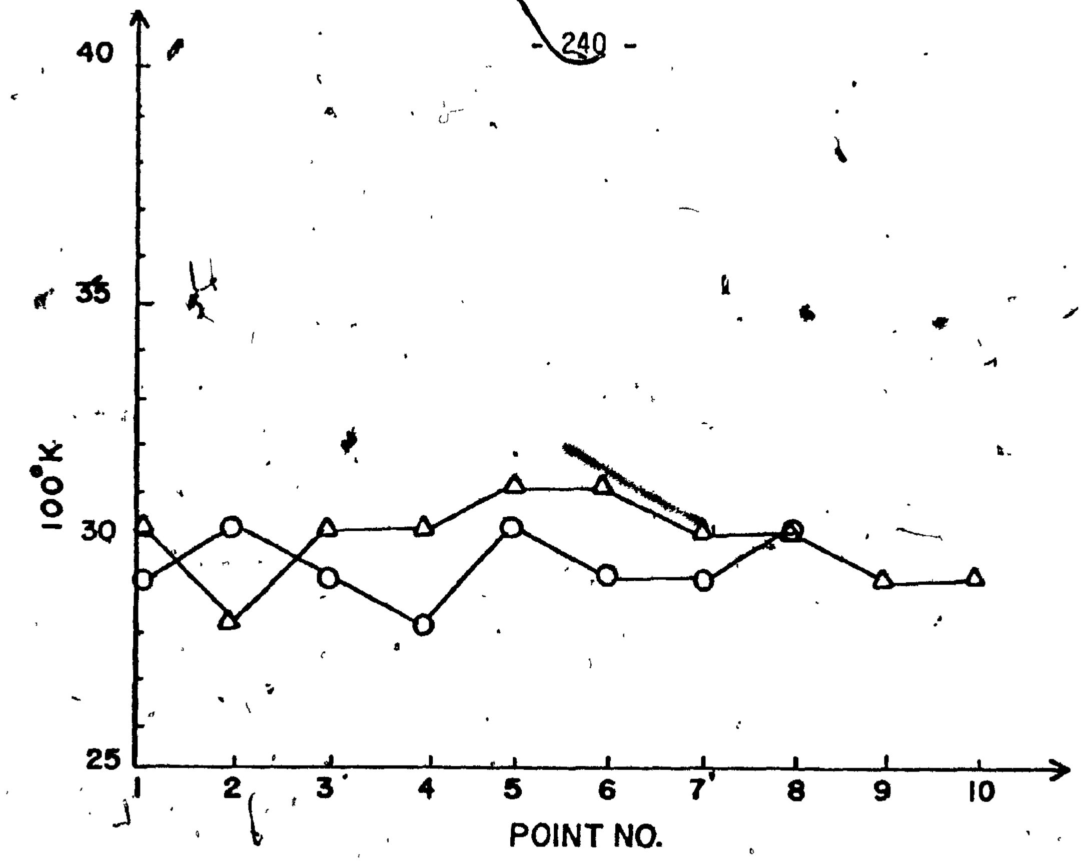



Plate 6.16.8, Color Temperature

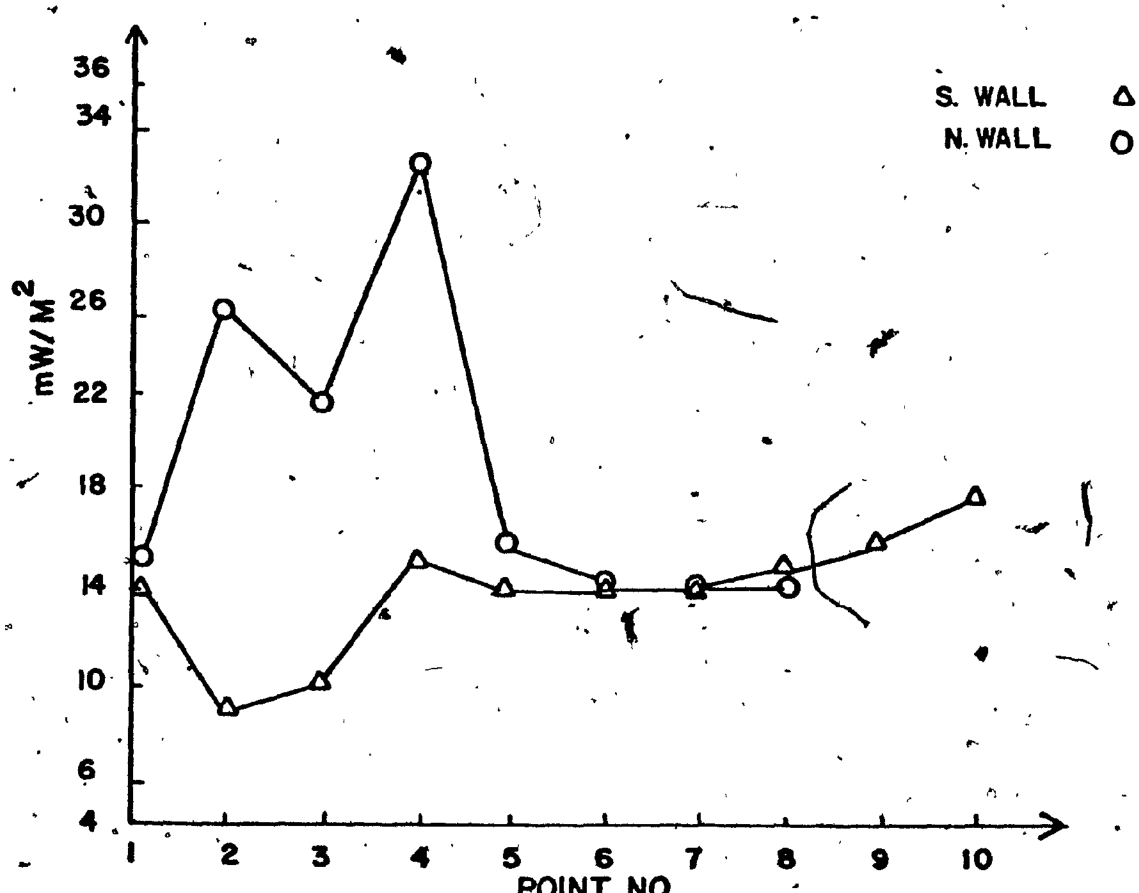



Plate 6.19.9, UV Content

## DATA SHEET

### FIELD STUDY (6.17)

**A. GENERAL**

1. Museum Name: Lehman Galleries, Metropolitan Museum of Fine Arts
2. Location: New York City
3. Architect: Kevin Roche John Dinkeloo and Associates
4. Lighting Designer: John Alteri
5. Date of Completion: 1974
6. Collections: Paintings, Period Rooms
7. Space Description: See Plate (6.17.4)

**B. GALLERY DOCUMENTED**

1. Gallery Name, Location: Gallery 3.
2. Date of Visit: September, 1982
3. Weather Condition: Clear, Sunny
4. Time of Measurements: 11:00 A.M. to 12 noon
5. Solar Altitude Angle: Start: 56 Finish: 58
6. Azimuth Angle: Start: 27 Finish: 0.0

## DATA SHEET

### TABLE OF FINDINGS

| NO. | SYSTEM | FACTORS | |
|---|---|---|---|
| 1. | HVAC | Exposed Ducts | ● |
| | | Integrated W/Structure | □ |
| | | Integrated W/Lighting | ⊗ |
| 2. | DAY LIGHT | Top Lighting | ○ |
| | | Side Lighting | ● |
| | | Court Lighting | ● |
| | | Clerestory | ● |
| | | Diffusing System | ○ |
| | | U.V. Control | ○ |
| | | Glare Control | ○ |
| | | Contrast | ○ |
| | | Color Rendering | ○ |
| | | Interaction W/Artificial | ○ |
| | | Interaction W.Structure | ○ |
| | | Heating Effect | ◒ |

| NO. | SYSTEM | FACTORS | |
|---|---|---|---|
| 3. | INTERIOR | Wall system | FI |
| | | Ceiling System | FI |
| | | Finishes | FI |
| 4. | EXHIBITION | 2-D Paintings | □ |
| | | 2-D Paper | ● |
| | | 3-D Sculpture | ● |
| | | Case Exhibition | ● |
| | | Tapestry | ● |
| | | Wall Mounted | □ |
| | | Free Standing | ● |
| 5. | ARTIFICIAL | Luminaire Type | IC |
| | | U.V. Control | ● |
| | | Modeling | ⊗ |
| | | Color Rendering | ○ |
| | | Color Temperature | ⊗ |
| | | Interaction W. Daylight | ○ |
| | | Interaction W Structure | ○ |
| | | Heating Effect | ◒ |
| | | Contrast | ○ |

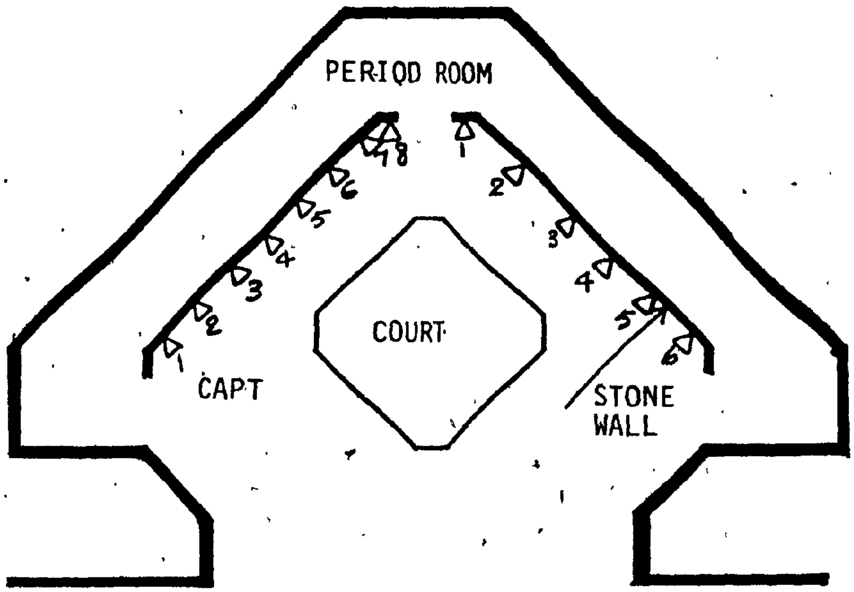
## DATA SHEET

### SUMMARY OF MEASURED DATA (6.17.3)

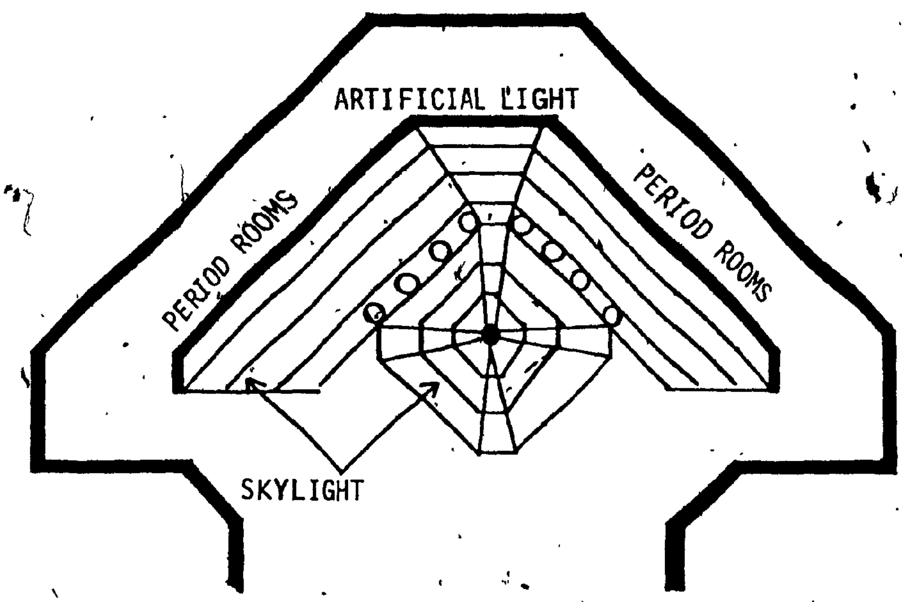
| COMPONENT OF LIGHT | Min. | Aug. | Max. |
|---|---|---|---|
| Illuminance (Lux) | * 250 | * 350 | * 400 |
| U.V. ($mw/cm^2$) | * 16 | * 21 | * 32 |
| U.V./lum (Crawford) | * 110 | * 160 | * 190 |
| Colour Temp. (°K) | ** 3000 | ** 3200 | 3500 |

* Exceeds Recommended Level
** Below Recommended level

1. Illuminance levels are above the recommended levels but they are within the limits suggested by this study.
2. No significant (above 10%) variation exists between the lower and upper readings. This is due to louver systems of skylight.
3. Color temperature readings are generally below the recommended levels and are constant across the wall.
4. U.V. content is low for a daylit gallery, but exceed the minimum recommended levels.
5. The use of cloth panel in the background has provided contrast.
6. Ambient lighting is provided by skylight, courtyard and artificial lighting.




FLOOR PLAN




REFLECTED CEILING PLAN

Plate 6.17.4, Floor plan and reflected ceiling plan.

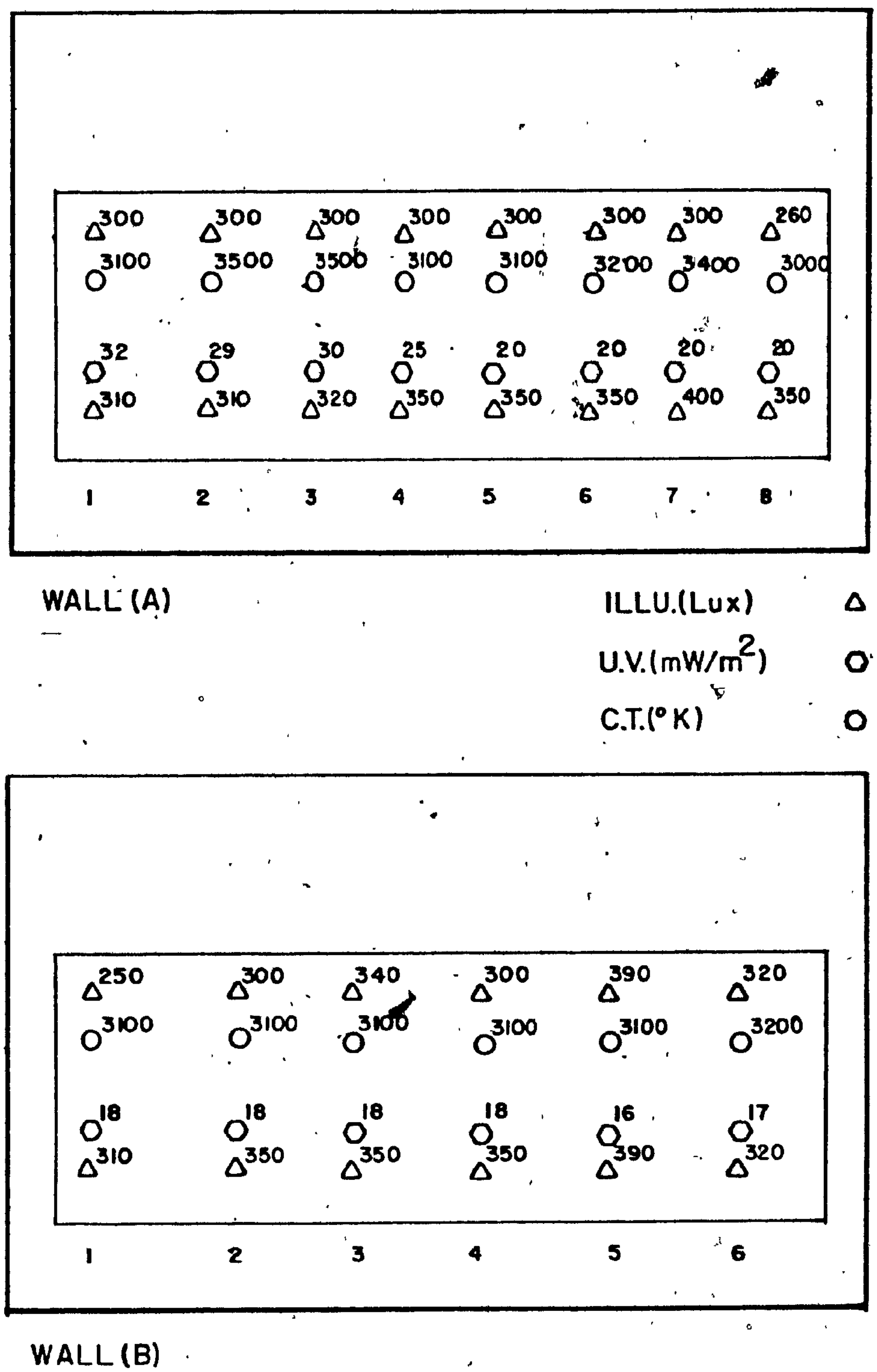



Plate 6.17.5, Interior elevations

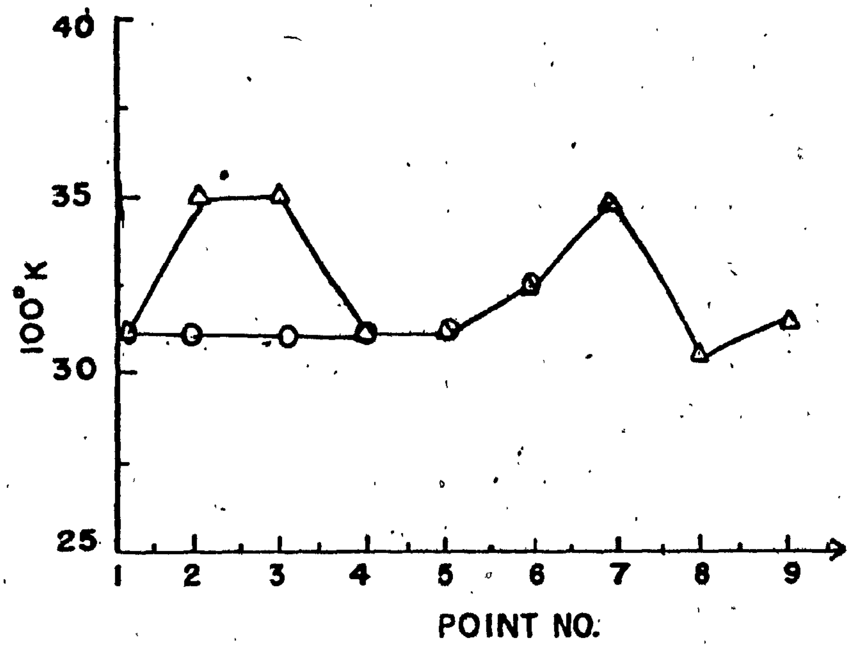



Plate 6.17.6, Color Temperature

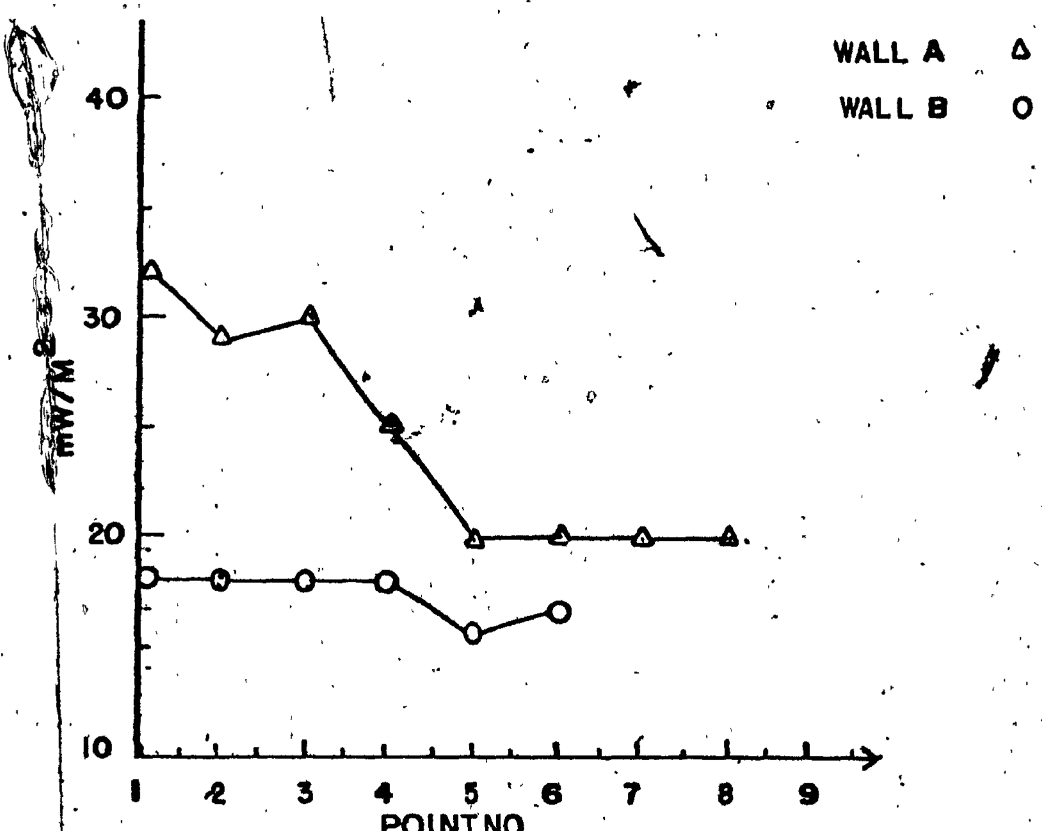



Plate 6.17.7, UV Content

## 6.18 ARTIFICIALLY LIT GALLERY

Gallery D of the Montreal Museum of Fine Arts was investigated as an example of an Artifically lit gallery. This gallery is illuminated by incandescent track lighting and it opens to the main circulation space which receives some daylight from clerestory daylight luminaires, but the daylight does not have any effect. The artificial lighting system has the following characteristics:

1. It is effective in task lighting, but some paintings receive no light due to scalloping.
2. The lighting system is very static.
3. The color of light is mostly in the red region.
4. It is not effective in modeling, particularly in lighting of the sculpture in the gallery.
5. All wall spaces are used for exhibition.
6. It does not provide any contact with the outside.
7. The problem of veiling glare exists, particularly from two glazed paintings.

## DATA SHEET (6.18.1)

### FIELD STUDY

A. **GENERAL**

1. Museum Name: Montreal Museum of Fine Arts
2. Location: Montreal, Quebec
3. Architect: ARCOP Assoc.
4. Lighting Designer: NI
5. Date of Completion: 1979
6. Collections: Paintings
7. Space Description: See Plate (6.18.4)

B. **GALLERY DOCUMENTED**

1. Gallery Name Location: Gallery D, 4th floor
2. Date of Visit: October, 1982
3. Weather Condition: Clear/Sunny
4. Time of Measurements: 2:30 P.M. to 3.00 P.M.
5. Solar Altitude Angle: Start: 32.0 Finish: 27
6. Azimuth Angle: Start: 46 Finish: 53

DATA SHEET

TABLE OF FINDINGS

| NO. | SYSTEM | FACTORS | |
|---|---|---|---|
| 1. | HVAC | Exposed Ducts | ● |
| | | Integrated W/Structure | ● |
| | | Integrated W/Lighting | ● |
| 2. | DAY LIGHT | Top Lighting | ● |
| | | Side Lighting | ● |
| | | Court Lighting | ● |
| | | Clerestory | ● |
| | | Diffusing System | ● |
| | | U.V. Control | ● |
| | | Glare Control | ● |
| | | Contrast | ● |
| | | Color Rendering | ● |
| | | Interaction W/Artificial | ● |
| | | Interaction W.Structure | ● |
| | | Heating Effect | ● |

| NO. | SYSTEM | FACTORS | |
|---|---|---|---|
| 3. | INTERIOR | Wall system | FI |
| | | Ceiling System | FI |
| | | Finishes | FI |
| 4. | EXHIBITION | 2-D Paintings | □ |
| | | 2-D Paper | ● |
| | | 3-D Sculpture | □ |
| | | Case Exhibition | ● |
| | | Tapestry | ● |
| | | Wall Mounted | □ |
| | | Free Standing | □ |
| 5. | ARTIFICIAL | Luminaire Type | IC |
| | | U.V. Control | ● |
| | | Modeling | ◓ |
| | | Color Rendering | ◓ |
| | | Color Temperature | ◓ |
| | | Interaction W. Daylight | ● |
| | | Interaction W Structure | ● |
| | | Heating Effect | ◓ |
| | | Contrast | ◓ |

## DATA SHEET (6.18.3)

## SUMMARY OF MEASURED DATA

| COMPONENT OF LIGHT | Min. | Avg. | Max. |
|---|---|---|---|
| Illuminance (Lux) | 140 | * 205 | * 240 |
| U.V. (mw/m$^2$) | * 7 | * 9 | * 12 |
| U.V./lm (Crawford) | 50 | 58 | 70 |
| Colour Temp. (°K) | ** 3000 | ** 3100 | ** 3100 |

* Exceeds Recommended Level
** Below Recommended level

1. Illuminance levels exceed the recommended levels, except at some points (which are 140 lux), but they are below the suggested levels by this study.
2. Upper illuminance levels are higher which are due to the direction of track lighting and low ceiling (very constant).
3. Color temperature is below the recommended levels, which is due to the C.T. of the source and the wood floor.
4. The U.V. content is low in comparison to daylit galleries.
5. Modeling light is very poor; paintings and sculptures are exhibited with the same lighting system.

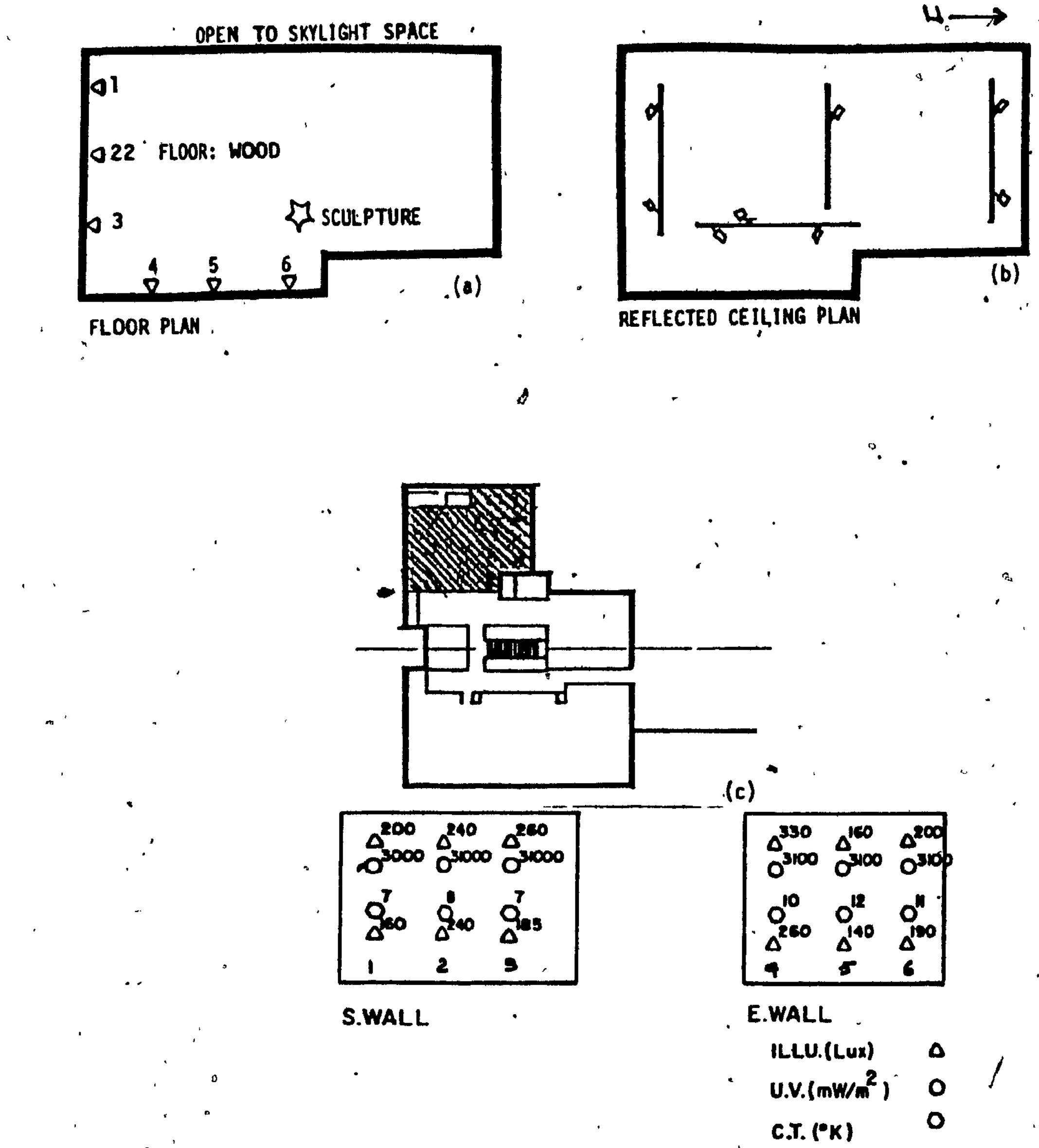



Plate 6.18.4. (a) Floor plan; (b) Reflected ceiling plan; (c) Fourth floor plan; (d) South wall elevation; (e) East wall elevation.

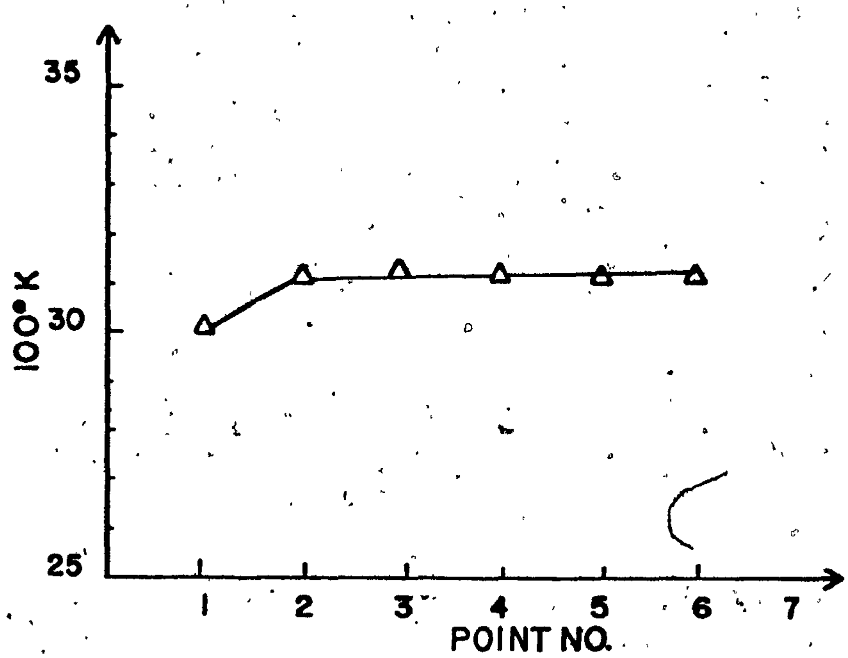



Plate 6.18.5, Color Temperature

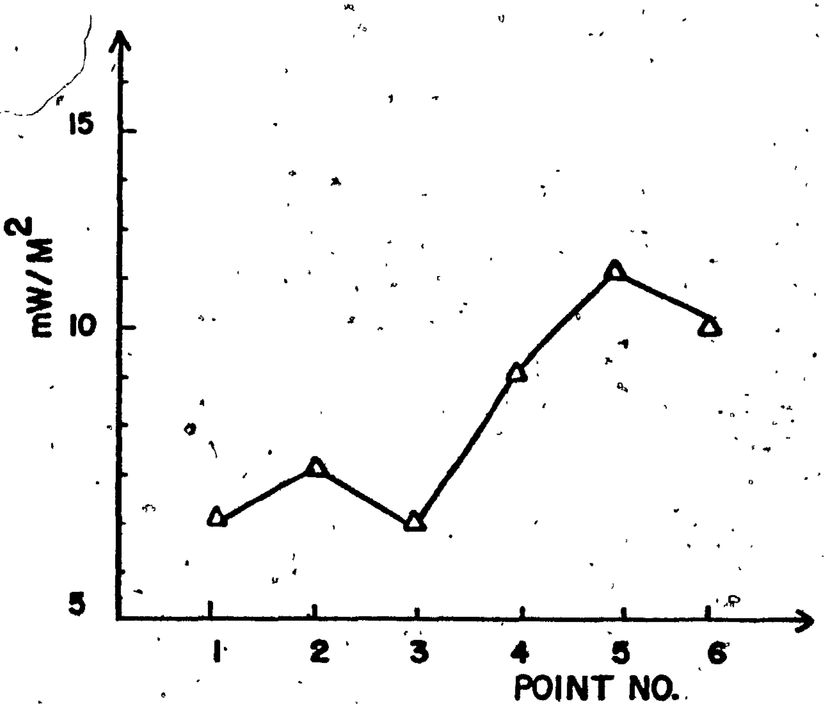



Plate 6.19.6, UV Content

## 6.19 DATA EXTRAPOLATION

Measurements made in this study were done for a brief period of time (usually 1 day). One may well object that a longer study period is required to fully understand daylight effects in a space. This is certainly true,however at a large expense in time and travel costs. Because of practical limits we decided to visit several museums briefly to have a broader range of examples and then to extrapolate the readings for the year. This extrapolation is of an "order of magnitude" precision limited by daylight availability data. Studying daylight in museums is difficult because no two museums are alike and daylight changes due to weather factors. Of these two fundamental types of variations, the former is more critical since daylight inside is proportional to some exterior conditions. If the knowledge of the interior variation is known then exterior changes can be applied proportionally inside.

In extrapolating exterior (lux and U.V.) readings, throughout the year, one can roughly approximate the region of highest and lowest illuminance and U.V. levels expected. By recording exterior illuminance values (lux) during one day, and having the exterior illuminance level throughout the year, one can estimate the approximate values (max. and min.) expected through the year for typical sky conditions.

One cannot make accurate predictions due to the lack of precise daylight data for Montreal or North America. Though radiation data has been collected by weather stations, no yearly luminous efficacy correlations have been made for Montreal or the other sites that were visited. The correlations that have been made for some centers, namely Washington D.C. [62], Port Allegany, Pa. [53] [52], and Nottingham, U.K. [64] are the best available. One can extrapolate daylight illuminance variations through existing solar radiation data, but the range of suggested luminous efficacy is so large (90-130 lum/watt) that the resulting curves can only give relative magnitudes. Similar problems exist with respect to U.V. content. No useful yearly data has been collected for Montreal and the sites visited. However using the curves produced through studies done by Kunerth, (by Miller and Kalitin) for clear sky [91] and by IES, one is able to approximate the illuminance variations, Plate (6.19.1).

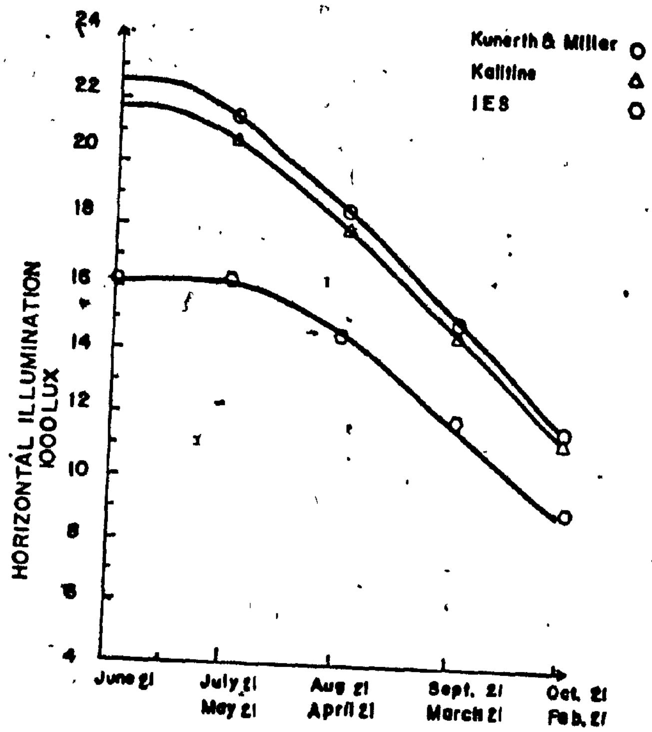



Plate 16.19.1, Horizontal illuminance levels at 12 noon diffuse sky.

The Johnson museum data can be used as an example. First one locates the measured illuminance values as on graph 16.19.2. Then one can approximate the change of expected exterior noon diffuse clear sky illuminance, for other times of the year.

The exterior value could increase by 60% or decrease by 20% from Sept. 21 throughout the year. Assuming that the interior illuminance levels follow the same pattern, the interior maximum illuminance level can increase to 2100 lux, or decrease to 1040 lux, compared to the mid September.

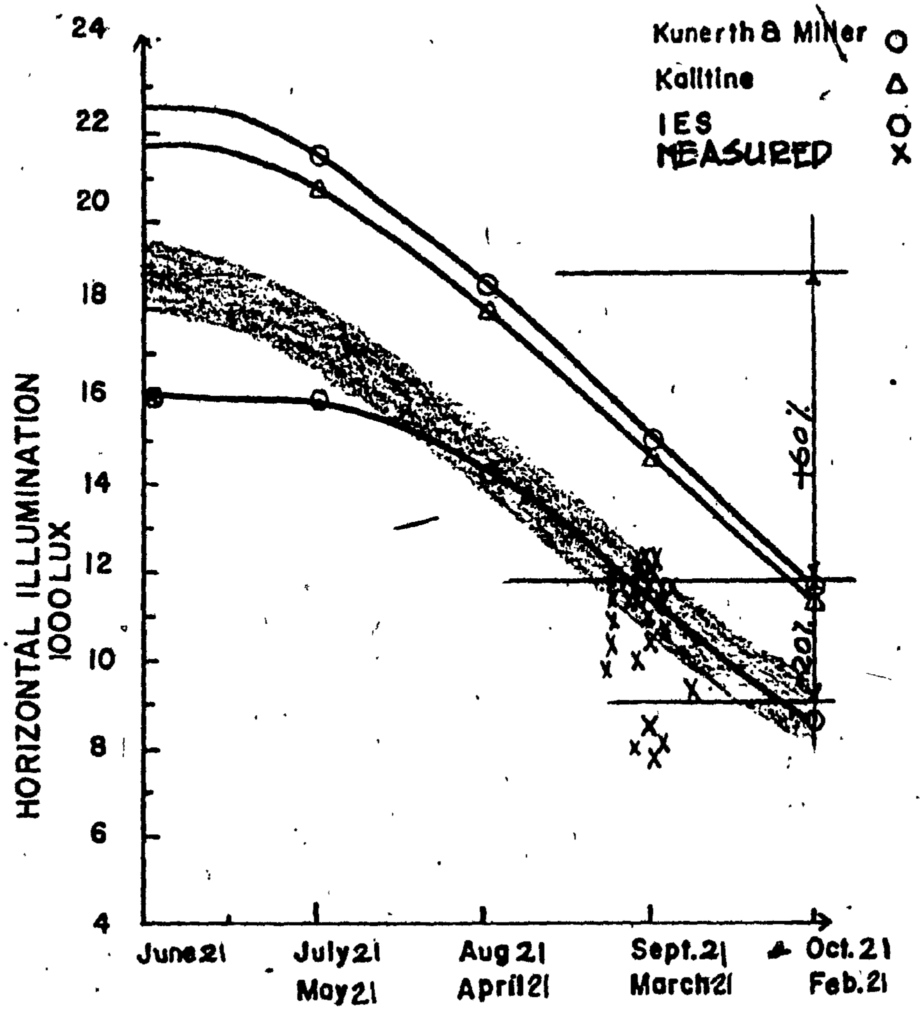



Plate 16.19.2 Diffuse clear sky illuminance levels at 12 noon. The exerior readings are shown.

| SYSTEM | HVAC: Exposed Ducts | HVAC: Integrated W. Structure | HVAC: Integrated W. Lighting | INTERIOR: Wall Systems | INTERIOR: Ceiling Systems | INTERIOR: Finishes | DISPLAY: 2-D, Paintings | DISPLAY: 2-D, Paper | DISPLAY: 3-D, Sculpture | DISPLAY: Case Exhibition | DISPLAY: Tapestry | DISPLAY: Wall Mounted | DISPLAY: Free Standing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WINDOW LIT | | | | | | | | | | | | | |
| Johnson Museum | ● | ● | ● | F | F | F | □ | ● | ● | ● | ● | □ | ● |
| Musée d'Art Contemporain | ● | ⊗ | ⊗ | F | F | F | □ | ● | ● | ● | ● | □ | ● |
| TOP LIT | | | | | | | | | | | | | |
| American Galleries | ● | ● | ⊗ | F | F | F | □ | ● | ● | ● | ○ | ● | |
| Islamic Galleries | ● | ● | ● | CH | F | F | □ | □ | □ | □ | □ | □ | ● |
| COURT LIT | | | | | | | | | | | | | |
| Everson Museum | ● | ⊗ | ● | F | F | F | □ | ● | □ | ● | ● | □ | ○ |
| Lehman Galleries | ● | □ | ⊗ | F | F | F | □ | ● | ● | ● | ● | □ | ● |
| ARTIFICIAL LIT | | | | | | | | | | | | | |
| Montreal Museum | ● | ● | ● | F | F | F | □ | | □ | | | □ | □ |

| SYSTEM | ARTIFICIAL: Luminaire Type | ARTIFICIAL: Lamp Type | ARTIFICIAL: U.V. Control | ARTIFICIAL: Modeling | ARTIFICIAL: Color Rendering | ARTIFICIAL: Color Temperature | ARTIFICIAL: Integration W. Daylight | ARTIFICIAL: Integration W. Structure | ARTIFICIAL: Contrast/Glare Control |
|---|---|---|---|---|---|---|---|---|---|
| WINDOW LIT | | | | | | | | | |
| Johnson Museum | IC | IC | ● | ◐ | ⊗ | ⊗ | ● | ● | ◐ |
| Musée d'Art Contemporain | K | K | ● | ⊗ | ⊗ | ⊗ | ◐ | ◐ | ◐ |
| TOP LIT | | | | | | | | | |
| American Galleries | IC | IC | ⊗ | ⊗ | ◐ | ◐ | ⊗ | ● | □ |
| Islamic Galleries | FL | FL | ● | ⊗ | ● | ⊗ | ○ | ⊗ | ○ |
| COURT LIT | | | | | | | | | |
| Everson Museum | | | ● | ◐ | ◐ | ◐ | ◐ | ◐ | ◐ |
| Lehman Galleries | IC | IC | ● | ⊗ | ⊗ | ○ | ○ | ○ | ○ |
| ARTIFICIAL LIT | | | | | | | | | |
| Montreal Museum | IC | IC | ● | ◐ | ◐ | ◐ | ● | ● | ◐ |

| SYSTEM | DAYLIGHT: Top Lighting | DAYLIGHT: Side Lighting | DAYLIGHT: Court Yard Lighting | DAYLIGHT: Clerestory | DAYLIGHT: Diffusing System | DAYLIGHT: U.V. Control | DAYLIGHT: Glare Control | DAYLIGHT: Modeling | DAYLIGHT: Contrast | DAYLIGHT: Color Rendering | DAYLIGHT: Integration W. Art. | DAYLIGHT: Integration W. Structure | DAYLIGHT: Heating Effect |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WINDOW LIT | | | | | | | | | | | | | |
| Johnson Museum | ● | ◐ | ● | ● | ● | ● | ● | ⊗ | ⊗ | ○ | ◐ | ◐ | ○ |
| Musée d'Art Contemporain | ● | □ | □ | ● | ⊗ | ● | ⊗ | ⊗ | ⊗ | ⊗ | ◐ | ● | ● |
| TOP LIT | | | | | | | | | | | | | |
| American Galleries | ○ | ● | ● | ● | ○ | ⊗ | ⊗ | ◐ | ◐ | ◐ | ○ | ○ | ◐ |
| Islamic Galleries | ○ | ● | ● | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ⊗ | ○ |
| COURT LIT | | | | | | | | | | | | | |
| Everson Museum | ● | ● | □ | ● | ● | ● | ● | ⊗ | ⊗ | ⊗ | ● | ● | ● |
| Lehman Galleries | ○ | ● | ● | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| ARTIFICIAL LIT | | | | | | | | | | | | | |
| Montreal Museum | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |

Plate 6.21, Table of comparison of galleries documented.

The precision of this method depends on the availability of yearly daylight data; however a useful understanding can be obtained for order of magnitude approximations.

## 6.20 CONCLUSIONS

The field studies are used to compare theoretical views and data with actual site situations, Plate (6.21). Through this comparison and the analysis of the data, with respect to, A) museum design and planning, B) museum's visual environment, C) deterioration of works of art, and D) interaction of all the factors affecting museum lighting, one can make the following conclusions:

A) Museum Design and Planning:

1) The interaction between HVAC, lighting and structure often has not taken place. This is due to the fact that lighting is always considered at a very late stage of the design and construction process.

2) Only in a few cases, has daylight luminaire design been considered at the conceptual design stage and implemented.

3) Flexibility is limited in some cases, and not provided for in others. Partitions and interior finishes are usually fixed.

4) Transition spaces have not been provided making accommodation from dark to light areas (and vice versa) difficult.

5) The movement pattern of the visitor in the museum is often confused and does not have a hierarchy or order with respect to qualities of the visual environment, i.e. light to dark.

6) The changes in the use of museum space can create inadequate viewing spaces and hazardous exposure to works of art. It is difficult to predict how a museum will change its functions and configuration in time. Thus ideally all spaces should be considered as potential galleries.

B) The Visual Environment

1) There are large variations in illuminance levels in all galleries.

2) Illuminance variation is much more even in top lit galleries and this vacation is a function of the galleries height. The upper points show higher values. Illuminances levels are generally higher than recommended levels.

3) There was excessive veiling glare in all windowed and courtyard galleries but not in toplit galleries which confirms the taxonomy of chapter 5. The Johnson gallery was by far the worst example. See also case studies.

4) The toplit American wing had very poor modeling due to large areas of diffuse laylights whereas the toplit Islamic gallery with a center skylight and high perimeter lighting in the Lehman gallery were very good. This confirms the requirements of chapter 2 and the taxonomy of chapter 5. No gallery had direct daylight that would cause excessive shadows.

5) The color temperature readings in the Lehman gallery and the American Wing were acceptable showing the value of daylight to raise color temperature. The artificially lit Montreal Museum was very poor as expected from chapter 3.

C) Deterioration

1) The illuminance levels exceed the levels recommended by conservationists (up to 10 times). In some exceptional cases the minimum level meets the standard.

2) The U.V. content exceeds the recommended levels (up to 8 times). This is due to the lack of U.V. filters in the luminaires.

3) Overheating is found to be a serious problem with respect to deterioration and comfort, as concluded from interviews with museum personnel.

4) Daylight control devices (louvres, covers ..) have not been provided. Louvres are provided in some galleries but they cannot be used to block the daylight during the hours that a museum is closed.

5) Lack of accurate yearly local daylight data makes any daylight analysis or prediction imprecise and hence makes a design study difficult or impossible in terms of precise damage prediction.

D) Interaction of Factors

1) The relationship of factors, influencing the visual environment has generally not been considered in the museums visited.. Providing for one factor has caused problems for the other. For example creation of high contrast has led to glare, or avoiding glare from the

skylight has caused loss of contrast. Increased color visibility by higher illuminance levels has increased the damage factor.

2) The needs of the viewer have not been considered in relation to the needs for conservation. Museums have often been designed for one or the other.

3) Massing and the design factors affecting the shape of the building have caused the interior needs to be over looked.

Of the museums visited the toplit galleries were judged the best with respect to evenness of illumination, lack of glare, modeling and color rendering. The worst was the Johsnon gallery due to the veiling and discomfort glare, lack of transition space, poor color temperature control and potential damage due to U.V. In fact it was closed last year after measurements were made due to problems in the mechanical system.

# CHAPTER VII

# CASE STUDIES

## 7.1 INTRODUCTION

The application of visual environment factors to museums display spaces was discussed in the first four chapters. In chapter five the application of factors and evaluation of daylight luminaire designs were presented. Finally in order to see how the factors and recommendations are applied in museums, field studies were undertaken and analyzed in chapter 6. It was concluded that more museums should be investigated which was not possible for this study. Therefore in order to have a better idea of the application of factors a number of well known museums are studied as a continuation to the field studies. Although no on site data was taken, the graphic studies and information tables are aimed at presenting:

1. The planning concepts with respect to transition areas and zoning of activities.
2. The geometrical concepts with respect to daylight luminaire design to survey the range of daylight systems available.
3. The integration of building systems with respect to HVAC, structure and lighting.
4. The lighting system, ie. artificial, daylight or a combination of the two.

5. The nature of objects on display, in relation to lighting.
6. The application of factors affecting the visual environment.
7. The interaction of these factors in the visual environment in relation to overall design.
8. Locating the problems and potentials for future designs.

Case studies will give the designers an overall idea of what is actually being done, and the possibilities and limitations of integration of daylight in the museum display spaces. The ideal study would be to visit these museums and document them for long duration, as any study in a new field has started. One can hope that these graphical documentations are a step towards that ideal direction.

The museums studied are divided into 5 categories with respect to their lighting system as was discussed in Chapter 5, they are:

a) Window lit
b) Clerestory lit
c) Top lit
d) Courtyard lit
e) Artificially lit

Some museums could fall into two categories, but the one which is most typical of the museum is chosen. Each museum is studied individually and a data sheet is drawn up for quick references. A table of building systems affecting lighting for all museums is presented for comparison.

## 7.2 MUSEUMS STUDIED

There are many museums that can be studied. Therefore the museums visited during site studies plus a few others that are known for their lighting designs were studied. The museums in which one gallery was documented and analyzed in Chapter 6 are included here. In Chapter 6 data analysis of one gallery was undertaken, in this chapter we will study the museum as a building. Galleries investigated and galleries documented through literature search are compared and evaluated against each other. The luminaire type, was discussed in Chapter 5, is the basis for comparisons of possibilities and limitations.

**A. - Window Lit**

1. Herbert F. Johnson Museum of Art, Ithaca, N.Y.
2. Musée D'art Contemporain, Montreal, Quebec

**B. - Clerestory Lit**

1. Museum of Contemporary Art, Tehran, Iran
2. Shiraz Art Gallery, Shiraz, Iran

**C. - Top Lit**

1. Frederick R. Mayer Art Center, New Hampshire
2. The Menil Collection, Houston, Texas
3. Yale Center for British Art, New Haven
4. Portland Museum of Art, Portland, Maine

5. Art Gallery of Ontario, Toronto, Ontario

6. American Art Galleries of Metropolitan Museum of Art, New York

7. Islamic Art Galleries of Metropolitan Museum of Art, N.Y.

8. Kimbell Art Museum, Fort Worth, Texas

9. Boston museum of Fine Arts, Boston

**D. Courtyard Lit**

1. Everson Museum of Art, Syracuse, N.Y.

2. Robert Lehman Galleries of Metropolitan Museum of Art, N.Y.

**E. Artificially Lit**

1. Montreal Museum of Fine Arts, Montreal, Quebec

**A.1 Herbert F. Johnson Museum of Art, Cornell University, Ithaca, New York**

In the Johnson Museum daylight has been introduced from different luminaires at a number of locations, but its use as an exhibition light source is minimal. This is due to changes made by the staff after the opening of the museum. The only daylit gallery is Gallery 14.b, which was intended to be used as a lounge by the architect. The circulation areas of the fifth floor are also used as exhibition areas (mostly sculptures), which again were meant to be used as administration areas by the designer. These changes have created many problems in terms of space organization and circulation.

Gallery 14-b has a very large window facing North, which floods the space with daylight. Nevertheless, the spotlights are kept on for modeling and to decrease the color temperature. The illuminance levels and U.V. content (not filtered) are very high and alarming. See Chapter 6 for data. Furthermore, the window creates a source of disability glare, reflected from the works of art. There are problems with adapting to the low illuminance level of the oriental galleries upon entering from bright daylit perimeter circulation areas on the 5th floor.

## DATA SHEET

MUSEUM NAME: Herbert F. Johnson Museum of Art

LOCATION: Ithaca, N.Y.

| NO. | SYSTEM | FACTORS | |
|---|---|---|---|
| 1. | HVAC | Exposed Ducts | ● |
| | | Integrated W/Structure | ● |
| | | Integrated W/Lighting | ● |
| 2. | CIRCULATION | Linear W. Corridors | ● |
| | | Linear WO/Corridors | □ |
| | | Transition Route | ◒ |
| 3. | PLANNING | Planning System | FP |
| | | Transition Space | ● |
| | | Multi Story Space | □ |
| | | Zoning | ◒ |
| 4. | INTERIOR | Wall System | FI |
| | | Ceiling System | FI |
| | | Finishes | CH |
| 5. | DISPLAY | 2-D, Paintings | □ |
| | | 2-D, Paper | □ |
| | | 3-D, Sculpture | □ |
| | | Case Exhibition | □ |
| | | Wall Mounted | □ |
| | | Free Standing | □ |
| 6. | ART. LIGHT | Luminaire Type | IC |
| | | Lamp Type | IC |
| | | U.V. Control | ● |

| | SYSTEM | FACTORS | |
|---|---|---|---|
| 6. | ARTIFICIAL LIGHTING | Glare Control | ● |
| | | Modeling | ◒ |
| | | Colour Rendering | ⊗ |
| | | Colour Temperature | ○ |
| | | Interaction W/Structure | ⊗ |
| | | Heating Effect | ⊗ |
| | | Contrast | ⊗ |
| 7. | DAYLIGHTING | Top Lighting | ● |
| | | Side Lighting | □ |
| | | Court Lighting | □ |
| | | Clerestory | ● |
| | | Diffusing System | ● |
| | | U.V. Control | ● |
| | | Glare Control | ● |
| | | Modeling | ● |
| | | Contrast | ⊗ |
| | | Colour Rendering | ○ |
| | | Interaction W/Art. | ◒ |
| | | Interaction W/Structure | ◒ |
| | | Heating Effect | ● |
| | | | |
| | | | |

Plate (7.1) General view of the Museum. Note the strip of glazing in the fifth floor galleries.

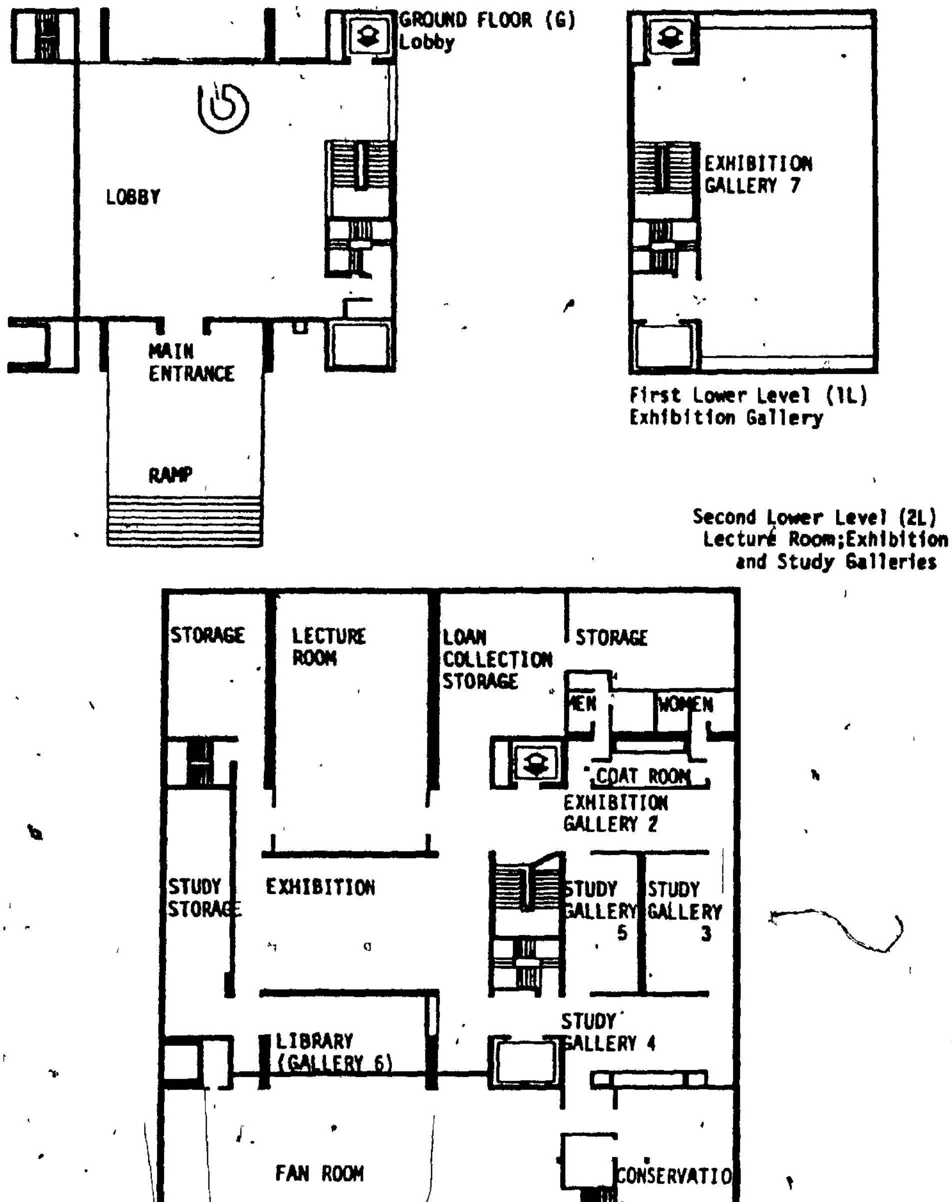



Plate 7.2 . Ground, first lower level and second lower level plans.

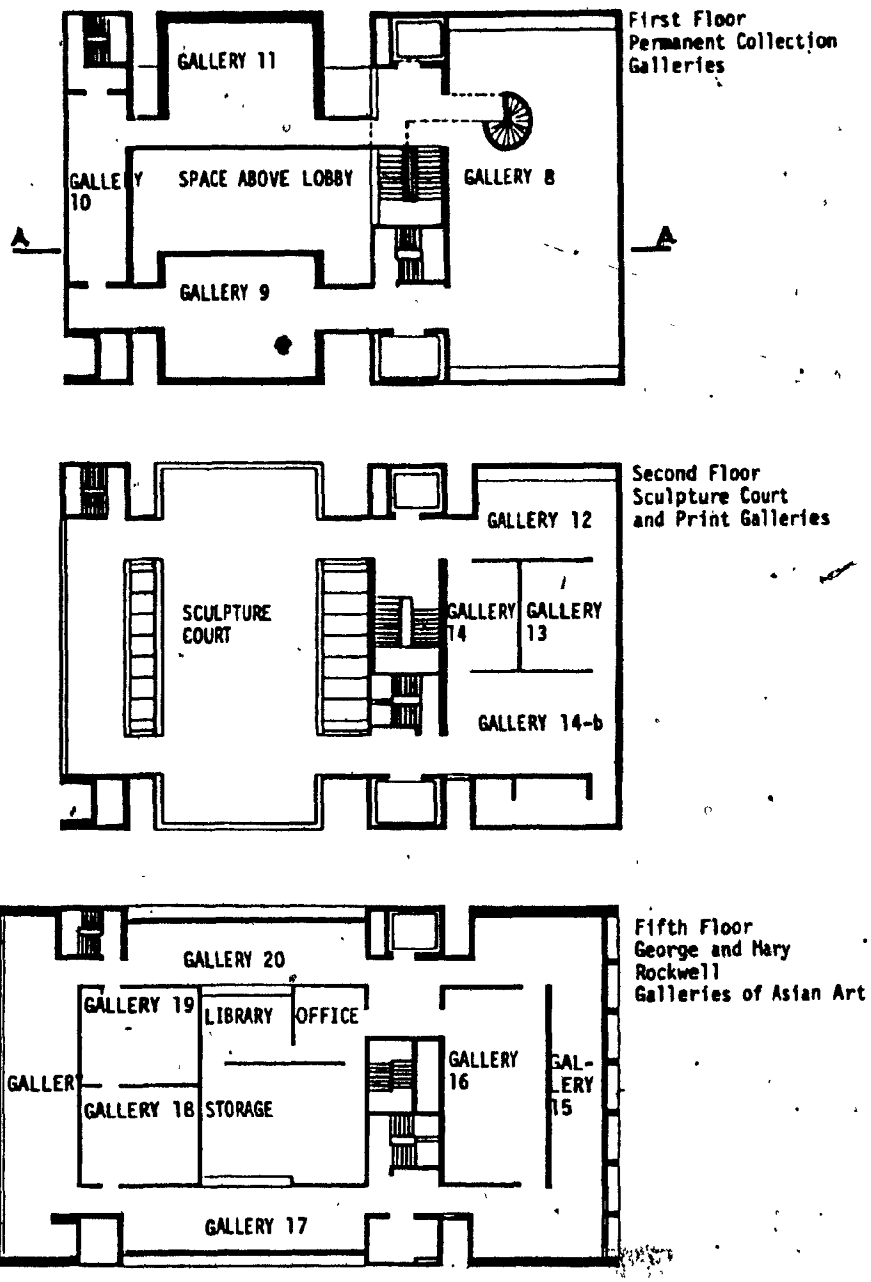



Plate 7.3, Plans

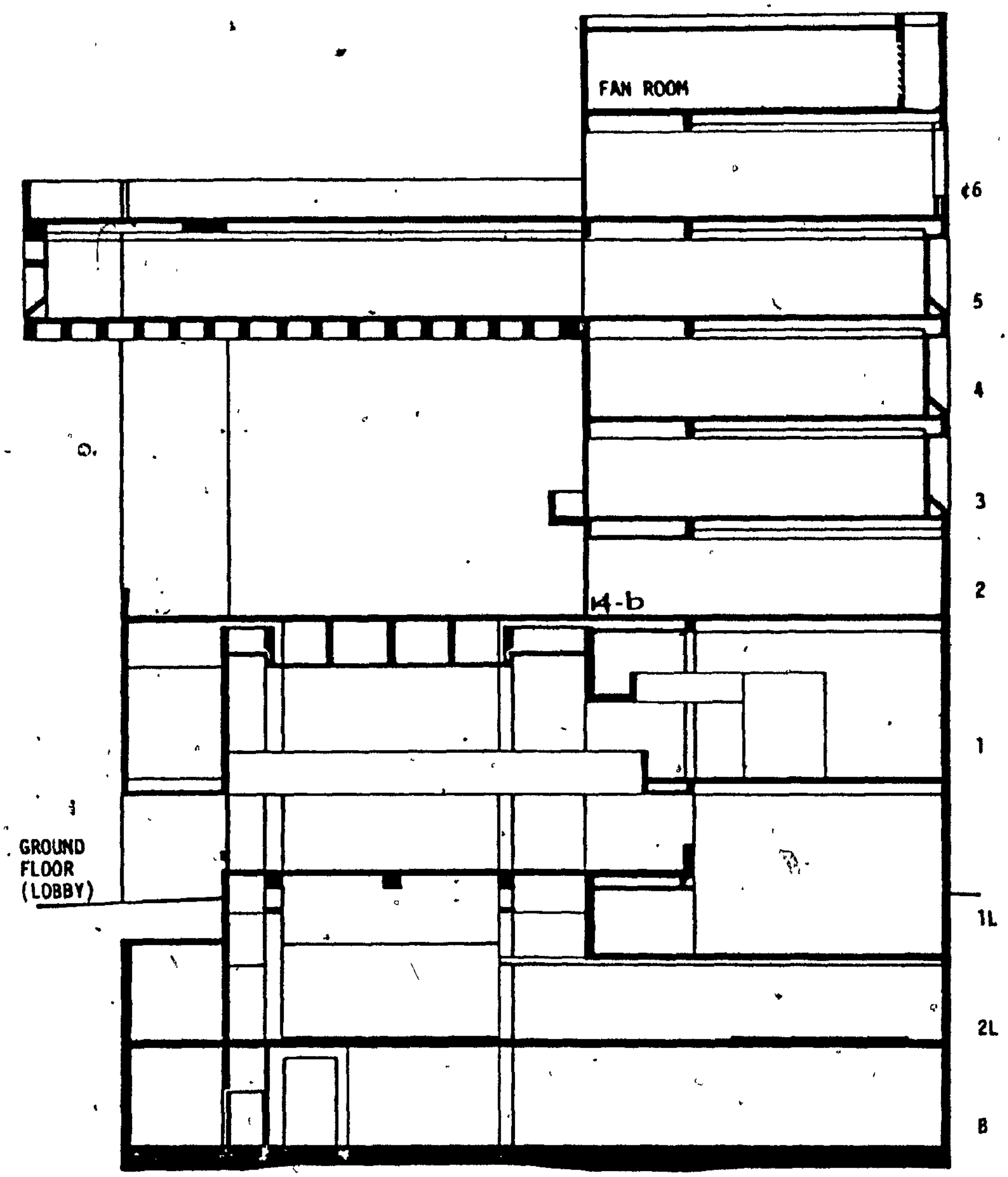
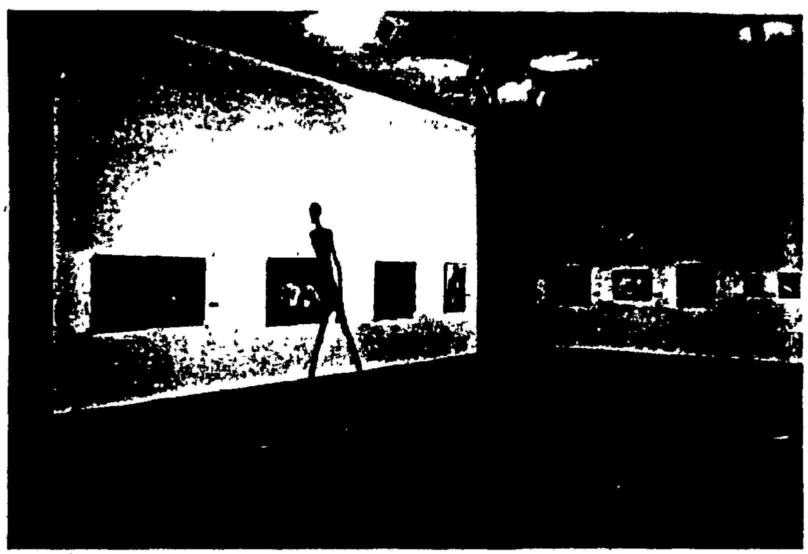



Plate 7.4. Section A.A.

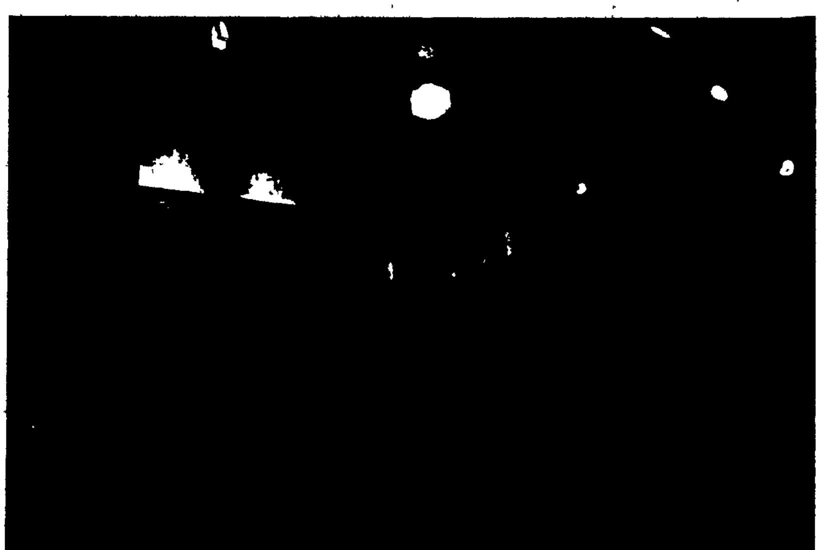
(a)



(b)

Plate 7.5, Interior views (a) Gallery 14.b;(b) Gallery 1

(c)



(d)

Plate 7.5, (c) Gallery 14; (d) Gallery 19.

**A.2 Musée D'art Contemporain, Montréal, Museum of Contemporary Art, Montreal**

In this museum large windows were installed in some galleries and transition spaces. The main staircase well is lit by a skylight from the top. The main galleries are artifically lit by track and spot lights.

The large window of gallery 3 has curtains, which are constantly drawn. The curators feel there is a pronounced lack of daylight options to light individual exhibitions. The malfunctioning of the HVAC has forced a lowering of the illuminance level to prevent overheating. The curators are also concerned about the overheating of paintings caused by incandescent sources. Since the modern artist uses many thick layers of paint, it takes a long time to dry thus heating causes cracks on the paintings (see Chapter 6 for data recorded in this museum).

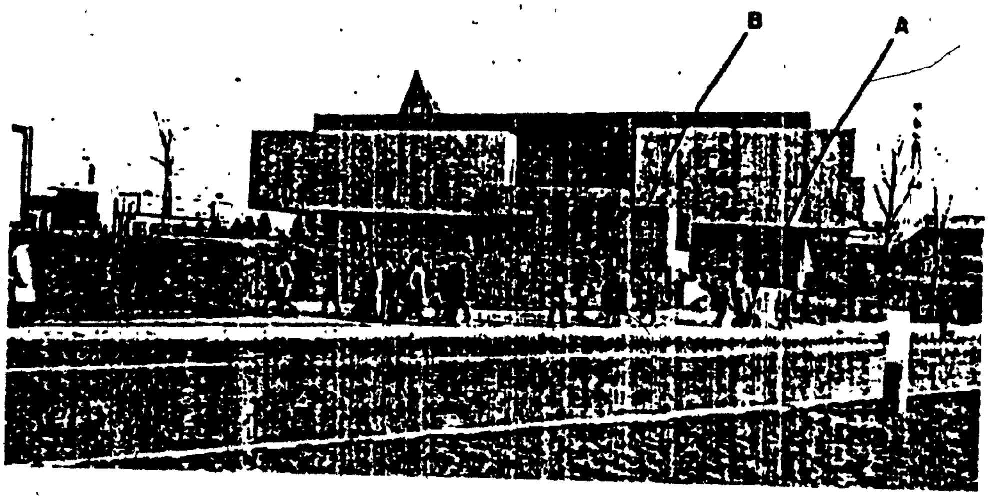
DATA SHEET

MUSEUM NAME: Musee D'art Contemporain

LOCATION: Montreal, Quebec

| NO. | SYSTEM | FACTORS | |
|---|---|---|---|
| 1. | HVAC | Exposed Ducts | ● |
| | | Integrated W/Structure | ● |
| | | Integrated W/Lighting | ● |
| 2. | CIRCULATION | Linear W. Corridors | ● |
| | | Linear WO/Corridors | □ |
| | | Transition Route | □ |
| 3. | PLANNING | Planning System | FP |
| | | Transition Space | □ |
| | | Multi Story Space | □ |
| | | Zoning | □ |
| 4. | INTERIOR | Wall System | FI |
| | | Ceiling System | FI |
| | | Finishes | FI |
| 5. | DISPLAY | 2-D, Paintings | □ |
| | | 2-D, Paper | □ |
| | | 3-D, Sculpture | □ |
| | | Case Exhibition | ● |
| | | Wall Mounted | □ |
| | | Free Standing | □ |
| 6. | ART. LIGHT | Luminaire Type | IC |
| | | Lamp Type | IC |
| | | U.V. Control | ● |

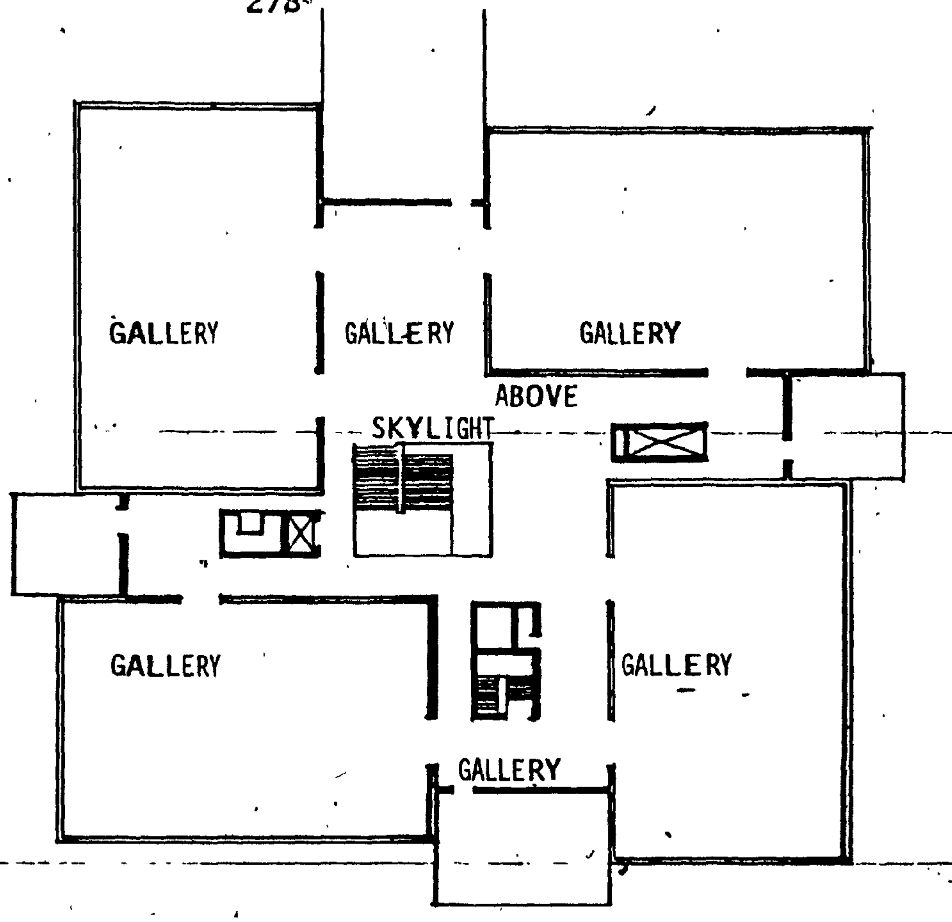
| NO. | SYSTEM | FACTORS | |
|---|---|---|---|
| 6. | ARTIFICIAL LIGHTING | Glare Control | ⊗ |
| | | Modeling | ⊗ |
| | | Colour Rendering | ○ |
| | | Colour Temperature | ◒ |
| | | Interaction W/Structure | ◒ |
| | | Heating Effect | ○ |
| | | Contrast | ⊗ |
| 7. | DAYLIGHTING | Top Lighting | ● |
| | | Side Lighting | □ |
| | | Court Lighting | □ |
| | | Clerestory | ● |
| | | Diffusing System | □ |
| | | U.V. Control | ● |
| | | Glare Control | ◒ |
| | | Modeling | ⊗ |
| | | Contrast | ⊗ |
| | | Colour Rendering | ⊗ |
| | | Interaction W/Art. | ◒ |
| | | Interaction W/Structure | ○ |
| | | Heating Effect | ◒ |
| | | | |
| | | | |



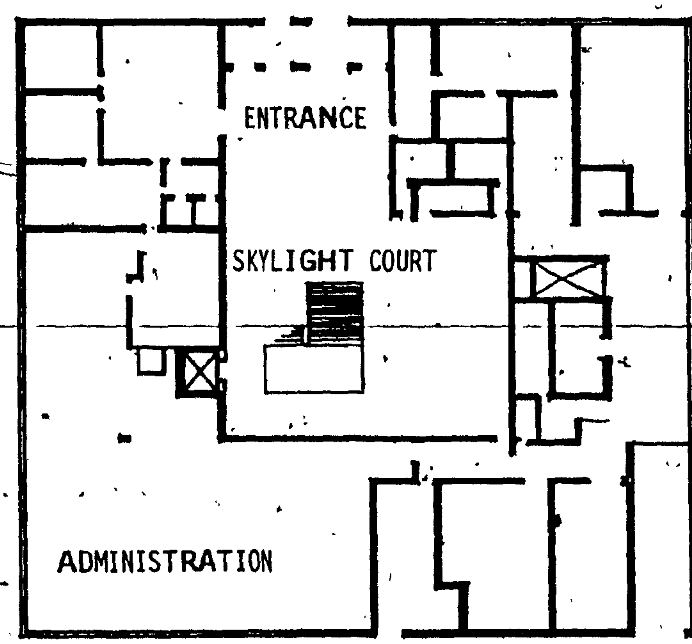

a

b

Plate 7.6. a, b, exterior views.

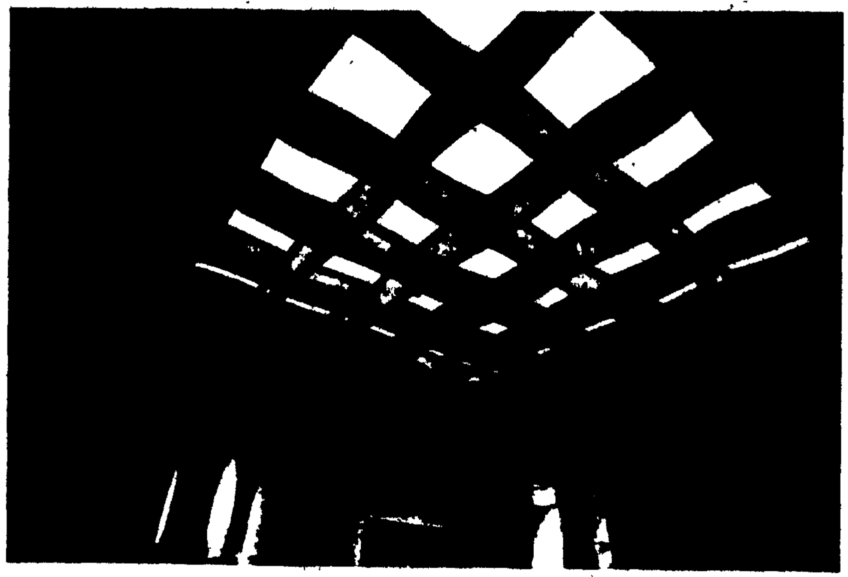



a. Second Floor




b. Ground Floor

Plate 7.7 Plans a,b



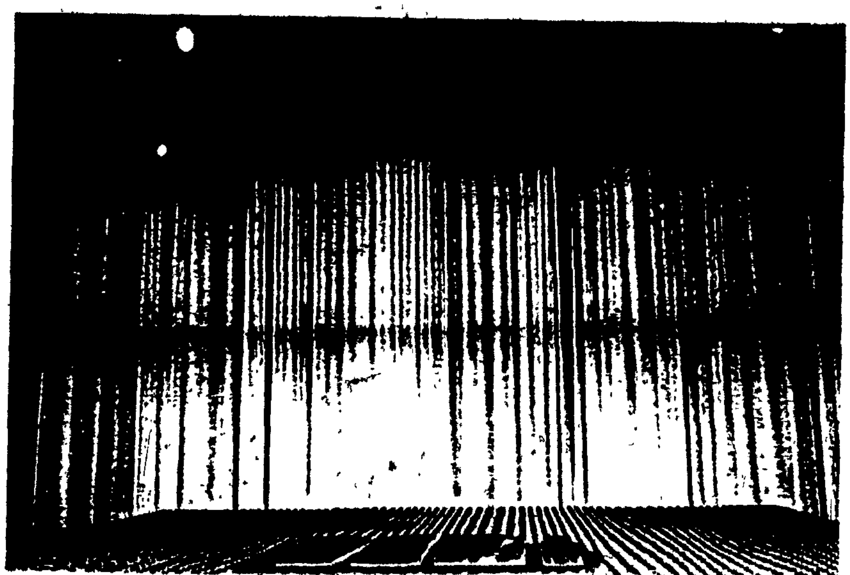


Plate 7.8, a. the skylight over the main stairs court,
b. the window with drawn curtains.

## B.1 The Museum of Contemporary Art, Tehran

Clerestory lighting is used to bring light into the galleries. All openings face Northwest, which get direct sunrays in the afternoon, especially during the summer. The luminaire designs have no mechanism to cut down the direct rays. U.V. filters are not used; overheating and very high illuminance are problems.

- The illuminance distribution is poor since the light entering the space falls directly on the painting without being reflected.

- Veiling glare is a problem, since direct sun rays are reflected from glossy surfaces of objects.

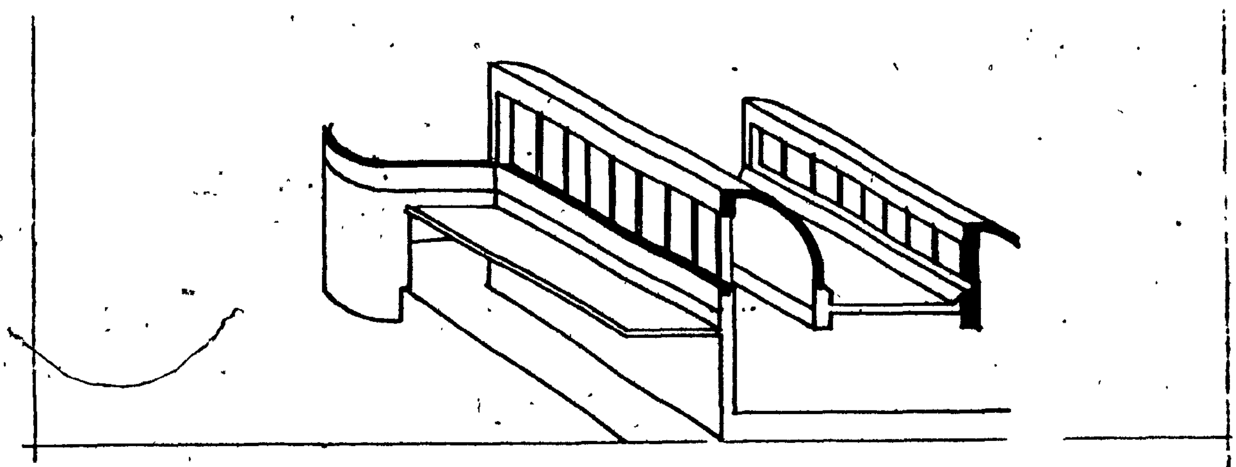


**Plate 7.9, Sectional Isometric illustration of the clerestory system facing north.**

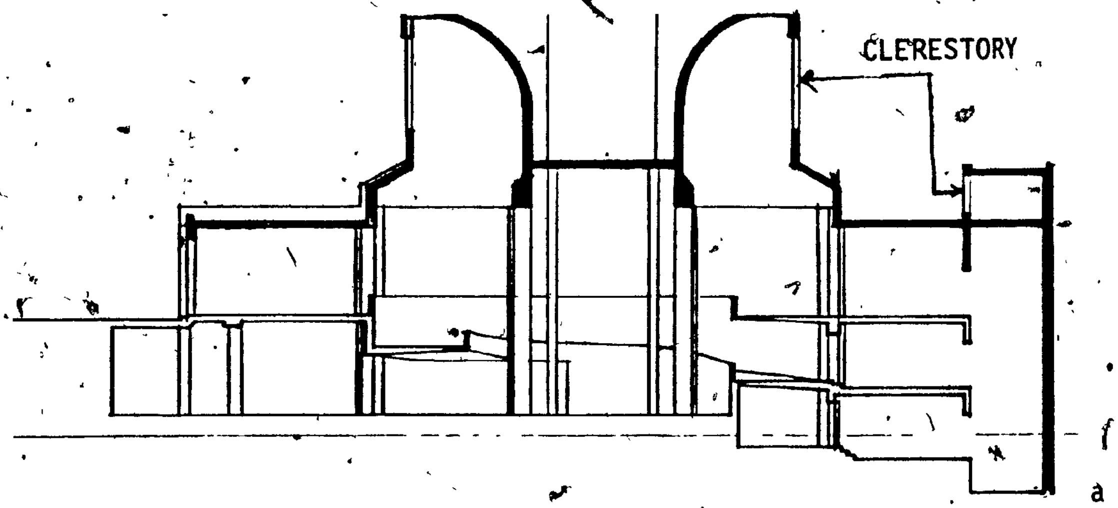
DATA SHEET

MUSEUM NAME: Museum of Contemporary Art

LOCATION: Tehran, Iran

| NO. | SYSTEM | FACTORS | |
|---|---|---|---|
| 1. | HVAC | Exposed Ducts | ● |
| | | Integrated W/Structure | ● |
| | | Integrated W/Lighting | ● |
| 2. | CIRCULATION | Linear W. Corridors | ● |
| | | Linear WO/Corridors | □ |
| | | Transition Route | □ |
| 3. | PLANNING | Planning System | FI |
| | | Transition Space | ● |
| | | Multi Story Space | □ |
| | | Zoning | □ |
| 4. | INTERIOR | Wall System | FI |
| | | Ceiling System | FI |
| | | Finishes | FI |
| 5. | DISPLAY | 2-D, Paintings | □ |
| | | 2-D, Paper | □ |
| | | 3-D, Sculpture | □ |
| | | Case Exhibition | ● |
| | | Wall Mounted | □ |
| | | Free Standing | ● |
| 6. | ART. LIGHT | Luminaire Type | IC |
| | | Lamp Type | IC |
| | | U.V. Control | ● |

| NO. | SYSTEM | FACTORS | |
|---|---|---|---|
| 6. | ARTIFICIAL LIGHTING | Glare Control | ● |
| | | Modeling | ◓ |
| | | Colour Rendering | ○ |
| | | Colour Temperature | ○ |
| | | Interaction W/Structure | ◓ |
| | | Heating Effect | □ |
| | | Contrast | ○ |
| 7. | DAYLIGHTING | Top Lighting | ● |
| | | Side Lighting | ● |
| | | Court Lighting | ● |
| | | Clerestory | □ |
| | | Diffusing System | □ |
| | | U.V. Control | ● |
| | | Glare Control | □ |
| | | Modeling | ⊗ |
| | | Contrast | ⊗ |
| | | Colour Rendering | ○ |
| | | Interaction W/Art. | ◓ |
| | | Interaction W/Structure | ◓ |
| | | Heating Effect | □ |
| | | | |
| | | | |



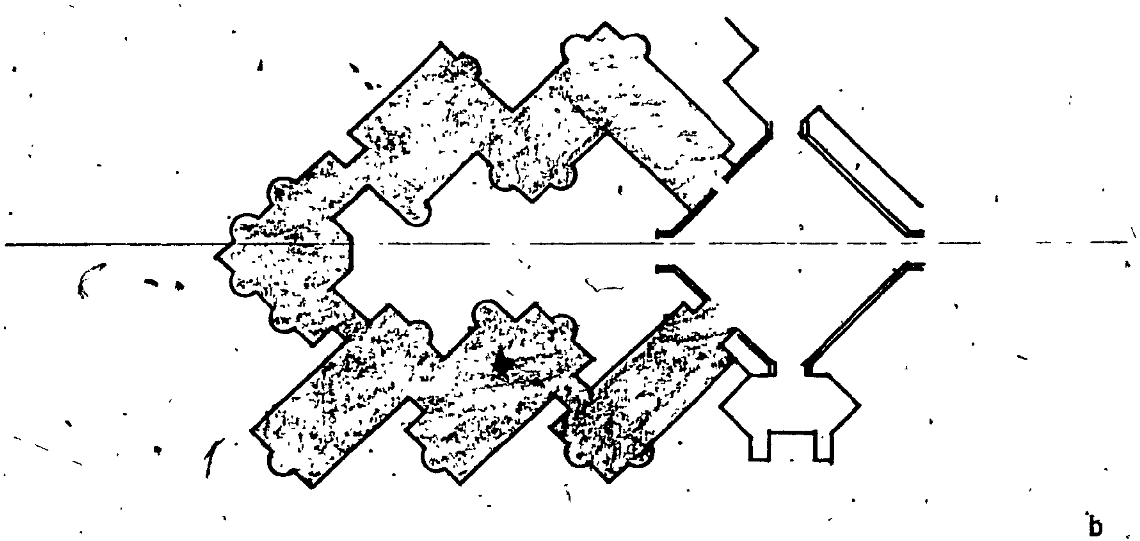




Plate 7.10, Section (a) and Floor Plan (b).

## B.2 Shiraz Art Gallery, Shiraz, Iran

The gallery is located on a hill top site. Open planning has been employed for flexibility. The clerestory luminaires are designed as an integral part of the overall form. Geometrical reflecting panels and a system of slats are used to diffuse daylight and to cut the direct sun rays in the galleries. No window luminaire is located in the gallery area.

- Illuminance distribution is excellent, since daylight is reflected through many daylight luminaires.
- Veiling glare does not exist due to ceiling height reflecting panels reducing the brightness of the luminaire.

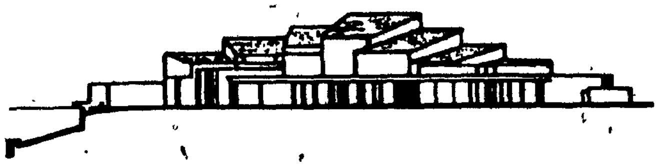
## DATA SHEET

MUSEUM NAME: Shiraz Art Gallery

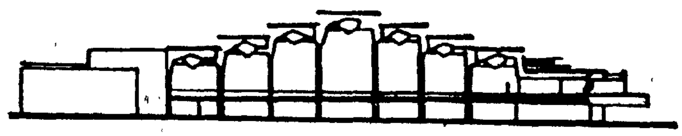
LOCATION: Shiraz, Iran

| NO. | SYSTEM | FACTORS | |
|---|---|---|---|
| 1. | HVAC | Exposed Ducts | HI |
| | | Integrated W/Structure | HI |
| | | Integrated W/Lighting | HI |
| 2. | CIRCULATION | Linear W. Corridors | ● |
| | | Linear WO/Corridors | ● |
| | | Transition Route | ● |
| 3. | PLANNING | Planning System | FP |
| | | Transition Space | ● |
| | | Multi Story Space | □ |
| | | Zoning | ● |
| 4. | INTERIOR | Wall System | FI |
| | | Ceiling System | FI |
| | | Finishes | FI |
| 5. | DISPLAY | 2-D, Paintings | HI |
| | | 2-D, Paper | HI |
| | | 3-D, Sculpture | HI |
| | | Case Exhibition | HI |
| | | Wall Mounted | HI |
| | | Free Standing | HI |
| 6. | ART. LIGHT | Luminaire Type | HI |
| | | Lamp Type | HI |
| | | U.V. Control | HI |

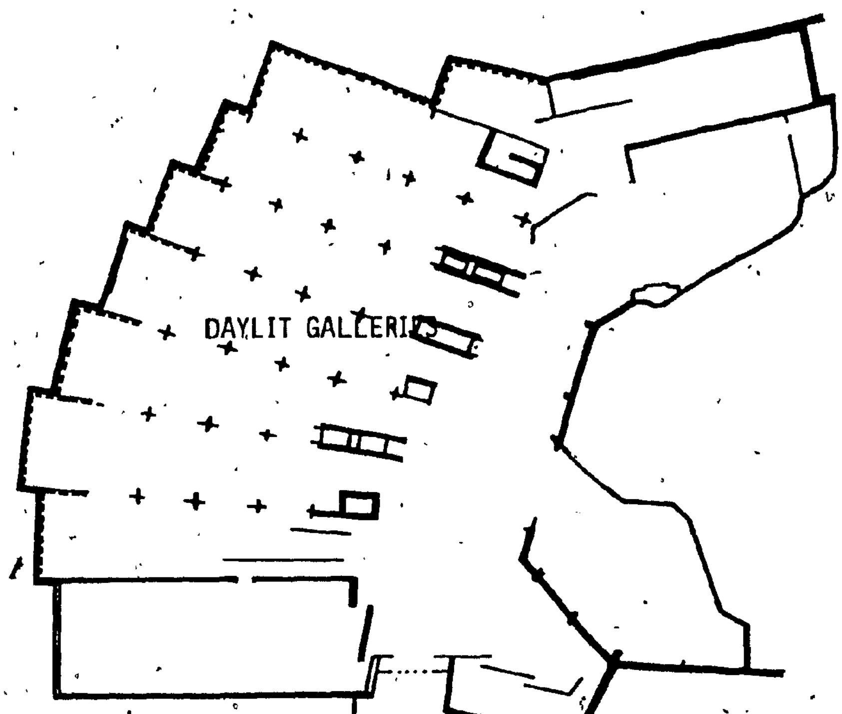
| | SYSTEM | FACTORS | |
|---|---|---|---|
| 6. | ARTIFICIAL LIGHTING | Glare Control | HI |
| | | Modeling | HI |
| | | Colour Rendering | HI |
| | | Colour Temperature | HI |
| | | Interaction W/Structure | HI |
| | | Heating Effect | HI |
| | | Contrast | HI |
| 7. | DAYLIGHTING | Top Lighting | ● |
| | | Side Lighting | □ |
| | | Court Lighting | ● |
| | | Clerestory | □ |
| | | Diffusing System | □ |
| | | U.V. Control | HI |
| | | Glare Control | □ |
| | | Modeling | ⊗ |
| | | Contrast | HI |
| | | Colour Rendering | HI |
| | | Interaction W/Art. | HI |
| | | Interaction W/Structure | HI |
| | | Heating Effect | HI |
| | | | |
| | | | |



(a) Perspective view.



(b) Section. Note the clerestory lighting system




(c) Floor Plan

Plate 7.11, Shiraz Art Gallery.

## C.1 Frederick R. Mayer Art Center, Center, New Hampshire

The simple and effective luminaire design in this gallery is a very good example of how daylight can be controlled. The illuminance level and modeling are controlled by a simple manual (automated) device. The shading system is comprised of fabric leaves hung the length of each skylight from the uppermost rafter bar. The fabrics are moved and controlled through a shaft system running at the bottom of the skylight.

The key in illuminance control is the quality and number of fabrics. A model was built to study the lighting effect and to experiment with different qualities of interior finishes. The effect of the illuminated skylight from the interior at night time was also studied. It was through the model study that the architect and curator could finalize the quality of fabric to be used.

Outermost leaves of fabrics are of grey woven fiberglass, trasmitting 4% light; the innermost leaves are 100% light blocking white - coated fiberglass. Light is diffused through the skylight and reflected from leaves in a vertical position. The position of the fabrics, one on one side and three on the other, or all four on one side create the flexibility for modeling. An U.V. filter, 0.06" Polyvinyl Butyral (PUB) resin sheeting is sandwiched between two layers of glass.

## DATA SHEET

MUSEUM NAME: Frederick R. Mayer Art Center

LOCATION: New Hampshire

| NO. | SYSTEM | FACTORS | |
|---|---|---|---|
| 1. | HVAC | Exposed Ducts | ● |
| | | Integrated W/Structure | ● |
| | | Integrated W/Lighting | □ |
| 2. | CIRCULATION | Linear W. Corridors | ● |
| | | Linear WO/Corridors | □ |
| | | Transition Route | □ |
| 3. | PLANNING | Planning System | |
| | | Transition Space | □ |
| | | Multi Story Space | ● |
| | | Zoning | ● |
| 4. | INTERIOR | Wall System | FI |
| | | Ceiling System | CH |
| | | Finishes | CH |
| 5. | DISPLAY | 2-D, Paintings | ● |
| | | 2-D, Paper | □ |
| | | 3-D, Sculpture | ● |
| | | Case Exhibition | ● |
| | | Wall Mounted | □ |
| | | Free Standing | ● |
| 6. | ART. LIGHT | Luminaire Type | IC |
| | | Lamp Type | IC |
| | | U.V. Control | ● |

| | SYSTEM | FACTORS | |
|---|---|---|---|
| 6. | ARTIFICIAL LIGHTING | Glare Control | □ |
| | | Modeling | ○ |
| | | Colour Rendering | ○ |
| | | Colour Temperature | ○ |
| | | Interaction W/Structure | ⊗ |
| | | Heating Effect | ◒ |
| | | Contrast | ⊗ |
| 7. | DAYLIGHTING | Top Lighting | ○ |
| | | Side Lighting | ● |
| | | Court Lighting | ● |
| | | Clerestory | ● |
| | | Diffusing System | ○ |
| | | U.V. Control | ○ |
| | | Glare Control | ○ |
| | | Modeling | ○ |
| | | Contrast | ○ |
| | | Colour Rendering | ○ |
| | | Interaction W/Art. | ○ |
| | | Interaction W/Structure | ○ |
| | | Heating Effect | ● |
| | | | |
| | | | |

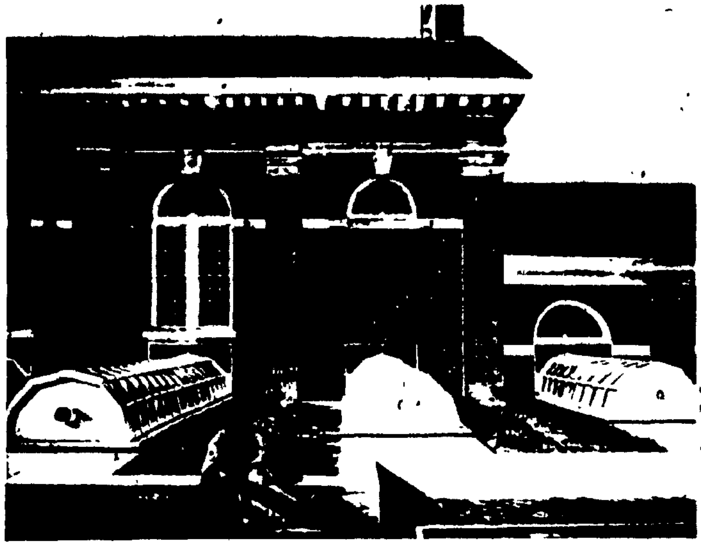


Plate 7.12, Exterior views of the skylight system.

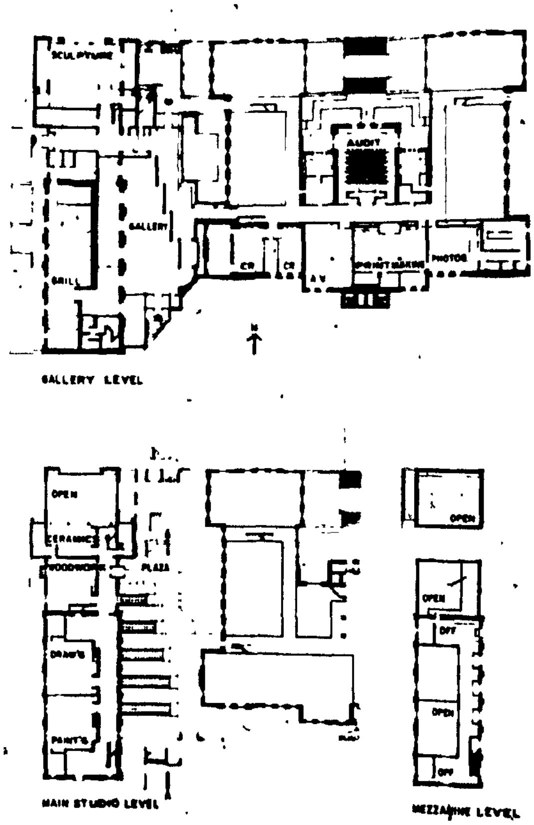
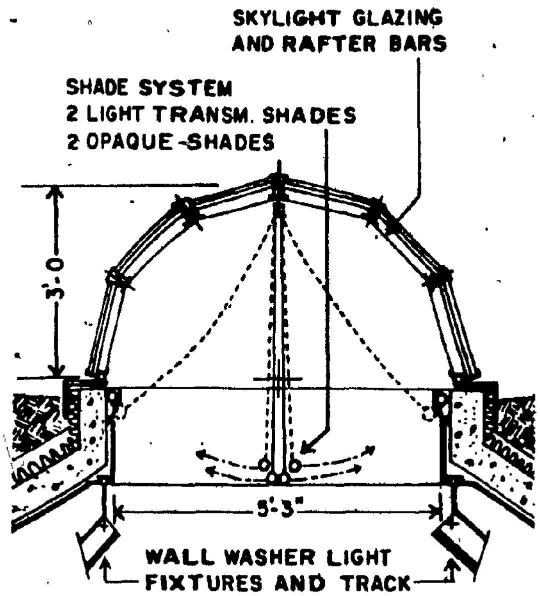
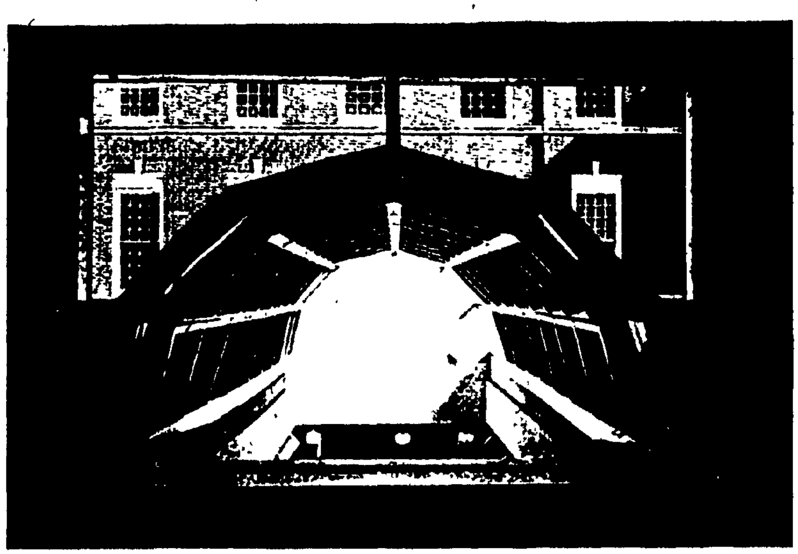



Plate 7.13, Plans of the gallery level and the main studio level. Note the skylight on the plaza.

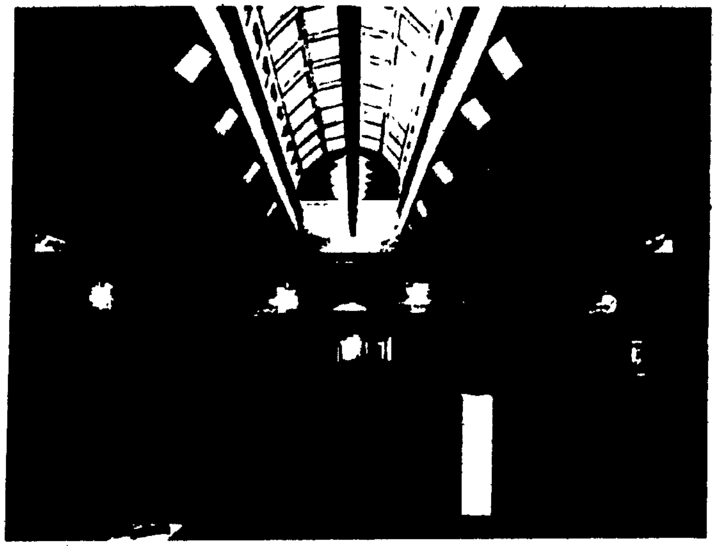



(a)



(b)

Plate 7.14, Section through the skylight system. (a) Details; (b) View.



(a)

(b)

Plate 7.15, The interior views of the gallery. (a) shades open; (b) shades closed.

## C.2 The Menil Collection, Houston, Texas

Daylight in conjunction with the structural system has generated the ceiling system. The advancement of technology was to be expressed through the design and the ceiling system was designed to express this concept. An extensive model study was undertaken in order to examine the problems and possibilities of the idea. Illuminance readings were taken with a number of opening options. Artificial lighting was studied with models too. The final project has employed new technology in the creation of a required visual environment as well as a structural system in line with function and expression.

- Daylight is used for ambient lighting as well as task lighting, whereas artificial lighting is used for modeling.

- Illuminance distribution is excellent, since reflecting panels distribute the diffused light, as well as create the required contrast.

- Veiling glare does not exist, since no bright source is located in the glare zone and exaggerated contrasts are avoided.

# DATA SHEET

MUSEUM NAME: The Menil Collection

LOCATION: Houston, Texas

| NO. | SYSTEM | FACTORS | |
|---|---|---|---|
| 1. | HVAC | Exposed Ducts | ● |
| | | Integrated W/Structure | □ |
| | | Integrated W/Lighting | □ |
| 2. | CIRCULATION | Linear W. Corridors | □ |
| | | Linear WO/Corridors | ● |
| | | Transition Route | □ |
| 3. | PLANNING | Planning System | FI |
| | | Transition Space | □ |
| | | Multi Story Space | ● |
| | | Zoning | ⊗ |
| 4. | INTERIOR | Wall System | FI |
| | | Ceiling System | FI |
| | | Finishes | NI |
| 5. | DISPLAY | 2-D, Paintings | □ |
| | | 2-D, Paper | □ |
| | | 3-D, Sculpture | NI |
| | | Case Exhibition | ● |
| | | Wall Mounted | □ |
| | | Free Standing | □ |
| 6. | ART. LIGHT | Luminaire Type | IC |
| | | Lamp Type | IC |
| | | U.V. Control | ● |

| | SYSTEM | FACTORS | |
|---|---|---|---|
| 6. | ARTIFICIAL LIGHTING | Glare Control | ○ |
| | | Modeling | ○ |
| | | Colour Rendering | ⊗ |
| | | Colour Temperature | ⊗ |
| | | Interaction W/Structure | ○ |
| | | Heating Effect | ◓ |
| | | Contrast | ○ |
| 7. | DAYLIGHTING | Top Lighting | □ |
| | | Side Lighting | ● |
| | | Court Lighting | ● |
| | | Clerestory | ● |
| | | Diffusing System | ○ |
| | | U.V. Control | ⊗ |
| | | Glare Control | ○ |
| | | Modeling | ○ |
| | | Contrast | ○ |
| | | Colour Rendering | ⊗ |
| | | Interaction W/Art. | ○ |
| | | Interaction W/Structure | ○ |
| | | Heating Effect | ○ |
| | | | |
| | | | |

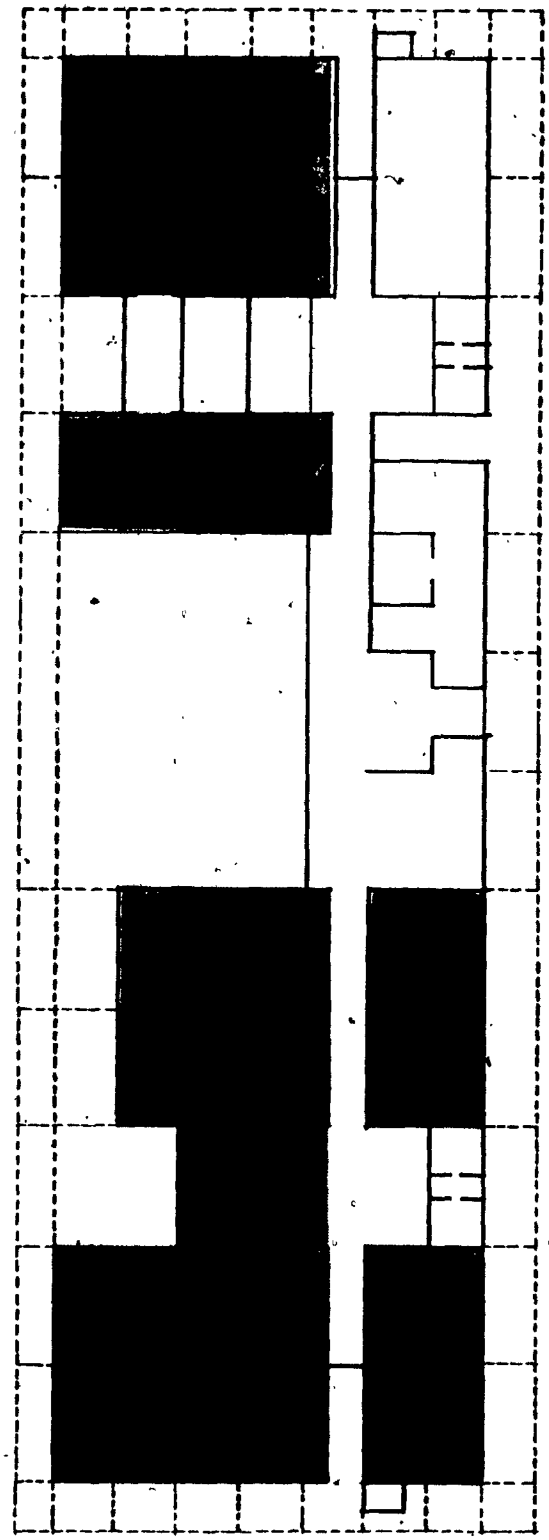
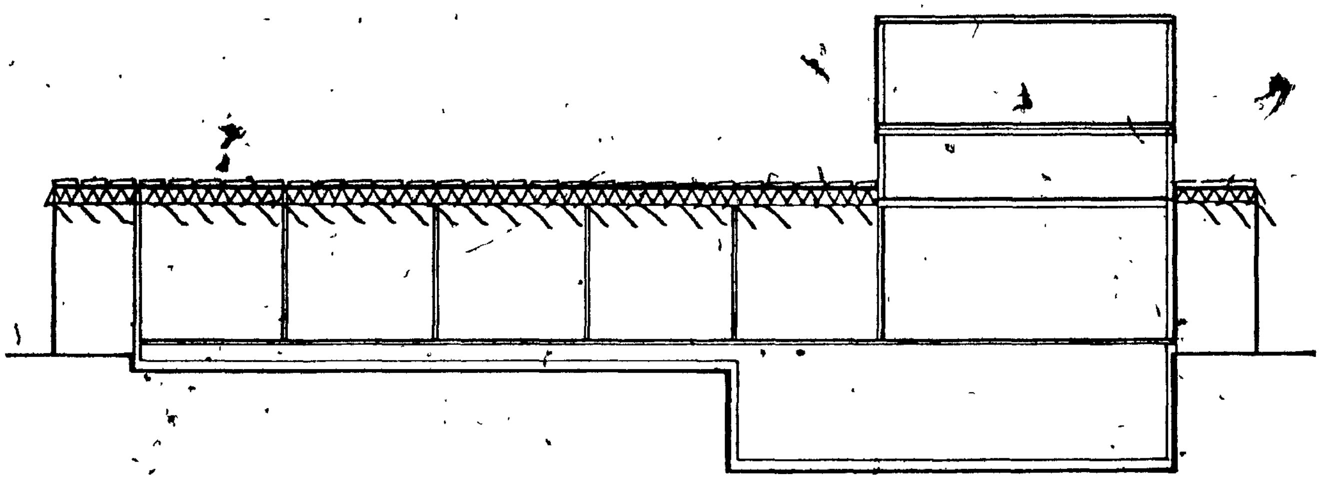
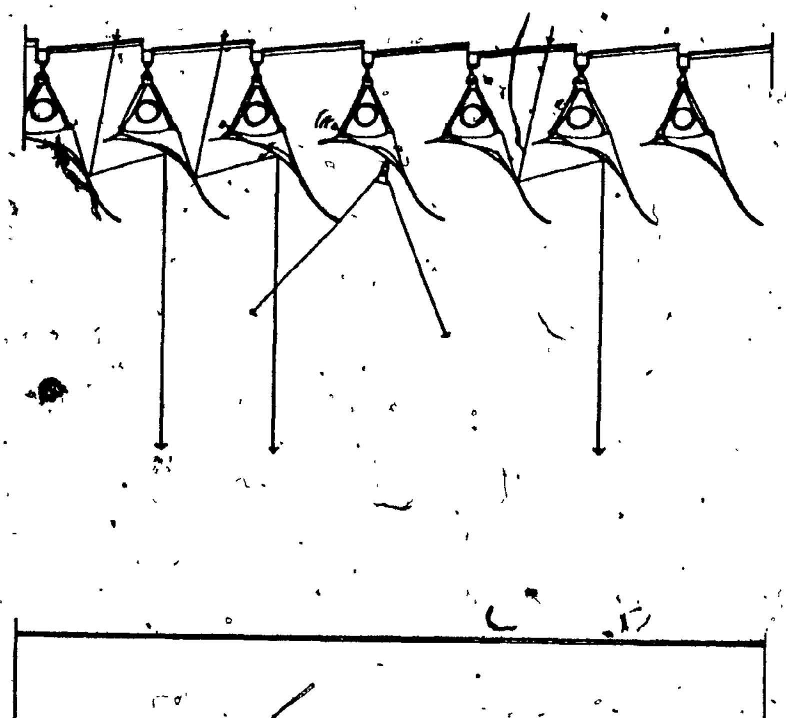


Plate 7.16, Floor plan. The gallery areas are shaded.



(a)



(b)

Plate 7.17, Sections; (a) Section through the gallery area.
(b) Section through the ceiling system.

## C.3 Yale Center for British Art

Daylight is used to extremes as exhibition and ambient light in this gallery. Daylight enters in most gallery spaces through skylights, courtyard and windows. The luminaires have been designed in order to avoid glare. The louvre system for skylights, the blind system for both the openings into the court and the windows have all been designed to eliminate high contrast, glare, and damage due to light for conservation. The color temperature is approximately 5000 °K which is the result of mixing daylight with incandescent light. The high space, the continuity of spaces and the visual environment are some of the strong concepts that have created a museum with the viewer in mind as well as the works of art.

- The illuminance distribution is excellent, which is due to modular planning and the skylight system.

- Veiling glare does not exist. This is due to the ceiling height and deep structural system.

- The planning system has provided for transition areas and zoning of activities.

- Excellent color response is due to the mixture of daylight and spot lights.

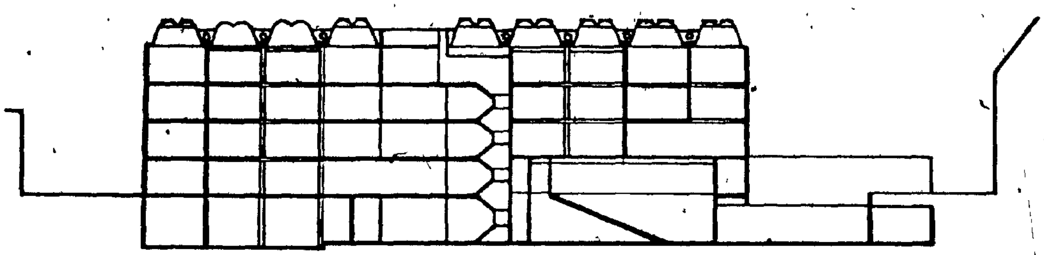
# DATA SHEET

MUSEUM NAME: Yale Center for British Art

LOCATION: New Haven

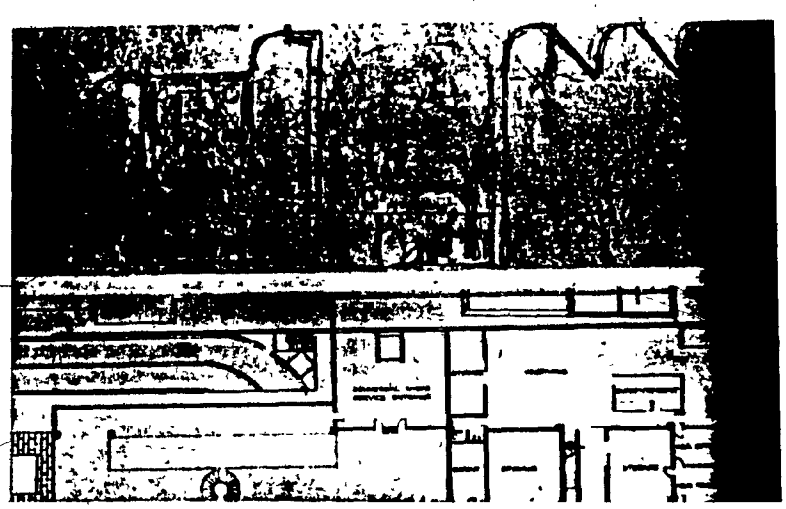
| NO. | SYSTEM | FACTORS | |
|---|---|---|---|
| 1. | HVAC | Exposed Ducts | ● |
| | | Integrated W/Structure | ○ |
| | | Integrated W/Lighting | ○ |
| 2. | CIRCULATION | Linear W. Corridors | ● |
| | | Linear WO/Corridors | □ |
| | | Transition Route | □ |
| 3. | PLANNING | Planning System | FI |
| | | Transition Space | □ |
| | | Multi Story Space | □ |
| | | Zoning | □ |
| 4. | INTERIOR | Wall System | FI |
| | | Ceiling System | FI |
| | | Finishes | FI |
| 5. | DISPLAY | 2-D, Paintings | □ |
| | | 2-D, Paper | □ |
| | | 3-D, Sculpture | □ |
| | | Case Exhibition | ● |
| | | Wall Mounted | □ |
| | | Free Standing | □ |
| 6. | ART. LIGHT | Luminaire Type | IC |
| | | Lamp Type | IC |
| | | U.V. Control | ● |

| | SYSTEM | FACTORS | |
|---|---|---|---|
| 6. | ARTIFICIAL LIGHTING | Glare Control | ⊗ |
| | | Modeling | ⊗ |
| | | Colour Rendering | ◒ |
| | | Colour Temperature | ⊖ |
| | | Interaction W/Structure | ⊗ |
| | | Heating Effect | ● |
| | | Contrast | ⊗ |
| 7. | DAYLIGHTING | Top Lighting | □ |
| | | Side Lighting | ● |
| | | Court Lighting | □ |
| | | Clerestory | ● |
| | | Diffusing System | ○ |
| | | U.V. Control | ○ |
| | | Glare Control | ○ |
| | | Modeling | ○ |
| | | Contrast | ○ |
| | | Colour Rendering | ○ |
| | | Interaction W/Art. | ○ |
| | | Interaction W/Structure | ○ |
| | | Heating Effect | ○ |
| | | | |
| | | | |



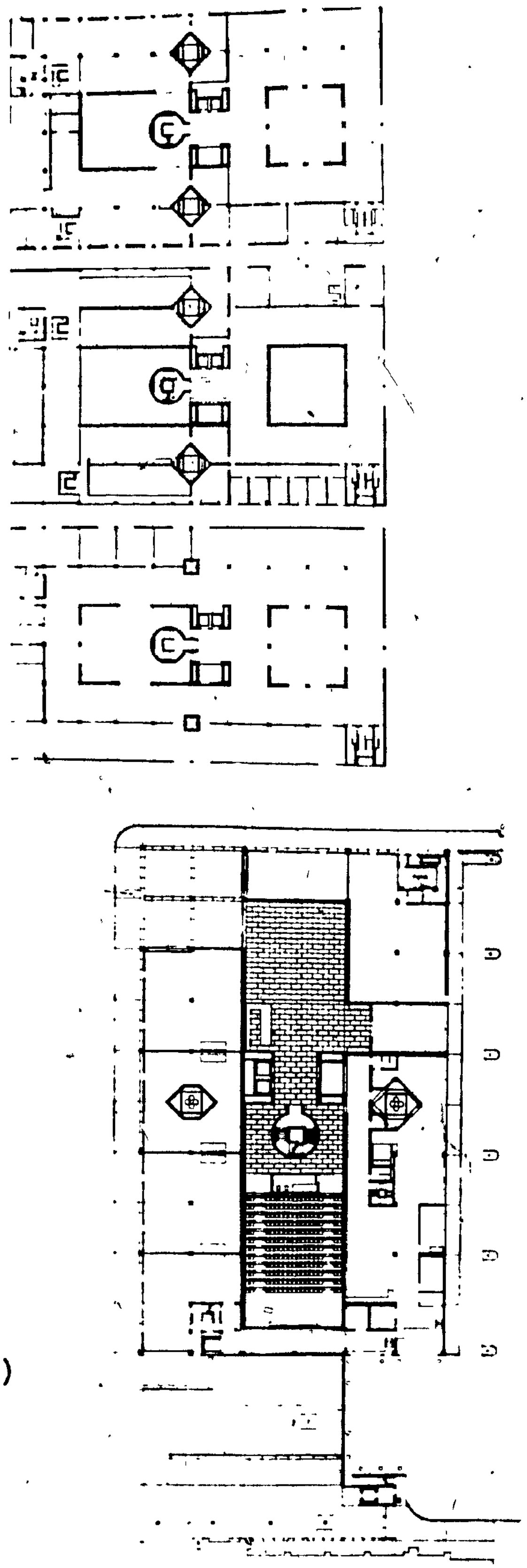
(a)





(b)

Plate 7.18, (b) the Architect's sketches of skylight system design; (a) section through the galleries and court.



(a)

(b)

(c)

(d)

Plate 7.19, (a) Third floor plan, the main exhibition area.

(b) Second floor plan; library stack and exhibition galleries for water colours, drawings and prints.

(c) First floor plan; libraries and special exhibition galleries.

(d) Ground floor plan; entrance, shops and ante-room to a lecture room extending into the basement.

(a)

(b)

Plate 7.20, (a) Interior view of gallery looking into the courtyard on left. (b) Interior view of the gallery looking in the skylight court.

## C.4 The Museum of Art, Portland, Maine

The Payson addition to the Portland Museum of Art has been recently completed. This Museum is one of the contemporary museums that has strongly considered using daylight. Daylight has played an important role commencing from the early stages of the design process. The site, the surrounding buildings and the existing part of the museum have all been considered in planning and massing of the building, but the need and desire for daylight have influenced the generation of forms. The use of daylight was recommended by the museum board and the architect made use of a lighthouse geometry, a local symbol, as a daylight luminaire. The Dulwich Gallery (Chapter 1) was used as a precedent for the creation of a visual environment.

A clerestory skylight in an octagonal shape is used. The vertical openings are sources of light. Blinds are pulled down at all times. Light is reflected and diffused by the planes of the skylight vault and are directed towards the works of art and the ambient lighting. As indicated in plans and sections, the modular planning and stepping down from each module create the opportunity for installing skylights in most (total of 10) galleries. However, mistakes do get repeated, as in the Johnson Museum (by the same firm). The openings to the square on the 2nd and 3rd floors create a bright source of light adjacent to the gallery walls which cause problems with adaptation and glare. The architect is trying to provide views to the outside, but at the expense of creating discomfort for the viewer. One has to move from a very bright area to a dimly lit gallery, without having the time and space for adaptation.

Openings are introduced at the end of circulation spaces. During the time of visit, these openings were not glazed yet and were very strong sources of glare, at the end of dark corridors. At the time of discussion with the lighting designers, it was stated that tinted glass should be used in order to cut the glare. The windows on the second floor are very small. They were cut down to the minimum size in order to curtail the contrast with the surrounding walls, but have created a higher source of glare. U.V. filters are used but the blinds are not adjustable. As part of the design process 2 models were built, one at 1/50 scale and one full size, in order to study the lighting performance. As the architect states, two fundamental elements of architecture, space and light, are put in the services of the museum visual environment.

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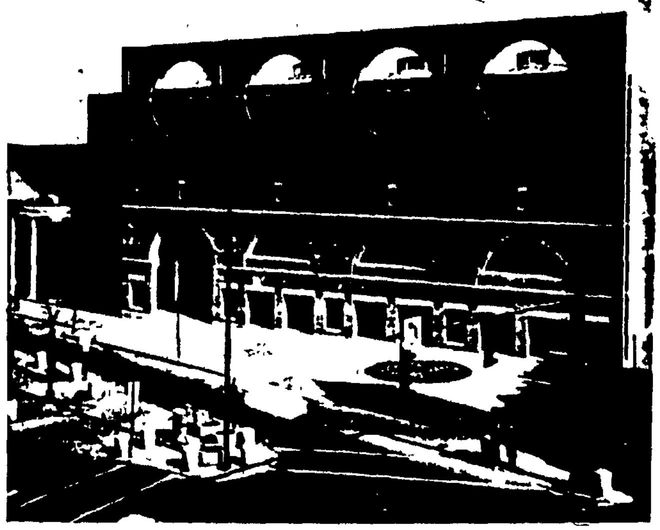


(a)

(b)

Plate 7.21 Exterior views(a) front facade (b) the side-view, windows located at end of corridors, source of glare

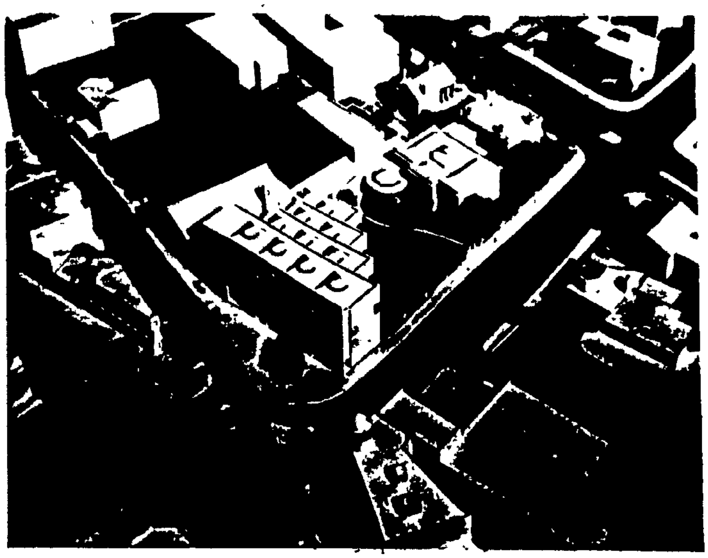


Plate 7.22, General view of museum, scale model.

Plate 7.23, The stepping down design, permits daylight to all galleries.

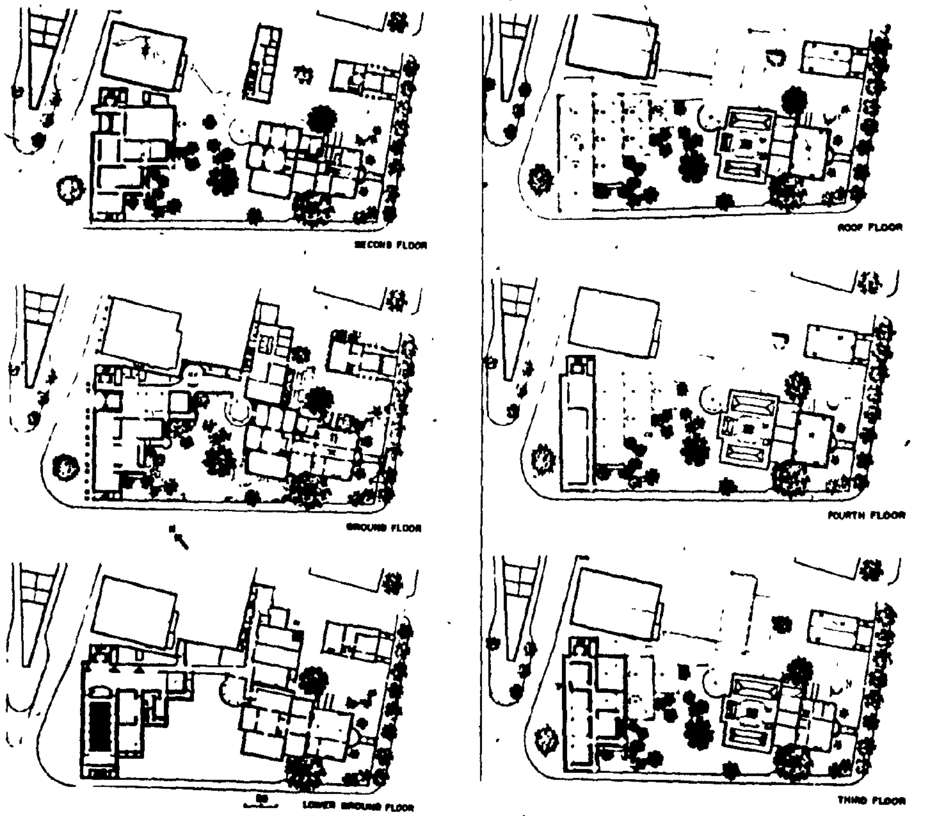



Plate 7.24, Floor Plans.

Plate 7.25, Interior views of skylit galleries.

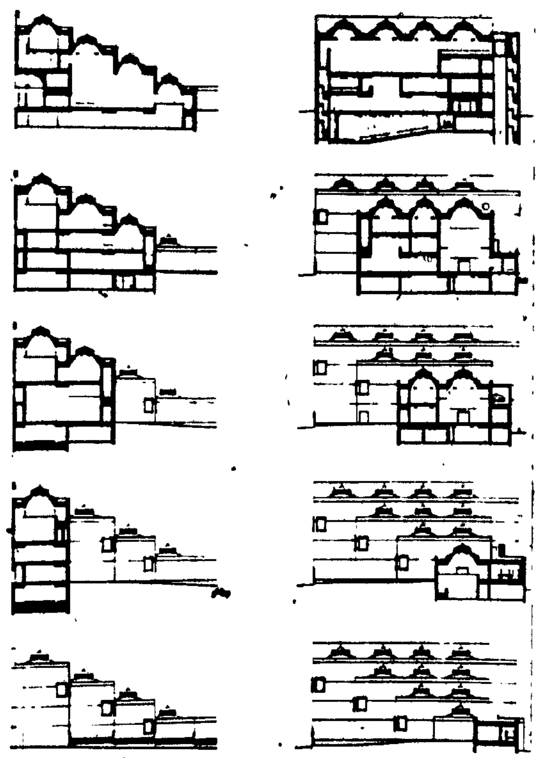


Plate 7.26, Sections throughout the building.

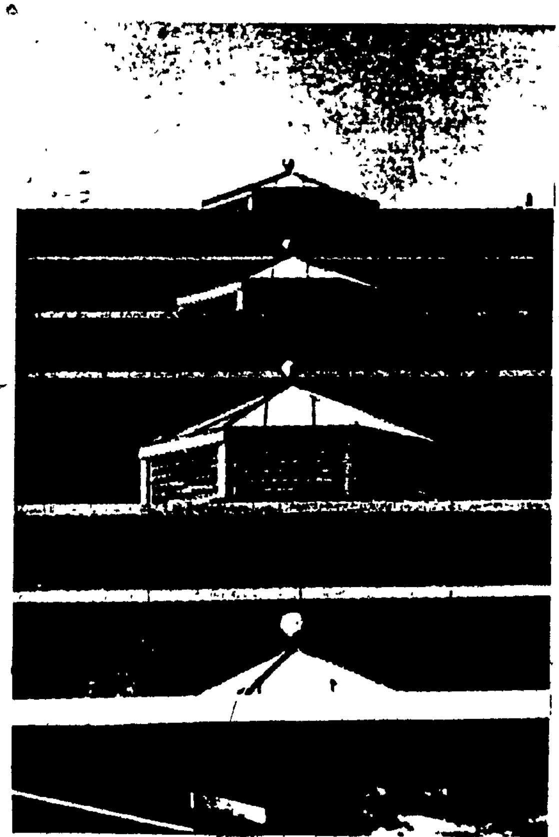


Plate 7.27, Exterior view of the skylights, note the louvre system.

## C.5 Art Gallery of Ontario

Sculpture galleries are the only daylit galleries in this Art Museum. Two skylight systems are employed to bring light into the galleries. One is the Modular top lighting system, located in the Moore Sculpture Center. The second is the Saw Tooth System in Gallery 3, New Canadian Contemporary Art Gallery, as indicated on the plan. In the Moore Gallery the exhibition design and finishes are in contradiction with the lighting design. The horizontal exhibitions, greyness of the stone and flat lighting have created a very cold, grave yard feeling space. Modeling in exhibition design and lighting has been ignored, which is very important to all exhibitions, particularly sculpture galleries.

The finishes and the modeling created by the Saw Tooth Skylight System have created a pleasant environment in Gallery 3. The use of carpeting on the floors and the introduction of color and contrast have added to the visual environment.

Clerestory lighting is used to light some of the circulation spaces. Works of art are installed in these areas. This lighting luminaire system causes over heating and high illuminance which are dangerous to the works of art. Controlling both the light and the blinds is very difficult as once a blind is broken, light flows in for a long time, before the blind is repaired.

Ultra-violet filters are used with all daylit luminaires. The artificially lit galleries have fluorescent lights for ambient lighting. These are installed in the pre-cast overhead beams and are protected with ultra-violet shielding. Spot incandescent track lighting is used for task lighting.

DATA SHEET

MUSEUM NAME: Art Gallery of Ontario

LOCATION: Toronto, Ontario

| NO. | SYSTEM | FACTORS | |
|---|---|---|---|
| 1. | HVAC | Exposed Ducts | ● |
| | | Integrated W/Structure | □ |
| | | Integrated W/Lighting | □ |
| 2. | CIRCULATION | Linear W. Corridors | ● |
| | | Linear WO/Corridors | □ |
| | | Transition Route | □ |
| 3. | PLANNING | Planning System | FI |
| | | Transition Space | □ |
| | | Multi Story Space | □ |
| | | Zoning | □ |
| 4. | INTERIOR | Wall System | FI |
| | | Ceiling System | FI |
| | | Finishes | CH |
| 5. | DISPLAY | 2-D, Paintings | □ |
| | | 2-D, Paper | □ |
| | | 3-D, Sculpture | □ |
| | | Case Exhibition | □ |
| | | Wall Mounted | □ |
| | | Free Standing | □ |
| 6. | ART. LIGHT | Luminaire Type | FL |
| | | Lamp Type | FL |
| | | U.V. Control | NI |

| NO. | SYSTEM | FACTORS | |
|---|---|---|---|
| 6. | ARTIFICIAL LIGHTING | Glare Control | ⊗ |
| | | Modeling | ⊗ |
| | | Colour Rendering | ⊗ |
| | | Colour Temperature | ◒ |
| | | Interaction W/Structure | ◒ |
| | | Heating Effect | ⊗ |
| | | Contrast | ⊗ |
| 7. | DAYLIGHTING | Top Lighting | □ |
| | | Side Lighting | ● |
| | | Court Lighting | ● |
| | | Clerestory | □ |
| | | Diffusing System | ⊗ |
| | | U.V. Control | ○ |
| | | Glare Control | ◒ |
| | | Modeling | ◒ |
| | | Contrast | ◒ |
| | | Colour Rendering | ◒ |
| | | Interaction W/Art. | ⊗ |
| | | Interaction W/Structure | ⊗ |
| | | Heating Effect | ◒ |
| | | | |
| | | | |

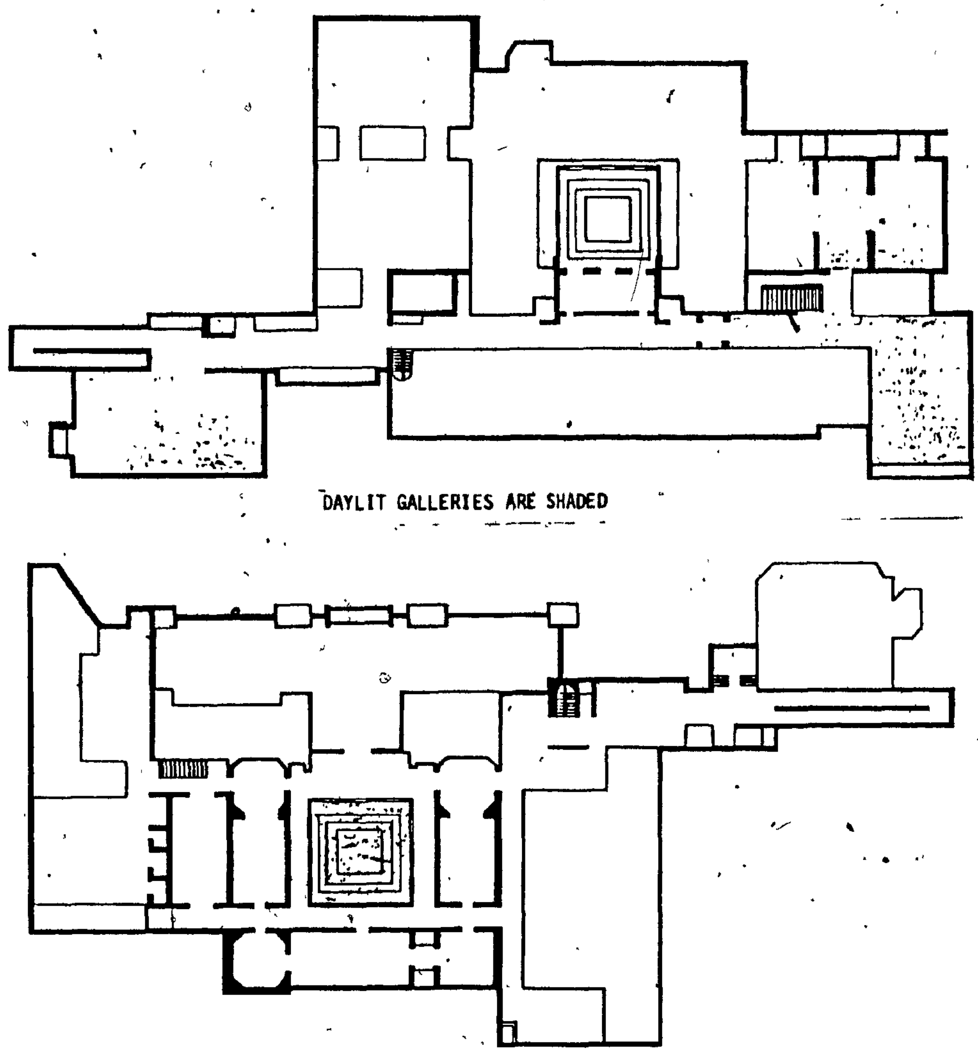



Plate 7.2.8, Floor plans, (a) 1st floor (b) second floor.

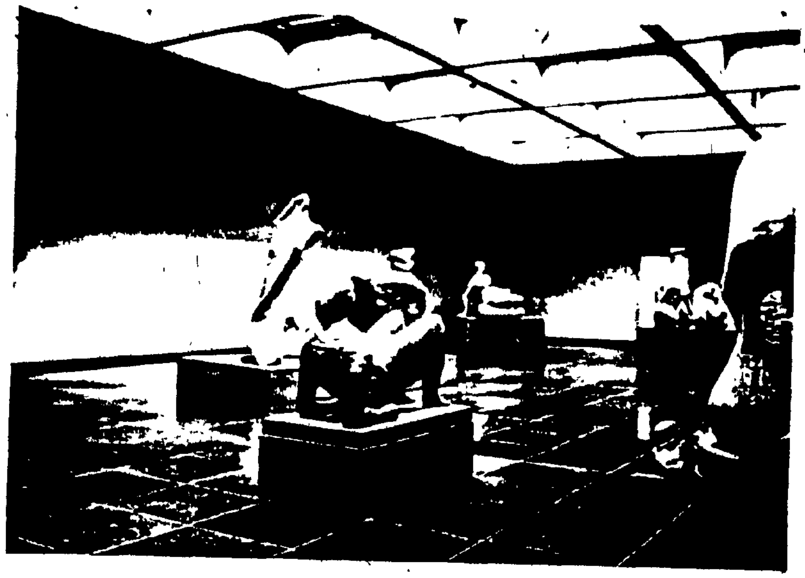


Plate 7.2.9, View of Moore sculpture center - skylight

Plate 7.30, Clerestory lit space, note the glare source due to broken blinds.

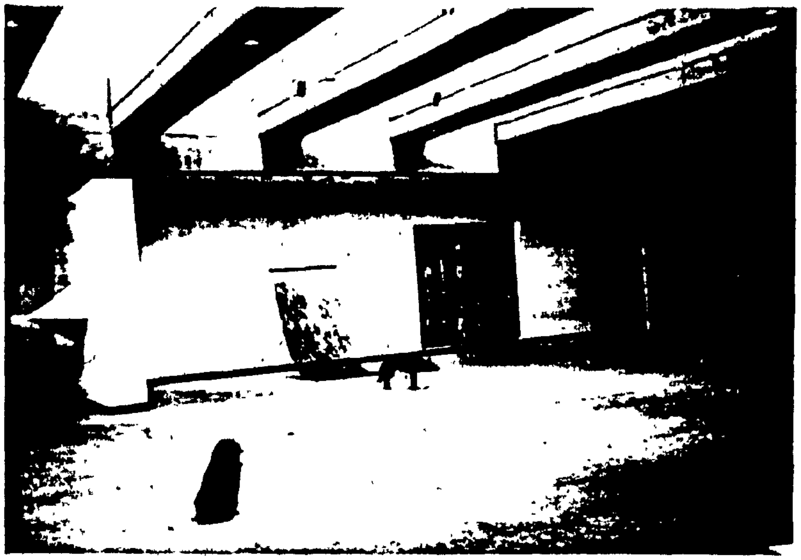


Plate 7.3, New Canadian Contemporary Gallery, sky lit.

Plate 7.32, Skylight system detail, see Chapter (5) for concept.

## C.6 American Art Galleries of Metropolitan Museum of Fine Arts

In the American wing the skylight system is designed in order to create even ambient lighting. Daylight is diffused through a laylight system. Incandescent lights, installed behind the laylight system, are the primary source of task lighting. The laylight system causes a feeling of flat lighting, lacking contrast and modeling. The continuity of the lighting system is criticised for its monotany. The color temperature is low for a daylit gallery which is due to the spot lights.

- Illuminance distribution is good. Lack of contrast and modeling is a problem.

- Veiling glare does not exist since light is diffused and transmitted through the laylight system.

- Overheating is a problem due to the large area of skylight, as was expressed by the gallery director.

- Free planning is used with partitioning of galleries, but the laylight system is continuous, thus lacking contrast and change.

# DATA SHEET

MUSEUM NAME: American Art Galleries of Metropolitan Museum of Art

LOCATION: New York

| NO. | SYSTEM | FACTORS | |
|---|---|---|---|
| 1. | HVAC | Exposed Ducts | ● |
| | | Integrated W/Structure | □ |
| | | Integrated W/Lighting | □ |
| 2. | CIRCULATION | Linear W. Corridors | ● |
| | | Linear WO/Corridors | □ |
| | | Transition Route | □ |
| 3. | PLANNING | Planning System | FP |
| | | Transition Space | □ |
| | | Multi Story Space | □ |
| | | Zoning | □ |
| 4. | INTERIOR | Wall System | FI |
| | | Ceiling System | FI |
| | | Finishes | CH |
| 5. | DISPLAY | 2-D, Paintings | □ |
| | | 2-D, Paper | □ |
| | | 3-D, Sculpture | □ |
| | | Case Exhibition | ● |
| | | Wall Mounted | □ |
| | | Free Standing | □ |
| 6. | ART. LIGHT | Luminaire Type | IC |
| | | Lamp Type | IC |
| | | U.V. Control | ● |

| NO. | SYSTEM | FACTORS | |
|---|---|---|---|
| 6. | ARTIFICIAL LIGHTING | Glare Control | ● |
| | | Modeling | ⊗ |
| | | Colour Rendering | ◒ |
| | | Colour Temperature | ◒ |
| | | Interaction W/Structure | ⊗ |
| | | Heating Effect | □ |
| | | Contrast | ◒ |
| 7. | DAYLIGHTING | Top Lighting | □ |
| | | Side Lighting | ● |
| | | Court Lighting | ● |
| | | Clerestory | ● |
| | | Diffusing System | □ |
| | | U.V. Control | □ |
| | | Glare Control | □ |
| | | Modeling | ◒ |
| | | Contrast | ◒ |
| | | Colour Rendering | ◒ |
| | | Interaction W/Art. | ◒ |
| | | Interaction W/Structure | ⊗ |
| | | Heating Effect | □ |
| | | | |
| | | | |

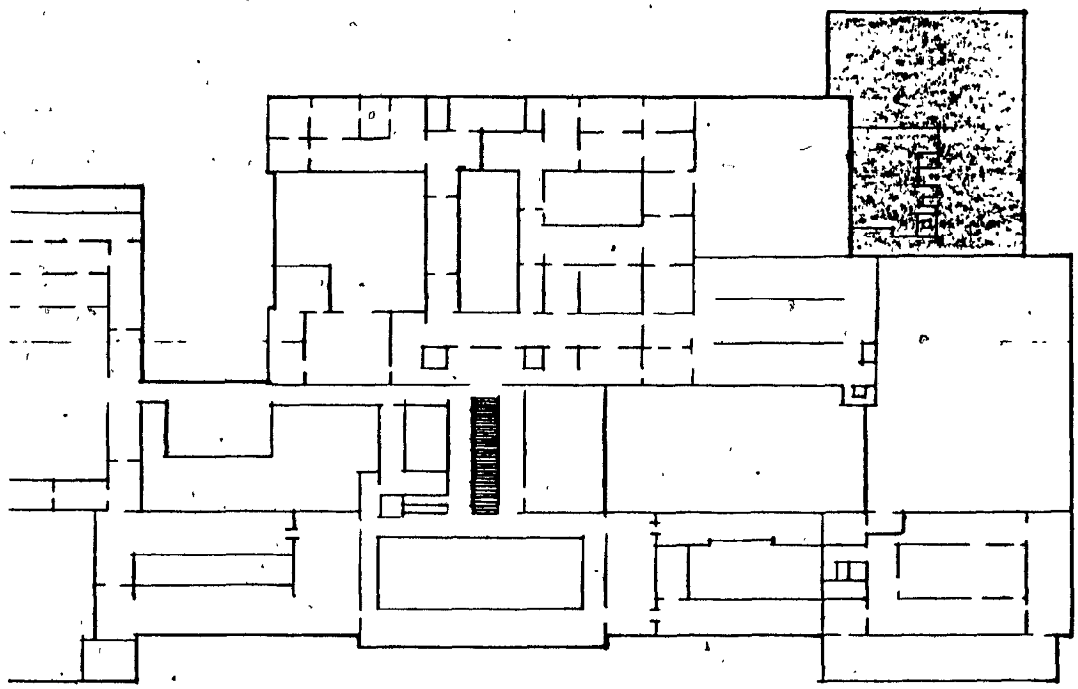


Plate 7.33, Second floor plan of the Museum, where the American wing is located.

Plate 7.34, The general exterior view of the American wing.

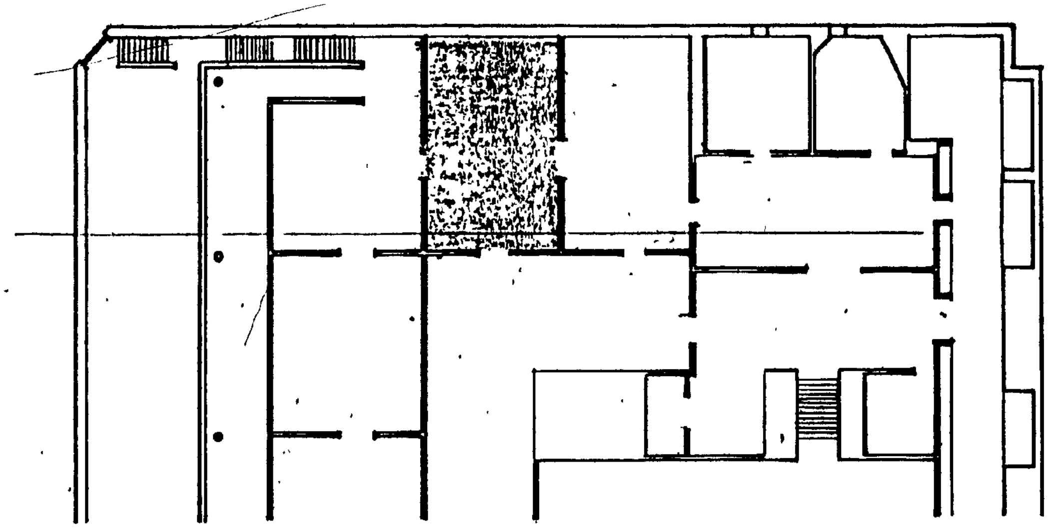


Plate 7.35 Partial floor plan of the American wing. Gallery 2|8 is shaded

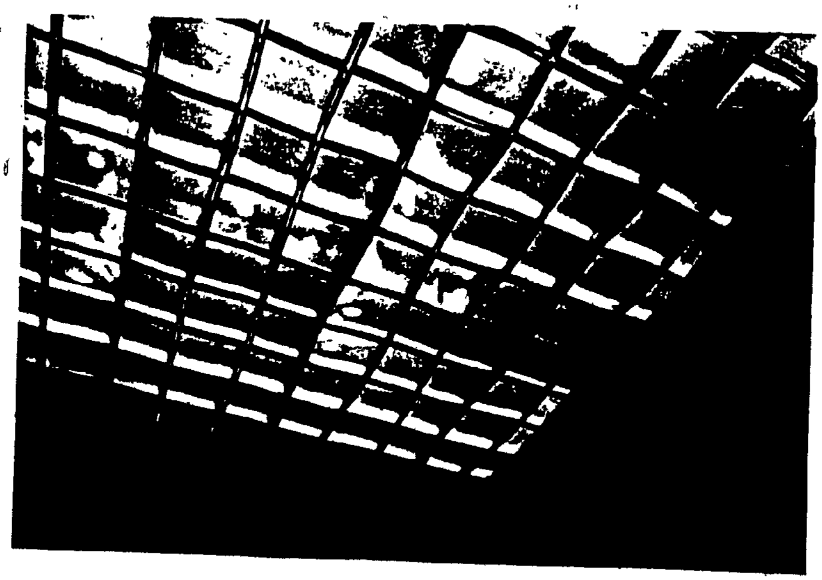


Plate 7.36 The laylight ceiling system of the galleries

## C.7 Islamic Wing

Most materials exhibited in the galleries of the Islamic Wing belong to the sensitive group and the illuminance level should be kept low. In response to this need the skylight is white washed in order to reduce the daylight density. Showcases are lit by fluorescent lights, which contribute to the ambient light. Incandescent spots are used for tapestry and carpets. The illuminance levels are in an acceptable range; the color temperature is slightly lower than the recommended level of 4500 °K.

- Illuminance distribution is good. The brightly lit showcases cause variations of illuminance.

- Veiling glare does not exist, due to the high ceiling and proper modeling.

- Discomfort glare is caused by fluorescent lit showcases.
- Transition areas are not provided from gallery to gallery, but due to the close range of illuminance levels adaptation takes place with decreasing visibility.

DATA SHEET

MUSEUM NAME: Islamic Art Galleries of Metropolitan Museum of Art

LOCATION: New York

| NO. | SYSTEM | FACTORS | |
|---|---|---|---|
| 1. | HVAC | Exposed Ducts | ● |
| | | Integrated W/Structure | ● |
| | | Integrated W/Lighting | ● |
| 2. | CIRCULATION | Linear W. Corridors | ● |
| | | Linear WO/Corridors | □ |
| | | Transition Route | □ |
| 3. | PLANNING | Planning System | FI |
| | | Transition Space | □ |
| | | Multi Story Space | ● |
| | | Zoning | □ |
| 4. | INTERIOR | Wall System | FI |
| | | Ceiling System | FI |
| | | Finishes | FI |
| 5. | DISPLAY | 2-D, Paintings | □ |
| | | 2-D, Paper | □ |
| | | 3-D, Sculpture | □ |
| | | Case Exhibition | □ |
| | | Wall Mounted | □ |
| | | Free Standing | ● |
| 6. | ART. LIGHT | Luminaire Type | IC |
| | | Lamp Type | FL |
| | | U.V. Control | ○ |

| NO. | SYSTEM | FACTORS | |
|---|---|---|---|
| 6. | ARTIFICIAL LIGHTING | Glare Control | ○ |
| | | Modeling | ○ |
| | | Colour Rendering | ○ |
| | | Colour Temperature | ○ |
| | | Interaction W/Structure | ○ |
| | | Heating Effect | ○ |
| | | Contrast | ○ |
| 7. | DAYLIGHTING | Top Lighting | □ |
| | | Side Lighting | ● |
| | | Court Lighting | ● |
| | | Clerestory | ● |
| | | Diffusing System | □ |
| | | U.V. Control | ○ |
| | | Glare Control | ○ |
| | | Modeling | ○ |
| | | Contrast | ○ |
| | | Colour Rendering | ⊗ |
| | | Interaction W/Art. | ⊗ |
| | | Interaction W/Structure | ⊗ |
| | | Heating Effect | ○ |
| | | | |
| | | | |

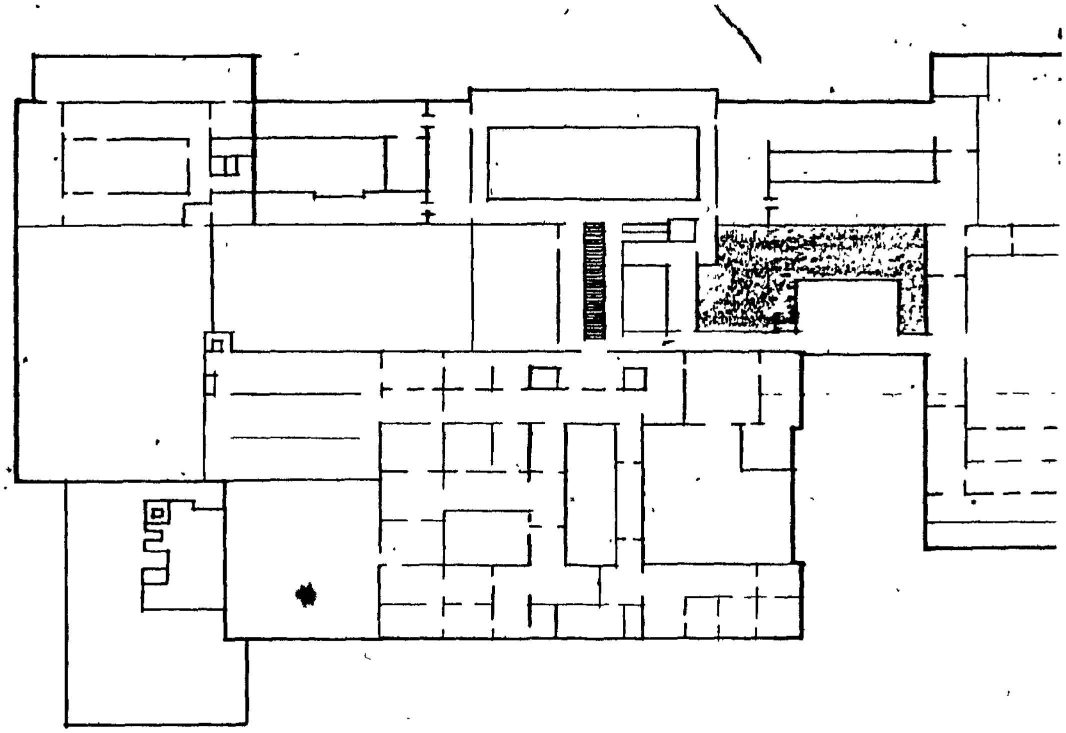


Plate 7.37, Floor plan of the second floor of the Metropolitan Museum of fine Arts, Islamic Gallery is shaded.

Plate 7.38 General view of the galleries.

Plate 7.39, View of the skylight. Paneled in the middle.

Plate 7.40, View of exhibition case, note the reflections of sources in the glass, just missing the work.

**C.8 Kimbell Art Museum**

The Kimbell Art Museum was created with Kahn's belief in daylight. As he was quoted by his partner, Mr. Meyers: "We were born of light, the seasons are felt through light. We only know the world as it is evoked by light, and from this comes the thought that material is spent light. To me natural light is the only light, because it has mood - it provides a ground of common agreement for man - it puts us in touch with the external" (20).

The Kimbell Art Museum is an example of extensive trial and error in the design process. A number of sections were experimented on in order to study the effects of light. Finally a reflector system was worked out in which light is reflected to the exposed concrete barrel vault ceiling. Perforated metal diffusers are used for diffusing and reflecting the light. Before installing the reflectors, the opening along the center of the vault was very bright and a source of glare. With the reflector and the geometry of the vault the light has created a comfortable visual environment for the visitor.

- Illuminance variation is excellent, since light is reflected and transmitted through the metal diffusers.

- The reflected light creates a luminous ceiling.

- Veiling glare does not exist, since the light is diffused. This can be seen by comparing the source of light before and after the diffusers were installed.

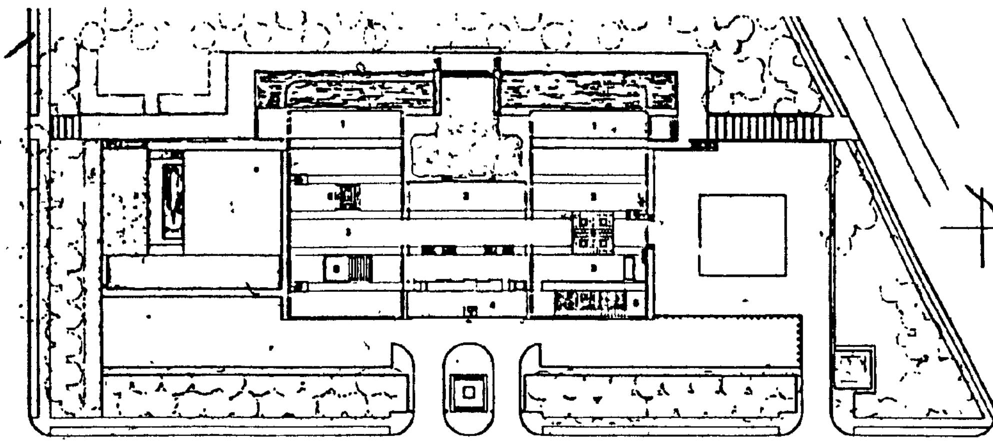
# DATA SHEET

MUSEUM NAME: Kimbell Art Museum .

LOCATION: Fortworth, Texas

| NO. | SYSTEM | FACTORS | |
|---|---|---|---|
| 1. | HVAC | Exposed Ducts | ● |
| | | Integrated W/Structure | ○ |
| | | Integrated W/Lighting | □ |
| 2. | CIRCULATION | Linear W. Corridors | □ |
| | | Linear WO/Corridors | ● |
| | | Transition Route | □ |
| 3. | PLANNING | Planning System | FI |
| | | Transition Space | FI |
| | | Multi Story Space | ○ |
| | | Zoning | □ |
| 4. | INTERIOR | Wall System | FI |
| | | Ceiling System | FI |
| | | Finishes | FI |
| 5. | DISPLAY | 2-D, Paintings | □ |
| | | 2-D, Paper | □ |
| | | 3-D, Sculpture | □ |
| | | Case Exhibition | □ |
| | | Wall Mounted | □ |
| | | Free Standing | □ |
| 6. | ART. LIGHT | Luminaire Type | IC |
| | | Lamp Type | IC |
| | | U.V. Control | ● |

| NO. | SYSTEM | FACTORS | |
|---|---|---|---|
| 6. | ARTIFICIAL LIGHTING | Glare Control | |
| | | Modeling | ⊗ |
| | | Colour Rendering | ⊗ |
| | | Colour Temperature | ⊗ |
| | | Interaction W/Structure | ◒ |
| | | Heating Effect | ◒ |
| | | Contrast | ⊗ |
| 7. | DAYLIGHTING | Top Lighting | □ |
| | | Side Lighting | ● |
| | | Court Lighting | ● |
| | | Clerestory | ● |
| | | Diffusing System | ○ |
| | | U.V. Control | ○ |
| | | Glare Control | ○ |
| | | Modeling | ○ |
| | | Contrast | ○ |
| | | Colour Rendering | ○ |
| | | Interaction W/Art. | ○ |
| | | Interaction W/Structure | ○ |
| | | Heating Effect | ● |
| | | | |
| | | | |



Plan – Gallery level.

1 Porch
2 Entrance
3 Gallery
4 Book sale
5 Auditorium
6 Open court

Plate 7.41, Floor plan of the museum.

Plate 7.42, The interior view of the gallery under construction. Note the high glare in the ceiling, before reflecting planes are installed.

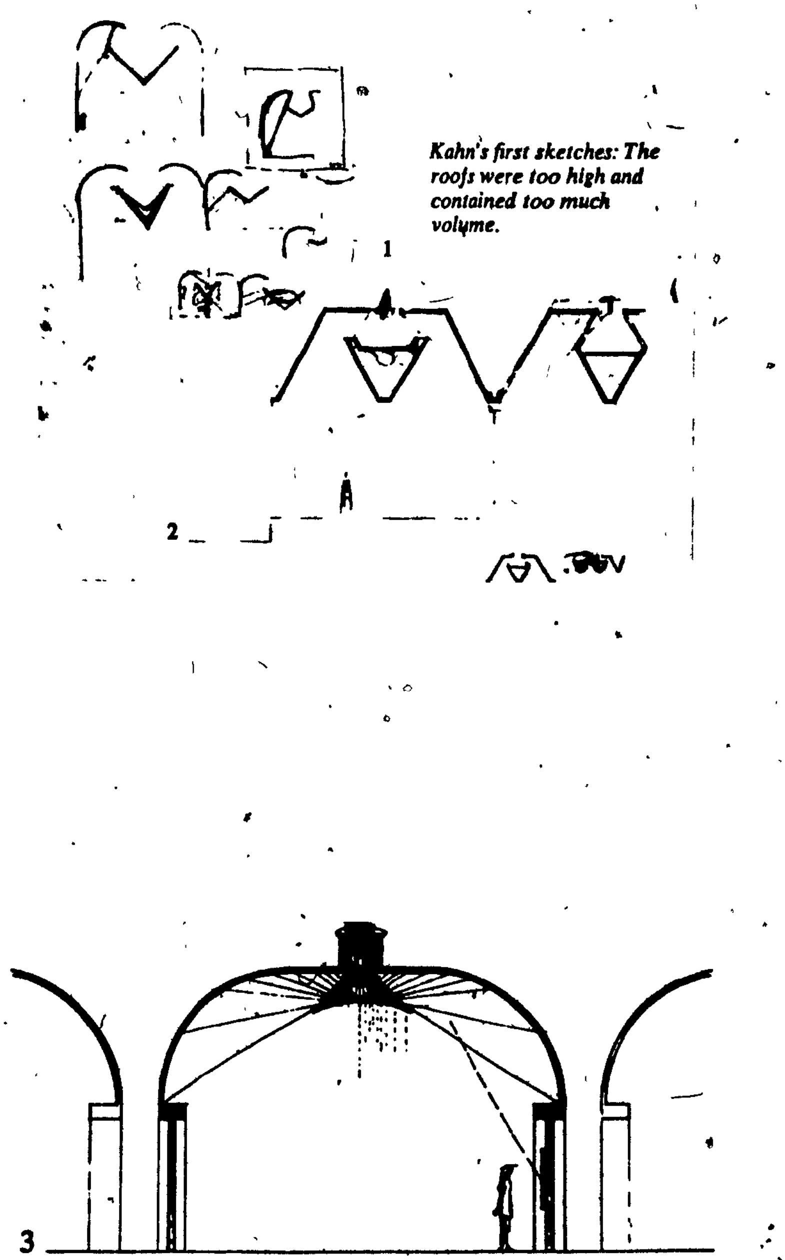



Plate 7.43, The architects conceptual drawings of the skylight system.

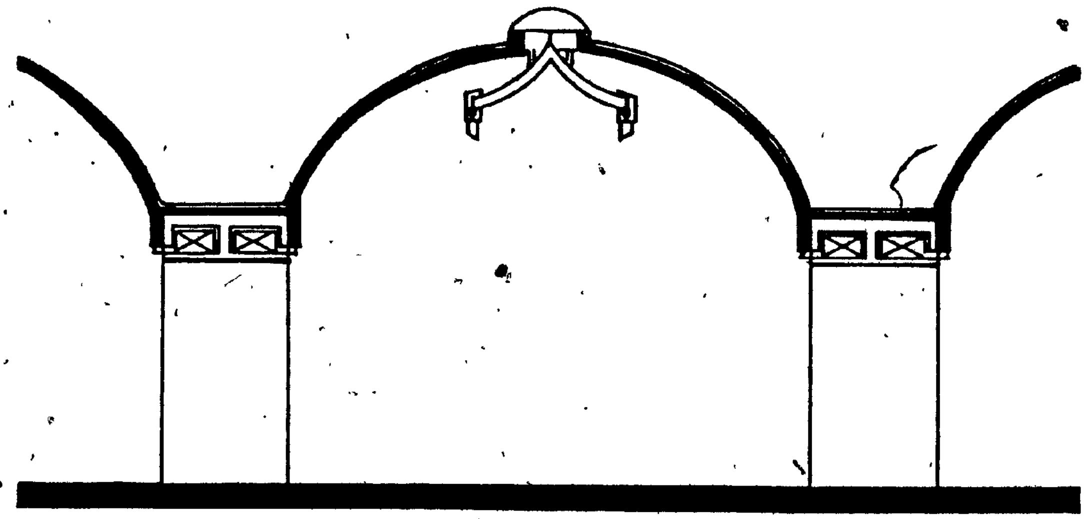


Plate 7.44, Section (a), and general view of the sky lit gallery.

## C.9 Boston Museum of Fine Arts West Wing

The new west wing was added primarily to provide space for existing inadequate facilities in the museum. Two new galleries have been added:

a) Foster Gallery which is artificially lit and

b) Gund Gallery which is daylit.

The Gund Gallery provides 10,000 sq.ft. of new gallery area for temporary exhibitions. A 15 foot square grid is used with the coffered ceiling system which contains another 5 foot square grid of skylight. The decision to install skylights was made very late in the construction stage due to a disagreement between the curators and the board of trustees. The ceiling system functions in reflecting, diffusing the light, and enclosing the light source. This design helps to eliminate the possible glare zone.

- Illuminance distribution is excellent, due to the modular skylight system.

- Veiling glare does not exist. The deep structural system and luminaire design have eliminated glare.

- Open planning is employed within the new wing.

# DATA SHEET

MUSEUM NAME: Boston Museum of Fine Arts

LOCATION: Boston

| NO. | SYSTEM | FACTORS | |
|---|---|---|---|
| 1. | HVAC | Exposed Ducts | ● |
| | | Integrated W/Structure | □ |
| | | Integrated W/Lighting | □ |
| 2. | CIRCULATION | Linear W. Corridors | ● |
| | | Linear WO/Corridors | □ |
| | | Transition Route | ● |
| 3. | PLANNING | Planning System | FI |
| | | Transition Space | ◓ |
| | | Multi Story Space | ● |
| | | Zoning | ⊗ |
| 4. | INTERIOR | Wall System | FI |
| | | Ceiling System | FI |
| | | Finishes | FI |
| 5. | DISPLAY | 2-D, Paintings | □ |
| | | 2-D, Paper | □ |
| | | 3-D, Sculpture | □ |
| | | Case Exhibition | □ |
| | | Wall Mounted | □ |
| | | Free Standing | □ |
| 6. | ART. LIGHT | Luminaire Type | IC |
| | | Lamp Type | FL |
| | | U.V. Control | ○ |

| | SYSTEM | FACTORS | |
|---|---|---|---|
| 6. | ARTIFICIAL LIGHTING | Glare Control | ○ |
| | | Modeling | ○ |
| | | Colour Rendering | ⊗ |
| | | Colour Temperature | ⊗ |
| | | Interaction W/Structure | ○ |
| | | Heating Effect | ◓ |
| | | Contrast | ⊗ |
| 7. | DAYLIGHTING | Top Lighting | □ |
| | | Side Lighting | ● |
| | | Court Lighting | □ |
| | | Clerestory | ● |
| | | Diffusing System | ○ |
| | | U.V. Control | ○ |
| | | Glare Control | ○ |
| | | Modeling | ○ |
| | | Contrast | ○ |
| | | Colour Rendering | ○ |
| | | Interaction W/Art. | ○ |
| | | Interaction W/Structure | ○ |
| | | Heating Effect | ○ |
| | | | |
| | | | |

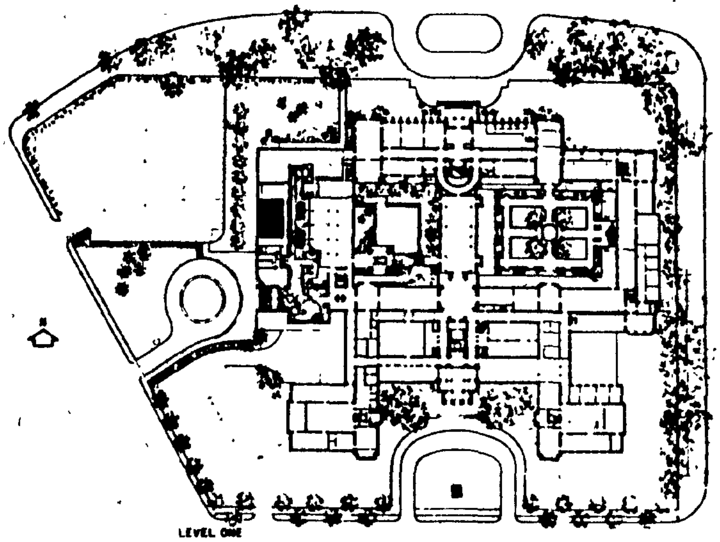



Plate 7.45, The general floor plan, the new addition is shaded.

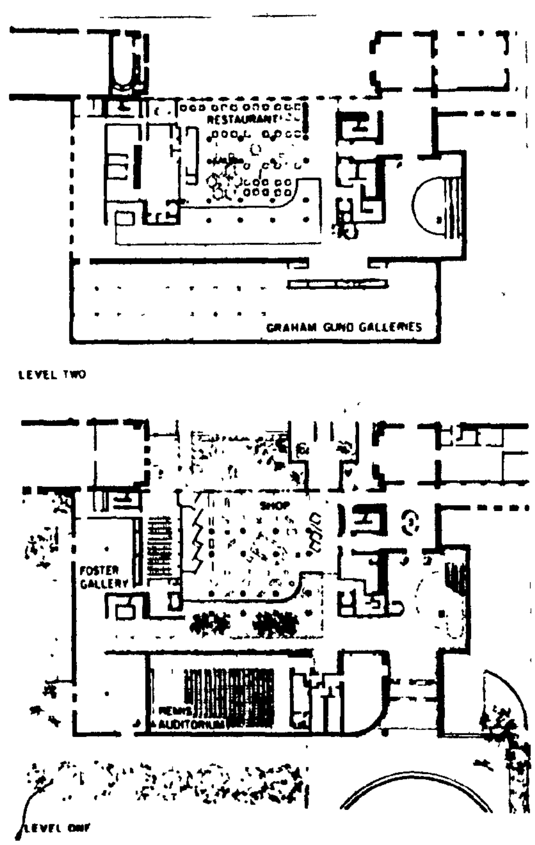



Plate 7.46, Floor plans of the new addition. the Graham Gund Galleries are sky lit.

Plate 7.47, The general view of the sky lit gallery. 'Glare is eliminated.

Plate 7.48, The view of the sky lit gallery, used as orientation space.

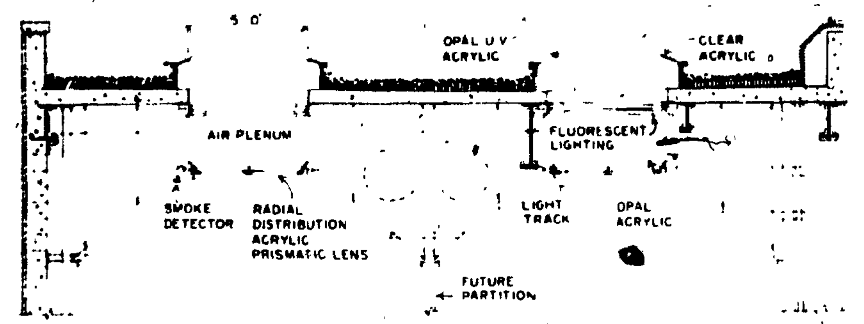



Plate 7.49, Section through the Skylight

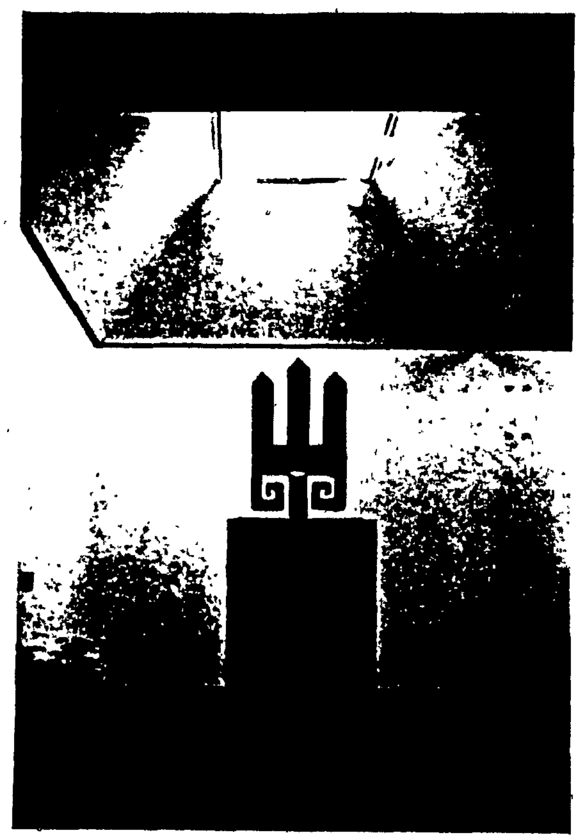


Plate 7.50, View of one sky lit unit.

**D.1 Everson Museum of Art**

In this museum the galleries are grouped around a 2 story central sculpture court which is lit by windows and clerestory luminaires. The galleries receive a minimal amount of natural light through this source, but in terms of contrast a more negative effect is created. The openings into the court create glare and seeing the dark artificially lit adjacent walls becomes impossible. The galleries are lit with incandescent spot lights and track lighting. The pattern created by the spot lights on the walls are very irregular and one finds some paintings left totally in the dark.

The garden court is now used as a sculpture painting gallery. It receives light from the top through skylights. Natural light provides the ambient light and incandescent sources are used for modeling and lighting of the objects (see Chapter 6 for data).

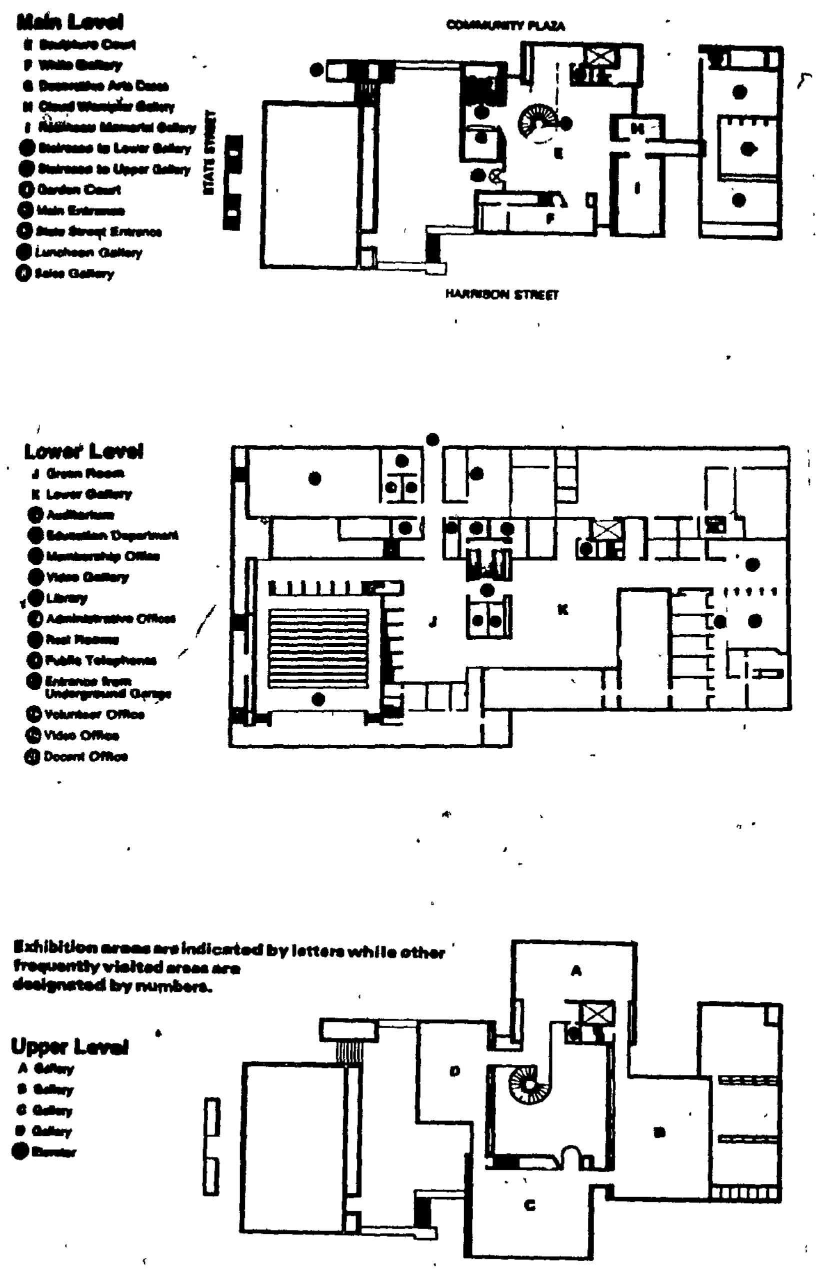
## DATA SHEET

MUSEUM NAME: Everson Museum of Art

LOCATION: Syracuse, N.Y.

| NO. | SYSTEM | FACTORS | |
|---|---|---|---|
| 1. | HVAC | Exposed Ducts | ● |
| | | Integrated W/Structure | ● |
| | | Integrated W/Lighting | ● |
| 2. | CIRCULATION | Linear W/Corridors | ● |
| | | Linear WO/Corridors | □ |
| | | Transition Route | □ |
| 3. | PLANNING | Planning System | FP |
| | | Transition Space | ⊗ |
| | | Multi Story Space | □ |
| | | Zoning | □ |
| 4. | INTERIOR | Wall System | FI |
| | | Ceiling System | FI |
| | | Finishes | CH |
| 5. | DISPLAY | 2-D, Paintings | □ |
| | | 2-D, Paper | □ |
| | | 3-D, Sculpture | □ |
| | | Case Exhibition | ● |
| | | Wall Mounted | □ |
| | | Free Standing | □ |
| 6. | ART. LIGHT | Luminaire Type | IC |
| | | Lamp Type | IC |
| | | U.V. Control | ● |

| | SYSTEM | FACTORS | |
|---|---|---|---|
| 6. | ARTIFICIAL LIGHTING | Glare Control | ● |
| | | Modeling | ◓ |
| | | Colour Rendering | ◓ |
| | | Colour Temperature | ◓ |
| | | Interaction W/Structure | ◓ |
| | | Heating Effect | ◓ |
| | | Contrast | ◓ |
| 7. | DAYLIGHTING | Top Lighting | ● |
| | | Side Lighting | ● |
| | | Court Lighting | □ |
| | | Clerestory | ● |
| | | Diffusing System | ● |
| | | U.V. Control | ● |
| | | Glare Control | ● |
| | | Modeling | ◓ |
| | | Contrast | ◓ |
| | | Colour Rendering | ◓ |
| | | Interaction W/Art. | ● |
| | | Interaction W/Structure | ● |
| | | Heating Effect | ◓ |
| | | | |
| | | | |




Plate, 7.51, Floor plans of the museum.

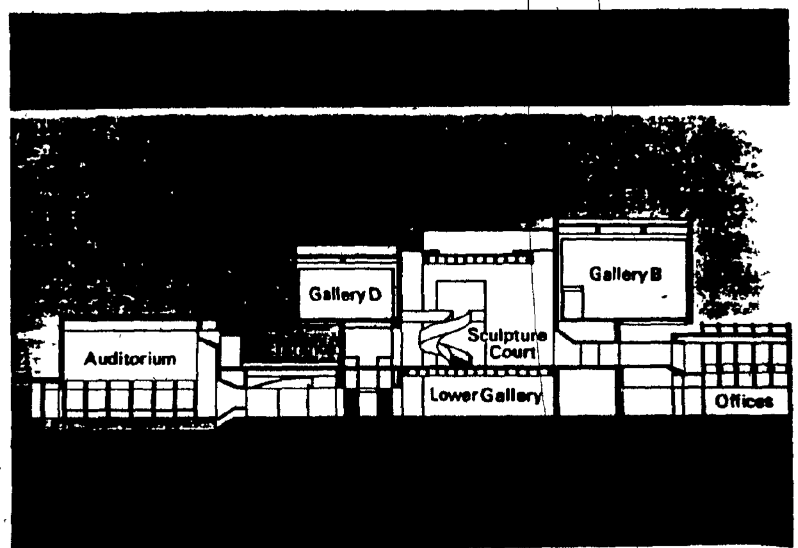



Plate 7.52, Section through museum.

Plate 7.53, View of the day lit sculpture court.

Plate 7.54, View of Gurden Court and detail of the skylight.

## D.2 The Robert Lehman Galleries

The Lehman Gallery was designed with a particular geometry around a sculpture court. Daylight enters the court without any reflections. The sun rays create bands of shadows of the mullions on the wall. The galleries in the perimeter are open to the court and are lit from above by skylights. A very deep louver system was installed long after construction, once it was realized that the illuminance was too high. It was stated by the curator of the galleries, that a huge sculpture was supposed to be installed in the middle of the court, in order to create a focal point. The heat gain through the court skylight was too much and the humidity control is very difficult. It was stressed that daylight was very appropriate for these galleries since the exhibitions are primarily 19th century art and were painted in outdoor conditions. See Chapter 6 for futher data.

## DATA SHEET

MUSEUM NAME: Robert Lehman Galleries of Metropolitan Museum of Art

LOCATION: New York

| NO. | SYSTEM | FACTORS | |
|---|---|---|---|
| 1. | HVAC | Exposed Ducts | ● |
| | | Integrated W/Structure | □ |
| | | Integrated W/Lighting | □ |
| 2. | CIRCULATION | Linear W. Corridors | ● |
| | | Linear WO/Corridors | □ |
| | | Transition Route | □ |
| 3. | PLANNING | Planning System | FI |
| | | Transition Space | □ |
| | | Multi Story Space | □ |
| | | Zoning | □ |
| 4. | INTERIOR | Wall System | FI |
| | | Ceiling System | FI |
| | | Finishes | FI |
| 5. | DISPLAY | 2-D, Paintings | □ |
| | | 2-D, Paper | □ |
| | | 3-D, Sculpture | ● |
| | | Case Exhibition | ● |
| | | Wall Mounted | □ |
| | | Free Standing | □ |
| 6. | ART. LIGHT | Luminaire Type | IC |
| | | Lamp Type | IC |
| | | U.V. Control | ● |

| | SYSTEM | FACTORS | |
|---|---|---|---|
| 6. | ARTIFICIAL LIGHTING | Glare Control | ● |
| | | Modeling | ⊗ |
| | | Colour Rendering | ⊗ |
| | | Colour Temperature | ⊗ |
| | | Interaction W/Structure | ⊗ |
| | | Heating Effect | ◓ |
| | | Contrast | ⊗ |
| 7. | DAYLIGHTING | Top Lighting | ● |
| | | Side Lighting | ● |
| | | Court Lighting | □ |
| | | Clerestory | ● |
| | | Diffusing System | □ |
| | | U.V. Control | ⊗ |
| | | Glare Control | ⊗ |
| | | Modeling | ⊗ |
| | | Contrast | ○ |
| | | Colour Rendering | ⊗ |
| | | Interaction W/Art. | ⊗ |
| | | Interaction W/Structure | ⊗ |
| | | Heating Effect | ◓ |
| | | | |
| | | | |

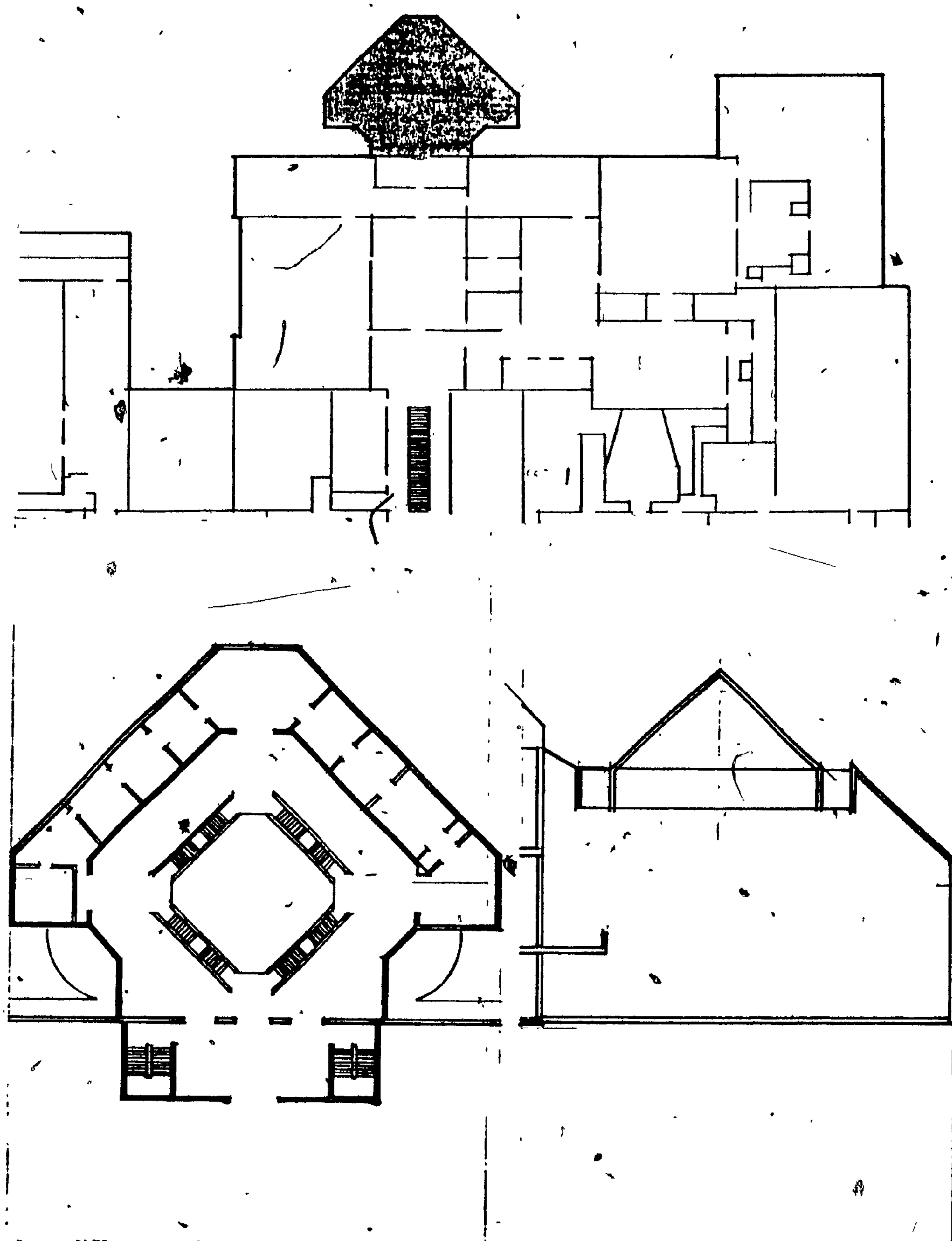


Plate 7.57, (a) Ground floor plan of the museum, Lehman Gallery,
(c) Section through skylight system.

Plate 7.58, The exterior view of the sky light system.

Plate 7.59, View of the Interior day lit Galleries.

**E.1 Musée des Beaux - Arts de Montréal**

Montreal Museum of Fine Arts

This museum has been used over and over again to illustrate examples of what must not be done in museum lighting. The visual environment is characterized by glare, high contrast, low illuminance and low color temperature. Most galleries are artificially lit. Sky lights in the older building (1912) are usually covered or white washed. A black plastic is spread over the skylight from the outside. As was stated by the chief curator this is very difficult and dangerous for the workers.

Daylight is preferred by the chief curator. The galleries of the new wing have no daylight luminaires, except for a few windows which are sources of glare. He also feels that the galleries are too dark but he cannot raise the illusinance level of spot lights. It is the ambient light which is missing. Furthermore the tracks are installed too close to the wall and the angle of incident is too small, causing veiling reflections from paintings. This was corrected to some extent but the problem still exists. See Chapter 6 for further data.

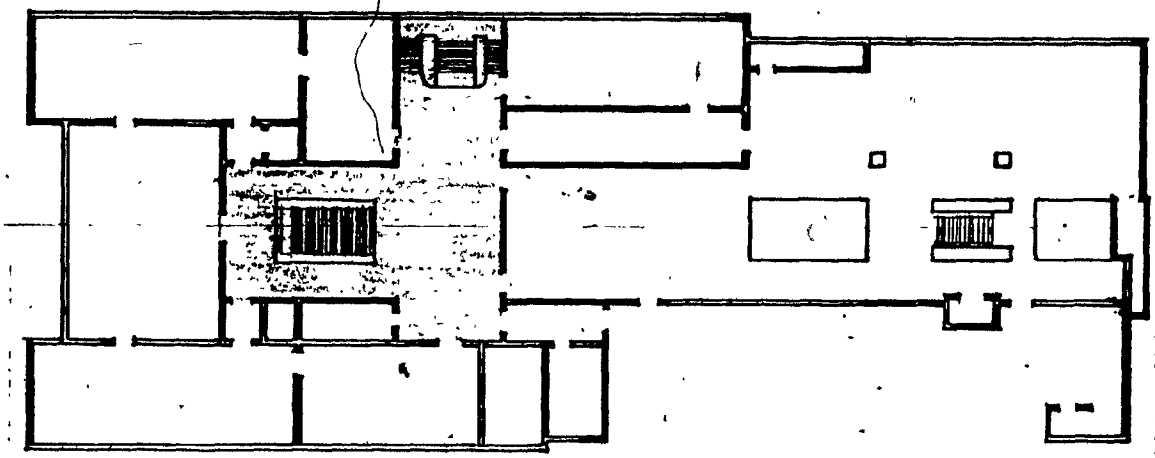
# DATA SHEET

MUSEUM NAME: Montreal Museum of Fine Arts.

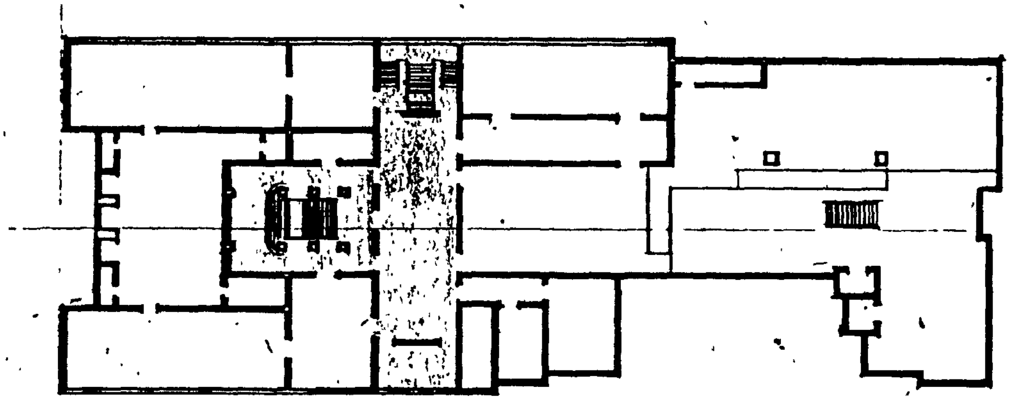
LOCATION: Montreal, Quebec

| NO. | SYSTEM | FACTORS | |
|---|---|---|---|
| 1. | HVAC | Exposed Ducts | ● |
| | | Integrated W/Structure | ● |
| | | Integrated W/Lighting | ● |
| 2. | CIRCULATION | Linear W. Corridors | ● |
| | | Linear WO/Corridors | ☐ |
| | | Transition Route | ● |
| 3. | PLANNING | Planning System | FI |
| | | Transition Space | ● |
| | | Multi Story Space | ☐ |
| | | Zoning | ◒ |
| 4. | INTERIOR | Wall System | FI |
| | | Ceiling System | FI |
| | | Finishes | FI |
| 5. | DISPLAY | 2-D, Paintings | ☐ |
| | | 2-D, Paper | ☐ |
| | | 3-D, Sculpture | ☐ |
| | | Case Exhibition | ○ |
| | | Wall Mounted | ☐ |
| | | Free Standing | ☐ |
| 6. | ART. LIGHT | Luminaire Type | IC |
| | | Lamp Type | IC |
| | | U.V. Control | ● |

| | SYSTEM | FACTORS | |
|---|---|---|---|
| 6. | ARTIFICIAL LIGHTING | Glare Control | ● |
| | | Modeling | ◒ |
| | | Colour Rendering | ◒ |
| | | Colour Temperature | ◒ |
| | | Interaction W/Structure | ◒ |
| | | Heating Effect | ⊖ |
| | | Contrast | ◒ |
| 7. | DAYLIGHTING | Top Lighting | ● |
| | | Side Lighting | ☐ |
| | | Court Lighting | ● |
| | | Clerestory | ● |
| | | Diffusing System | ● |
| | | U.V. Control | ● |
| | | Glare Control | ● |
| | | Modeling | ● |
| | | Contrast | ◒ |
| | | Colour Rendering | ○ |
| | | Interaction W/Art. | ◒ |
| | | Interaction W/Structure | ◒ |
| | | Heating Effect | ◒ |
| | | | |
| | | | |



Third Floor



Second Floor

Plate 7.60 Floor plans

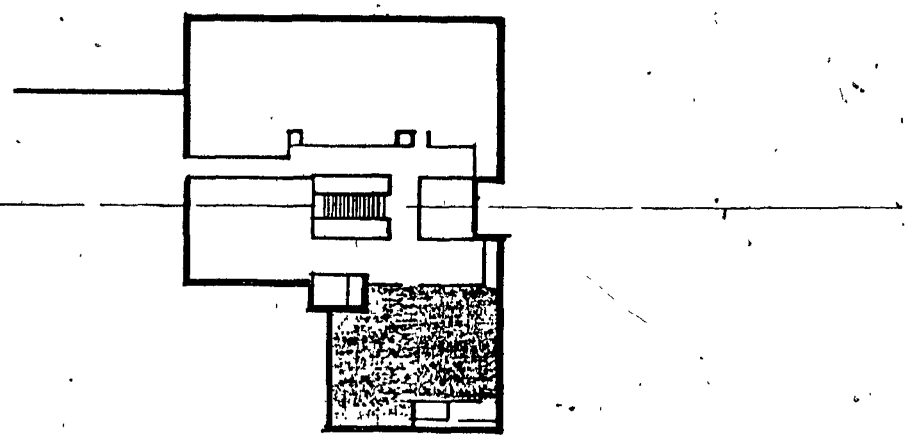


Plate 7.62 Fourth floor plan, Gallery D, documented, shaded

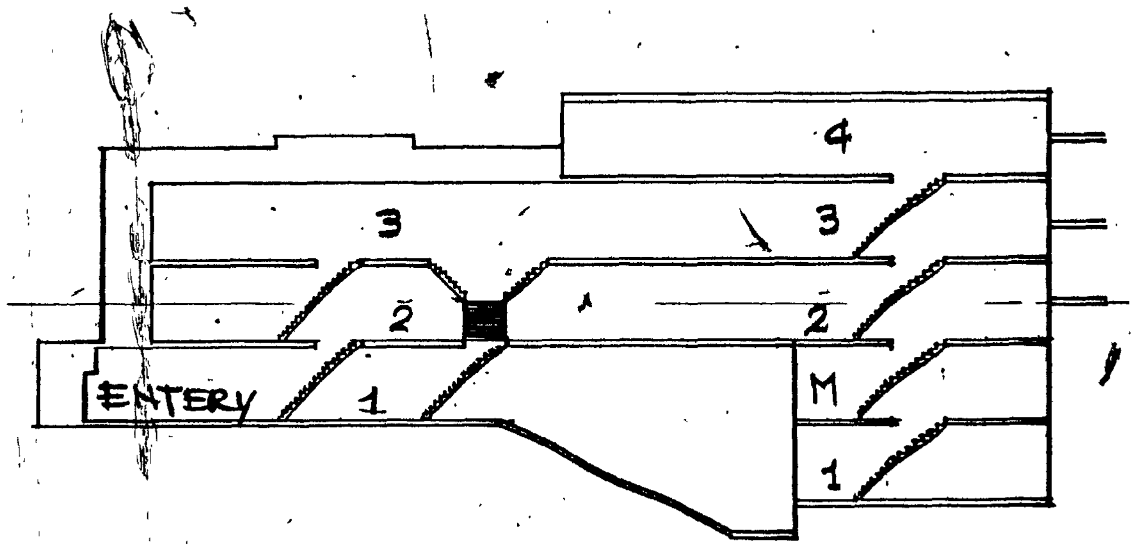



Plate 7.62 Section through the museum

## 7.3 CONCLUSIONS

Table (7.63) Illustrates the comparisons of factors that have been discussed with each museum. Through thé study of individual museums and comparisons we can conclude that:

1. HVAC is not integrated with other systems in general. The lack of integration is more evident in window lit and artificially lit museums, but it has been considered in skylit museums. This is due to the fact that the designers have considered the ceiling as an integral part of the gallery and have considered its design at the time of skylight design. This reveals that if lighting design is considered at the design stage, it will affect other elements of the space.

2. The provision for a transition route has been made in most museums, but it has been better integrated in skylit museums than other types. Linear circulation without corridors is employed in all museums except two. This is due to the need for open space and flexibility in planning.

3. The planning system is fixed in all galleries except in three. Once the gallery is defined, modular or open, it tends to stay like that. This is due to the fact that changes in the lighting system and levels of illuminance require transition space.

| SYSTEMS / FACTORS — MUSEUMS | HVAC | | | CIRCULATION | | | PLANNING | | | | INTERIOR | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Exposed Ducts | Integrated W/Structure | Integrated W/Lighting | Linear W/Corridors | Linear W.O./Corridors | Transition Route | Planning System | Transition Space | Multi-Story Space | Zoning | Wall Systems | Ceiling Systems | Color of Finishes |
| Herbert F. Johnson Museum | ● | ● | ● | ● | □ | ◒ | FI | ● | □ | ◒ | FI | FI | FI |
| Musée D'Art Contemporaine | ● | ● | ● | ● | □ | □ | FI | □ | □ | □ | FI | FI | CH |
| Museum of Contemporary Art | ● | ● | ● | ● | □ | □ | FI | ● | □ | □ | FI | FI | FI |
| Shiraz Art Gallery | NI | NI | NI | ● | ● | ● | FP | ● | □ | ● | FI | FI | FI |
| Frederick R. Mayer | ● | ● | □ | ● | □ | □ | FI | □ | ● | ● | FI | CH | CH |
| The Menil Collection | ● | □ | □ | □ | ● | □ | FI | □ | ● | ○ | CH | FI | NI |
| Yale Center for British Art | ○ | ○ | ○ | ○ | □ | □ | FI | □ | □ | □ | FI | FI | FI |
| Portland Museum of Art | ● | □ | □ | ● | □ | □ | FI | ○ | □ | □ | FI | FI | FI |
| Art Gallery of Ontario | ● | □ | □ | ● | □ | □ | FI | □ | □ | □ | FI | FI | FL |
| American Art Galleries | ● | □ | □ | ● | □ | □ | FI | □ | □ | □ | FI | FI | CH |
| Islamic Art Galleries | ● | ● | ● | ● | □ | □ | FI | □ | ● | □ | FI | FI | FI |
| Kimbell Art Museum | ● | ○ | □ | □ | ● | □ | FI | ● | ● | □ | FI | FI | FI |
| Boston Museum of Fine Arts | ● | □ | □ | ● | □ | ● | FI | ◒ | ● | ⊗ | FI | FI | FI |
| Everson Museum of Art | ● | ● | ● | ● | □ | □ | FP | ⊗ | □ | □ | FI | FI | CH |
| Robert Lehman Galleries | ● | □ | □ | ● | □ | □ | FI | □ | □ | □ | FI | FI | FI |
| Montreal Museum of Fine Arts | ● | ● | ● | ● | □ | ● | FI | ● | □ | ◒ | FI | FI | FI |

| SYSTEMS / FACTORS — MUSEUMS | DISPLAY SYSTEM | | | | | | ARTIFICIAL | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2-D Paintings | 2-D Paper | 3-D Sculpture | Case Exhibition | Wall Mounted | Free Standing | Luminaire Type | Lamp Type | U.V. Control | Glare Control | Modeling | Colour Rendering | Colour Temperature | Interaction W/D.L. | Interaction W/Structure | Heating Effect |
| Herbert F. Johnson Museum | □ | □ | □ | □ | □ | □ | IC | IC | ● | ● | ◒ | ⊗ | ○ | ⊗ | ⊗ | ⊗ |
| Musée D'Art Contemporaine | □ | □ | □ | ● | □ | □ | IC | IC | ● | ⊗ | ⊗ | ○ | ◒ | ◒ | ◒ | ○ |
| Museum of Contemporary Art | □ | □ | □ | ○ | □ | ○ | IC | FL | ● | ● | ◒ | ○ | ○ | ○ | ◒ | □ |
| Shiraz Art Gallery | NI | NI | NI | NI | NI | NI | NI | NI | NI | NI | NI | NI | NI | NI | NI | NI |
| Frederick R. Mayer | ● | □ | ● | ● | □ | ● | IC | IC | ● | □ | ○ | ○ | ⊗ | ◒ | ⊗ | ○ |
| The Menil Collection | □ | □ | NI | ● | □ | □ | K | K | ● | ○ | ○ | ⊗ | ⊗ | ○ | ◒ | ○ |
| Yale Center for British Art | □ | □ | □ | ○ | □ | □ | K | K | ● | ⊗ | ⊗ | ◒ | ◒ | ⊗ | ● | ⊗ |
| Portland Museum of Art | □ | □ | □ | □ | □ | □ | IC | IC | ● | ⊗ | ○ | ⊗ | ⊗ | ⊗ | ⊗ | ◒ |
| Art Gallery of Ontario | □ | □ | □ | □ | □ | □ | FL | FL | NI | ⊗ | ⊗ | ⊗ | ⊗ | ⊗ | ◒ | ◒ |
| American Art Galleries | □ | □ | □ | ● | □ | □ | IC | IC | ● | ● | ⊗ | ◒ | ◒ | ⊗ | ⊗ | □ |
| Islamic Art Galleries | □ | □ | □ | □ | □ | ● | IC | FC | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Kimbell Art Museum | □ | □ | □ | □ | □ | □ | IC | K | ● | ⊗ | ⊗ | ⊗ | ⊗ | ◒ | ◒ | ◒ |
| Boston Museum of Fine Arts | □ | □ | □ | □ | □ | □ | FL | K | ○ | ○ | ○ | ⊗ | ⊗ | ○ | ○ | ◒ |
| Everson Museum of Art | □ | □ | □ | ● | □ | □ | K | IC | ● | ● | ◒ | ◒ | ◒ | ◒ | ◒ | ◒ |
| Robert Lehman Galleries | □ | □ | ● | ● | □ | □ | K | IC | ● | ● | ⊗ | ⊗ | ⊗ | ⊗ | ◒ | ⊗ |
| Montreal Museum of Fine Arts | □ | □ | □ | ○ | □ | □ | K | K | ● | ● | ◒ | ◒ | ◒ | ● | ◒ | ◒ |

| SYSTEMS / FACTORS — MUSEUMS | DAYLIGHTING | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Top Lighting | Side Lighting | Court Yard Lighting | Clerestory Lighting | Diffusing System | U.V. Control | Glare Control | Contrast | Modeling | Color Rendering | Interaction W/Arts. |
| Herbert F. Johnson Museum | ● | □ | □ | ● | ● | ● | ● | ⊗ | ● | ○ | ◒ |
| Musée D'Art Contemporaine | ● | □ | □ | ● | □ | ● | ◒ | ⊗ | ⊗ | ⊗ | ◒ |
| Museum of Contemporary Art | ○ | ● | ● | □ | □ | ● | ○ | ⊗ | ⊗ | ○ | ◒ |
| Shiraz Art Gallery | ● | □ | ● | □ | □ | NI | NI | NI | NI | NI | NI |
| Frederick R. Mayer | ○ | ● | ● | ● | ○ | ○ | ○ | ○ | ○ | ○ | ● |
| The Menil Collection | □ | ● | ● | ● | ○ | ⊗ | ○ | ○ | ○ | ⊗ | ○ |
| Yale Center for British Art | □ | ● | □ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Portland Museum of Art | □ | □ | ● | ● | ○ | ○ | ○ | ○ | ○ | ⊗ | ○ |
| Art Gallery of Ontario | □ | ● | ● | □ | ⊗ | ○ | ◒ | ◒ | ⊗ | ◒ | ⊗ |
| American Art Galleries | □ | ● | ● | ● | □ | □ | □ | ◒ | ◒ | ◒ | ⊗ |
| Islamic Art Galleries | □ | ● | ● | ● | □ | ○ | ○ | ○ | ⊗ | ◒ | ⊗ |
| Kimbell Art Museum | □ | ● | ● | ● | ○ | ○ | ○ | ○ | ○ | ○ | ● |
| Boston Museum of Fine Arts | □ | ● | □ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Everson Museum of Art | ● | ● | □ | ● | ● | ● | ● | ◒ | ◒ | ◒ | ● |
| Robert Lehman Galleries | ● | ● | □ | ● | □ | ⊗ | ⊗ | ○ | ⊗ | ⊗ | ⊗ |
| Montreal Museum of Fine Arts | ● | □ | ● | ● | ● | ● | ● | ◒ | ● | ○ | ◒ |

TABLE (7-63) COMPARISONS OF SYSTEMS IN CASE STUDIES.

4. Interior finishes are in general fixed in terms of material and flexible in terms of paint. This reveals that museums do not require flexibility in quality of material (stone) of interior finishes even though exhibitions change. This will affect the lighting design with respect to contrast and performance.
Therefore in order to meet these constraints, distinctions between ambient lighting and task lighting must be made.

5. Display systems are varied (free standing, wall mounted). This again affects the design of ambient lighting and task lighting as in number (4).

6. Incandescent lamps are used in almost all museums except for those museums whereby they are combined with fluorescent lamps. One expects poor color visibility, except in cases whereby artificial lighting is combined with daylighting. The heating effect is expected to be a serious problem with artificial lighting as was concluded during field studies. Modeling has been considered in artificial lighting design, although the veiling glare problem has not been resolved in most galleries. This reveals the fact that the three factors ie. modeling, glare and contrast always have to be considered together as they affect each other.

7. Factors affecting daylight design reveal the failure of window lit galleries. Toplit designs have considered most of the factors affecting the visual environment. Provisions for glare, U.V., modeling etc. have not been considered in side lit galleries. The top lit galleries have been mostly rated excellent with respect to diffusing system, U.V. control, glare control, modeling and color rendering.

   Some factors have been considered by some museums and some have considered other factors. For example U.V. control has been installed in the Art Gallery of Ontario but glare control and contrast have been ignored, and in the Menil Collection glare and contrast have been considered and U.V. control is left out.

8. In comparing the conclusions made through field studies and the above conclusions one can see that the case studies are the continuation of the field studies. For example the illuminance distribution factor is considered in the same degree in all top lit museums. i.e. Yale Center for British Art and Rohert Lehman galleries. Therefore the case studies can be used as a base for future site investigation and data collection.

## FOOTNOTES CHAPTER 7

20. Meyers, "Masters of Light," AIA Journal, September 1979, p.60.

# CHAPTER VIII

## CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE STUDIES

### 8.1 CONCLUSIONS:

1. All early museums were daylit and most showed apparent problems with veiling and discomfort glare. A few exceptions resolved these problems and became prototypes for later museums including some contemporary examples visited in this study.

2. Museums have been and continue to be multifunctional environments for display, curation, education, conservation and other social activities. However the relative importance and methods for accomplishing these functions have changed greatly with time. Old museum designs do not meet contemporary requirements such as daylighting since the viewer to object relationship has changed and will change in the future. Daylighting systems should be able to adapt to these changes. Even recently built museums visited as a part of this study have not provided for changing needs.

3. Daylight's characteristics (variation, high color rendering, good modeling) meet the needs of human perception. However it usually requires substantial control of illuminance levels, direction and spectral content.

4. Daylight is best used for ambient lighting and supplemented with more controlled artificial light sources as required for display.

5. Veiling glare can be analyzed with graphic and mathematical tools to locate zones in which sources should not be placed. The requirements of contrast, brightness and modeling can be met by a correct room geometry (location and size of sources, room size and configuration) that provides for appropriate interreflections and directional control.

6. The color rendering index is by definition not useful for varying source color temperatures. In daylit galleries measured there was a wide variation in color temperature and thus other standards to evaluate the rendition of color in daylit museums are required. However since daylight's spectral distributions are used as standards to judge colors, by extension, the use of daylight in museums should provide optimum color visibility.

7. The damage factor approach should be used to evaluate radiative exposure rather than simple lux levels. This approach allows higher illuminance levels if the light is correctly filtered and limited during non operating hours. The complex interactions of materials, radiation (UV, visible, IR), humidity, air content and room geometry should be considered in daylight system design. Measurements made in recently built museums have shown that this concept is not widely used. Standard measuring devices in common use are erratic and unreliable.

8. The integration of daylight is a multifactored problem. There are many different ways to introduce daylight into a space. The results should be evaluated with respect to the multifactored needs of the space. Since daylight luminaires are considered at the earliest stage of design, the analysis and comparison of system alternatives must be done at the same time. Control devices added to luminaires at a later design stage are usually complex, expensive and fail to perform over the long term.

9. The geometrical relationship of viewer/object/source is the fundamental relationship that influences the performance of the daylight luminaire. Graphic studies, model studies and full scale mockups are the only present adequate devices for evaluation of this complex three dimensional problem. Field studies showed that this relationship was not sufficiently considered in some contemporary museum design.

10. Most existing museums do not meet the requirements as have been set by conservationists. Their illuminance levels and U.V. content exceed the recommended levels by a large amount. Color temperatures are generally below the recommended levels. Based on measurements and analysis, one can conclude that an illuminance range of 250 - 300 lux is an acceptable level. A recommended level of 4500 °K - 5000 °K color temperature is not produced and these levels have to be met. U.V. contents are all higher than recommended levels; although no minimum exists, since U.V. is

damaging regardless of its magnitude. Further studies with respect to I.R. levels are required and should not be ignored as insignificant.

11. All factors discussed in this study are requirements of the visual environment and none should be ignored. Nevertheless a 100% response to constraints is impossible and factors should be considered in degree of importance and compromises have to be made. Each contemporary museum, around the world, has been successful in meeting one or two of its functional requirements. Some museums have resolved the problem of glare and some have provided for modeling. This is due to the fact that designers have neglected the interaction of factors influencing the visual environment. The integration of solutions used in existing museums can be used for future design concepts.

12. An optimization technique may in the future be developed to rate each factor based on its functional importance and performance. Through this optimization process, existing and future designs can be evaluated and the best and worst design be presented. D.J. Carter describes such a system for artificially lit spaces [132]. Factors that can be included in optimization and the rating system are summarized.

| FACTOR | CRITERIA & RATING |
|---|---|
| 1. Illuminance levels on vertical plane | a - Visual comfort<br>b - Damage factor |
| 2. Illuminance distribution | a - Even distribution<br>b - Concentrated (spots) |
| 3. Veiling Glare | a - Scale value rating<br>b - Limitation imposed on wall space and viewer's movement. |
| 4. Discomfort Glare | a - Ranked on visual comfort probability |
| 5. Damage Factor | a - U.V. content<br>b - I.R. content<br>c - Object's sensitivity |
| 6. Modeling | a - Scalar/vector ratio<br>b - Object's requirements (painting vs. sculpture) |
| 7. Color | a - Spectral power distribution of the source<br>b - Spectral absorption of the object. |
| 8. Visual Comfort | a - Viewer's need and limitations<br>b - Three level step function. |
| 9. Changing Nature | a - Need for change vs. static conditions. |
| 10. Psychological Needs | a - Needs of the visitor<br>b - Degree of importance |

The first four chapters of this study provided a global understanding of these factors and their relationship. A much deeper investigation with respect to some factors is required before a correct rating can be done. One still has to make judgements with respect to conflicting requirements.

13. The lack of available information on daylight makes an analytical study of the problem difficult and tentative. Therefore estimates have to be made and judgement is required.

14. The design of museum galleries, following from the present work, is both an art and science. Solving the functional issues will not guarantee high quality lighting. On the otherside, no matter how ingenious the means devised to admit daylight, the results will be a failure if the functional issues of veiling glare, color rendering and preservation are neglected. The functional issues are largely aimed at avoiding problems and tend to be of a yes/no type of decision. These resules are:

    1. Avoid sources of veiling glare - see the equation page 138. This means placing luminaires high in the space.
    2. Make luminaire openings small to reduce the illuminance inside and to make control devices small and easily moveable.
    3. Use reflective surfaces in and around the luminaire to reflect light in order to: distribute it in the space, reduce a too strongly directional modeling, remove U.V.

from the light and control contrast and brightnesses in room surfaces.

4. Locate the opening so that one would have to climb a small stool to see it. This puts it out of the visibile zone but does not make it a hidden and modified that the liveliness of the daylight variation is sacrificied.
5. Avoid direct solar radiation from entering into the gallery spaces to minimize control of heating, U.V. and illuminance levels. Exterior or interior shades or louvres can be used with a thorough shade study.
6. Locate artificial systems in the same locations as the daylight luminaire to keep the modeling direction consistent, provide proper mixing of the two sources and allow easy transitions to night conditions. Use artificial sources with high color rendering, well filtered such as quarts halogen and fluorescent lamps.
7. Provide a device to completely close off the luminaire during non-gallery hours. This closure should be based on the limits of the general luminaire control and should have a simple control logic.
8. Use sections through the gallery to test solutions. Use the existing gallery designs shown in this study as prototypes. See the taxonomy chapter 5. Avoid windows, courtyards, low clerestories and shiny surfaces.

9. Use models at various scales to test options of distribution of illuminance, luminance and modeling. Build a full scale mockup on site to test visibility, color rendering, glare and the effects of daylight variability.
10. Calibration and aiming of the system is the most important step including education of museum personnel. Note the above techniques are useful for both new designs and retrofits.
11. The best gallery ever built was a retrofit. It is limited with respect to possibilities but it too can be studied with models. Full size mockups and careful documentation are possible, allowing close fine tuning of the system. Because existing designs are usually different, one from another, no single retrofit technique could be used.

For the field studies, certain retrofit possibilities are apparent. In the Johnson gallery, the north facing window should have controls to reduce glare and U.V. and more evenly distribute the illuminance. This control would be either a venetian blind or curtains with a U.V. filter.

## 8.2 CONTRIBUTIONS OF THE WORK

1. On site measurements of vertical illuminance variation, ultraviolet radiation, color temperature and daylight conditions have been taken in seven museum galleries. These measurements are compared to recommended levels. The spaces chosen are representative of the daylight taxonomy and are analyzed with respect to these measurements. The variations in performance throughout the year can be predicted. See Chapter 6.

2. A taxonomy of daylight luminaires is proposed and they are organized based on daylight luminaire types. Four categories of daylight luminaires are identified: 1. window, 2. clerestory, 3. skylight, 4. courtyard. A rating system based on illuminance distribution and veiling glare is proposed. Illuminance distribution is analyzed according to the size of the solid angle viewed from the picture wall. Veiling glare evaluation system is based on the location and the size of the veiling glare zone for the moving observer in the gallery. See Chapter 5. This organization allows designers to see the range of options and expected performance for each type.

3. A useful formula for studying veiling glare is devised. This formula a) allows the gallery proportions to be compared with respect to the location of daylight luminaire. b) provides an assessment tool for daylight design evaluation. The designer can locate veiling zones and their relative importance. See Chapters 2 and 5.

4. A museum lighting survey procedure has been developed and is organized in a handbook. This handbook shows specific visible and non visible radiation data collection procedures for display spaces. See Chapter 6 and Appendix 3.

5. The illogic of a widely used U.V./lm monitor is exposed. The measurement taken with the monitor and the derived values from illuminance and ultraviolet radiation measurements are compared. The monitor was found to be erratic. See Chapters 4 and 6.

6. The high U.V. reflectance of exposed concrete suggested by lighting designers is confirmed and found to be useful if double and triple reflection occurs to reduce the U.V. content. See Chapter 4.

7. It is proved that the concept of the color rendering index (CRI) does not apply to museum daylighting. CRI is based on the assumption that C.T. reference is kept constant whereas in measured museums, high variations of C.T. exist. See Chapters 3 and 6.

8. Transition time and transition space for adaption from light to dark are derived. This allows the designer to provide for this zone at the planning stage, see Chapter 2.

9. A history of daylight in museums is complied. This shows the evaluation of daylight luminaires with respect to museum's functions and display techniques. See Appendix 1.

10. In summary, this study provides a useful guide book for the integration of daylight in museum display spaces. It describes the problems, their interactions, available resources, solution types and allows the performance of these solutions to be predicted.

## 8.3 FUTURE STUDIES AND RECOMMENDATIONS

a) One or many museums should be documented in detail for long periods with respect to all the factors, especially the changing nature of daylight and its influence on the visual environment.

b) Documentation techniques used in this study should be improved based on the experienced problems. A rational procedure to extrapolate data from one or more site visits requires detailed and long collections of daylight data for various locations.

c) Establish graphical and analytical procedures to evaluate factors influencing the visual environment such as veiling glare.

d) Model studies of daylight luminaire designs outside or with an artificial sky should be done. Each model should be evaluated with respect to all important factors.

e) Daylight control devices should be studied with respect to material and geometry. Information on what is available and their performance should be collected. Future studies in evaluating them and methods of improving future designs should take place.

f) Although cost is not an important criteria in museum construction (since not many get to be built and society is prepared to pay for its cultural values), the factors and elements of the visual environment and daylight luminaire can be rated in terms of cost and performance.

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# APPENDIX I

## HISTORICAL REVIEW

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## HISTORICAL REVIEW

### 1.1 INTRODUCTION

Here we shall examine museum functions, how they have changed and the response of designers to the needs and changes in museums. We will look at the complicated problem of providing the ultimate visual environment that subtly presents the object as a work of art to the viewer, conserves it in order to satisfy the conservationist, organizes it intellectually for the curator and is given an appropriate context and place by the architect. We will look at the history of lighting design, the need for museums, examples of early museums, the current trends in museum lighting and museum planning.

### 1.2 MUSEUM DEFINITION

Designers of our living, working and leisure environments have to understand what activities take place in these environments in order to provide the appropriate designed elements for function and enjoyment. The museum as a multi-functional environment is no exception. Depending upon the author's view point various definitions have been proposed: the most straight forward is Webster's: "an institution devoted to the procurement, care and display of objects of lasting interest or value ..." in more detail as "... a permanent, non-profit institution, essentially educational or aesthetic in purpose, with professional staff, which acquires objects, cares for them, interprets them, and exhibits them to the public on some regular schedule."(1) A more extreme definition is: "... museums were temples and directors priests."(2)

As more museums opened to the public and the size of collections grew, the definition changed towards "... the museum ... intricate organism that incorporated shops, lecture halls, restaurants, book and photo libraries, studios, accessible storage areas and laboratories, as well as the customary exhibition galleries."(3) In looking at these definitions combined with todays demands on museums, one can define museums as: Institutions devoted to the care and display of objects of lasting interest, where works of art are conserved and exhibited in such a manner and environment that communication for education, information or pure enjoyment, between the viewer and the works of art can take place indefinitely.

There are basic motives which can be found in museum visitors such as: enjoyment, contemplation, meditation and education. Although their relative importance has changed with time, the basic requirements have not altered very much.

## 1.3 EARLY MUSEUMS AND DAYLIGHT SYSTEMS

The rise of museums is said to have originated at the same time as the publication of encyclopedias. Both being the result of a spirit rampant in the 18th century for enlightenment and an equality of opportunity in learning. The British Museum and Chamber's Encyclopedia appeared in England at the same time as the show of royal collections and Encyclopédistes appeared in France. The first museum was founded on July 23, 1773 in France. The belief was that people could be trusted to

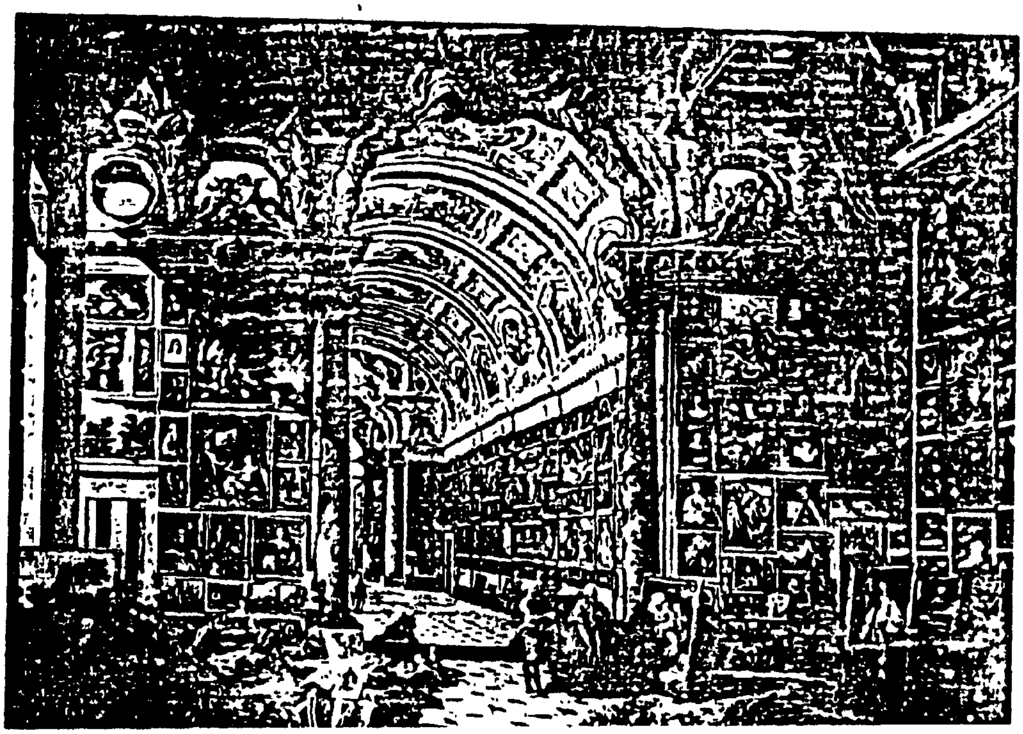

Plate (1.1), Rome, Galleria Valentia Gonzaga, c., 1740, painting by G.P. Pannini, 1749.

educate themselves and that public bodies should provide the opportunities for this process to take place, although the first collections were opened to the public with restrictions, by private collectors. Galleries for private collections were almost a standardized element of palace design, as in Plate 1.1, painting of the galleria in the villa of Gardinal Valenti Gonzaga painted by Pannini in 1749. Gradually many of these private collections became open to the public.

Entry to museums was a privilege limited to a certain class or with a certain education. With the establishment of museums by governments this trend continued. "The effect of such short sighted meanness on the part of the government was to perpetuate the tradition which made admission to a museum a privilege and a favor, not a right, a tradition which should have been brought to an end by the establishment of public museums. It is a curious paradox that until the middle of the 19$^{th}$ century the people with the best chance of seeing the pictures and other works of art in private collections belonged to a class that was probably little interested in its opportunities.(4)" Nevertheless, the rise of social equality, the bourgeoisie and the ideals of democracy, provided opportunity for other classes to have a democratic access to the exhibitions of works of art.

In Europe or America, much emphasis was put on the "usefulness" of museums, however, 'useful' must be defined. Is it simply being helpful, improving people's general knowledge, or is it the transmission of other social, economical, and political messages? The deciding person for this interpretation was the director or curator of the museum exhibition(s). Although a public organization, the museum was still very much the creation of its director who decided on the design of the building, what system of display was to be used and what material was to be shown.

Why people go to museums have changed with time and will continue to change. For example in the 18$^{th}$ century common reasons given were

a) to study; to advance oneself in one's profession; b) curiosity; to widen one's horizons; (c) for the pleasure of seeing; d) to meet people with the same cultivated tastes as oneself. Later other reasons were added to the list; e) snobbish reasons; to rub shoulders with people of superior knowledge, taste or social status; f) in order to say one has been, and finally; g) for political reasons; to demonstrate that the nation's cultural assets belong to the people as a whole [108]. To meet these functional requirements, regardless of their importance, buildings have been designed, and mostly built, in order to provide the required setting. Designs have evolved from purely monumental buildings to purely functional and utilitarian, or in between. Design philosophies for museums have changed along with other architectural ideas.

### 1.4 NEEDS FOR MUSEUMS

It has been argued that participation and communication with works of art do not need museum settings. André Malraux suggests that every work of art is seen in relaxation at its original place, and once moved to a museum it has to compete with other works of art. But one might pose the question: where is the original setting of an 18th century expressionist painting? in the park? the collector's home? Museums have been referred to as collectors too, but on a much larger scale. Negatively, "collectors are essentially robbers and destroyers. It makes little difference whether the collector is Andrew Mellon or the Metropolitian Museum of Fine Arts."(5) Museums exhibit, not only collections, but all cultural aspects of the nation; it emphasizes the fact that culture is something shared by a group, many groups or humanity as a whole.

Are museums needed, since all works of art can be mechanically reproduced? For example, concerts were not destroyed by the production of phonographic records. Do reproductions make the originals worthless? [67]. Malraux takes up this argument and concludes that "the uniqueness of a work of art is inseparable from its being imbedded in the fabric of tradition" (6). People should be able to see, study and enjoy the original works of art before being able to relate to the reproduction.

## 1.5 EXAMPLES OF EARLY MUSEUM LAYOUTS AND DAYLIGHT

Early museums were all necessarily lit by daylight as we shall see. Thus they have become important influences on contemporary museum designs [109][111][76], etc. Because of the lack of understanding of daylight on display visibility, the unthinking initiation of well known examples has led to very bad museum lighting. This is a serious problem!

P.E.L. Boullée (1728-1788), proposed the first design for a museum as a building type in 1783 (Plate 1.2). A monument with a Greek cross in a square and a rotunda at the center, with no functional reason. The lighting by daylight was primarily from the central dome's occulus and perimeter clerestory. Sunlight was not excluded thus threatening the works of art; however the large size of the space and high location of

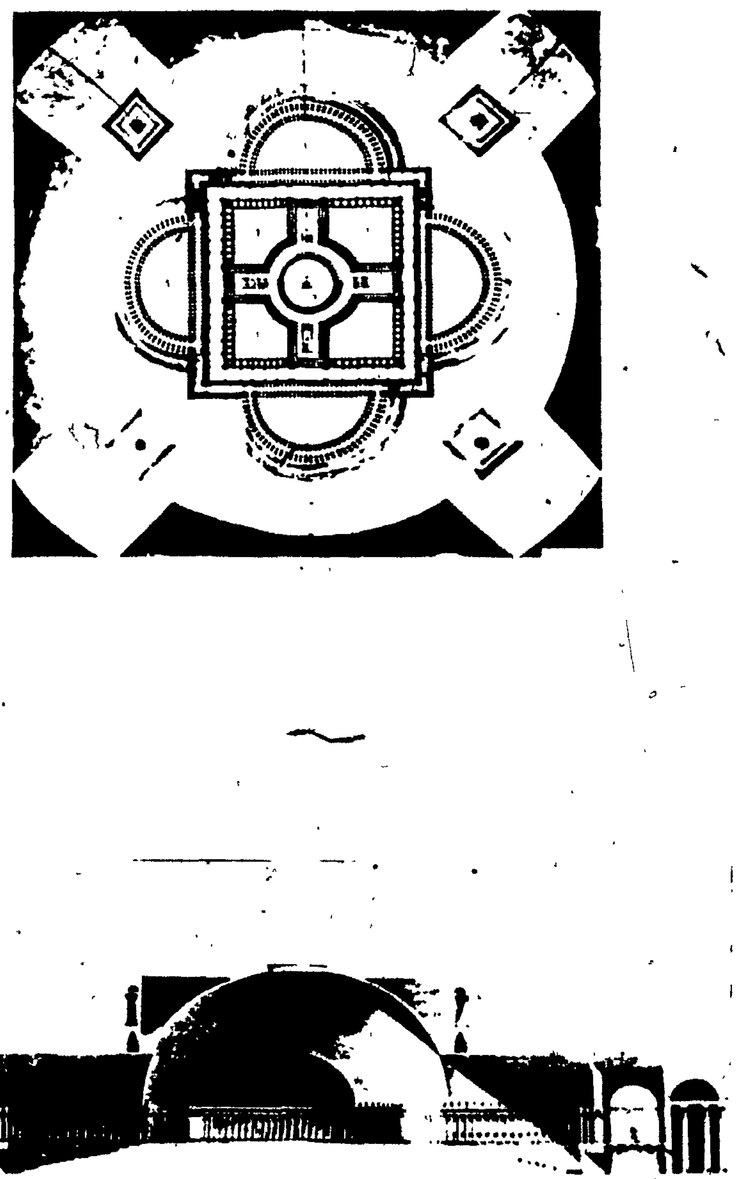

Plate (1.2), E.L. Boullée, Project for Museum, 1783, Plan and Section [14] [109]

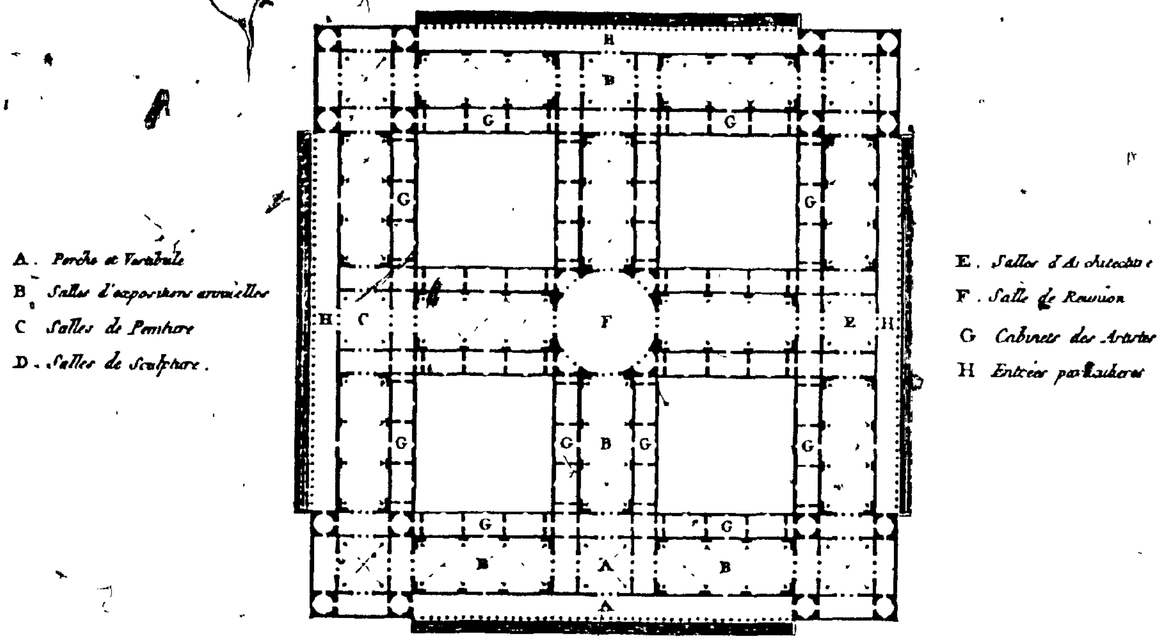


Plate (1-3) J.N.L. Durand, design for a museum (Précis, 1802-09) plan [114]

sources would reduce veiling glare. There was relatively little wall exhibition space for the size of the building. In any event it was not built.

Boullée's student, Durand continued these ideas with an emphasis on symmetry and massed columns, along with consideration on how exhibitions must be arranged in a more rational scheme (Plate 1.3). "A powerful precedent, and demonstrates his rationalistic method of planning, where units of space and structure were suavely combined, horizontally and vertically, to compose the whole."(7) Durand's lighting was more subtle and useful for exhibitions. The smaller "pantheon" center space is top lit which gives well distributed daylight; however there is little wall area here. The long galleries are lit by semi circular clerestory openings above a continuous frieze. These would likely cause veiling glare on the paintings.

The notion of creating a museum in the galleries of the Louvre, to be called Musée Français was put forward and proposals were made for lighting of the galleries. Hubert Robert's design for a skylight system (done in 1786) was realized after the French revolution P(1.4). The museum was opened in 1793, but other galleries have been added later and lit with side windows.

It was a while before the first museum as a completely detached building was built in America. In Philadelphia, the Pennsylvania Academy of Fine Arts opened in 1805-6, employing overhead natural lighting, P(1.5). "Keeping with 19th century ideas of expressive ornament, is the assertive iconography of the American eagle crowning the entrance, which brandishes in one talon the sculpter's mallet and in the other, the painter's palette and brushes" (8). This museum was also lit through the opening in the center of the rotunda.

The most significant model for contemporary museum design was completed in 1814. The Dulwich College Museum in London combined a number of galleries and a Mausoleum for the donor's family. Sir John Soane designed the galleries and 5 main rooms all lit from the top, with a clerestory skylight system Plate (1.6). The Dulwich gallery has been

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* These museums will be examined in detail in future chapters.

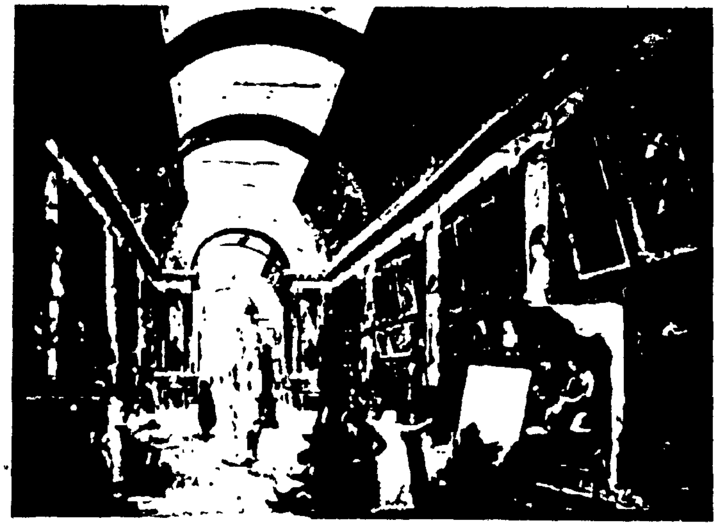


Plate 1.4, Hubert Robert, 'Project for lighting the Grande Galerie of the Louvre through the roof and for dividing it without taking away the view of the length of the premises', made c. 1876 and shown at the Salon of 1796 (Private Collection) [114].

Plate 1.5. Pennsylvania Academy of the Fine Arts, Philadelphia, First Building. John Dorsey, 1805-6; destroyed by fire, 1845. Exterior. Engraving by Benjamin Tanner. [109].

Plate 1.6, Dulwich Gallery, 1811-14, by Sir John Soane.

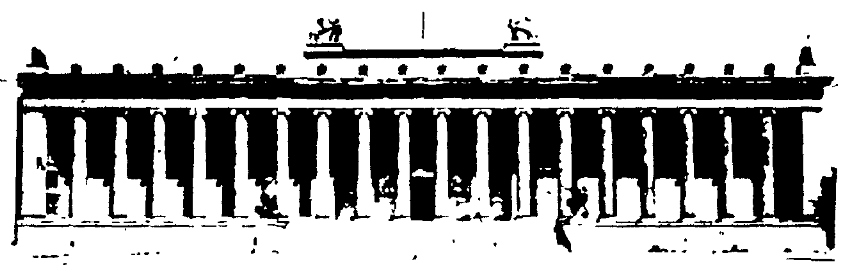
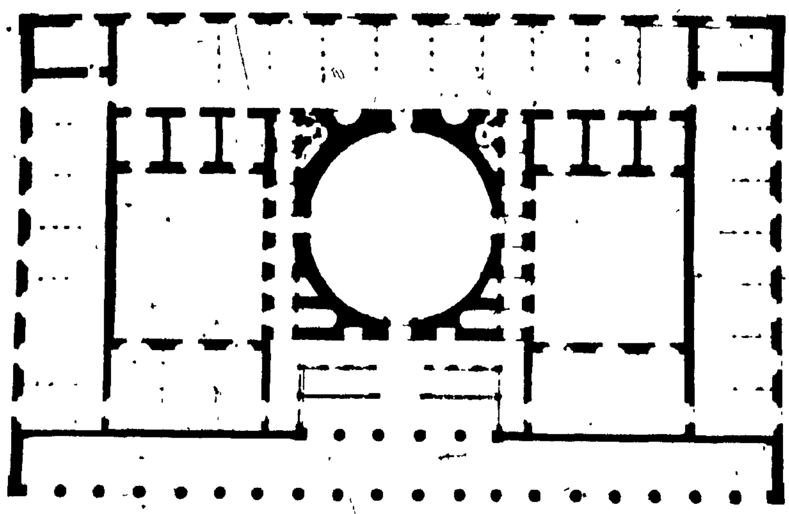


Plate 1.7 (a), Altes Museum, Berlin, Karl Friedrich Schinkel, 1823-30, Front elevation.

the model for the recently built Portland Museum by Henry Cobb* and the Mellon Center for British Art* at Yale by Louis Kahn. The clerestory is located out of the viewing zone and the truncated ceiling vaults distribute light evenly to the vertical walls.

At about the same time competitions were held for another major museum of the $19^{th}$ century [114], the Glyptothek in Munich, which prompted many design proposals and discussion of ideas centered on museums as building types Plate (1-12). Durand's design for museums was still influencing designers, as was the case with Altes Museum in Berlin. The large columned central rotunda became a precedent for many future museums, P(1-7). Unfortunately, the large number of vertical windows cause significant veiling glare on the exhibits.



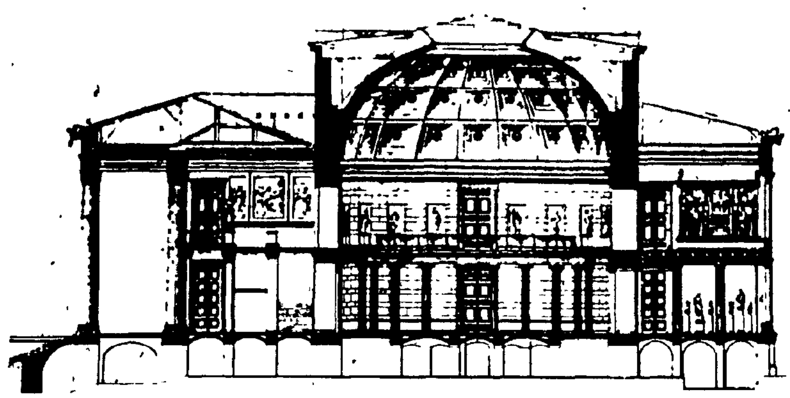


Plate 1.7, (b,c), Altes Museum, Berlin, Karl Friedrich Schinkel, 1823-30. Plan of upper floor and section. (Schinkel, Sammlung architektonischer Entwurfe, Berlin, 1819-43).

## 1.6 PUBLIC MUSEUMS

Museums remained as monumental places and functioned in this manner in Europe. On the other hand in America, public museums were there before private collections were formed, creating an institution for the good of the community as a whole, and not purely temples of art. Nevertheless there were people who collected works of art and the museum had to give some satisfaction to the donor's celebrated desires for monumentality. To respond to this need architects employed the 17$^{th}$ century classical motifs. Museums erected in this line of thought were the Chicago Art Institute 1893, Corcoran Gallery 1896, Metropolitian Museum 1902, and the Boston Museum 1909. These museums grew with the growth of their collections and new wings were added as the needs arose.

This was made possible due to the new principles of planning, such as independent wings, with independent circulation patterns, vertical divisions of galleries, and most importantly natural lighting in all galleries, either by opening to court yards through windows or sky lights on all second floor galleries. This can be clearly seen in the evolution of the Boston Museum of Fine Arts*, which has continued up to the present time Plate (1.8). Circulation and divisions of galleries were important design criteria, but none spurred more discussion than lighting. "If in 1917, Mondrian expressed a desire to paint his canvas in the same locale in which it would be hung, it was because he realized that the place in which a painting is encountered determines the viewer's perception of it."(9)

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* This museum will be examined in future chapters.

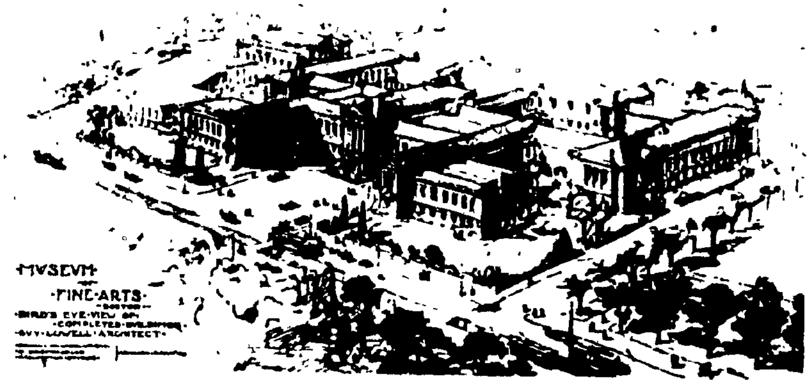


Plate (1.8.a), Museum of Fine Arts, Boston, Design for the completed museum adopted July 1906, some portions not executed. Bird's-eye view [114].

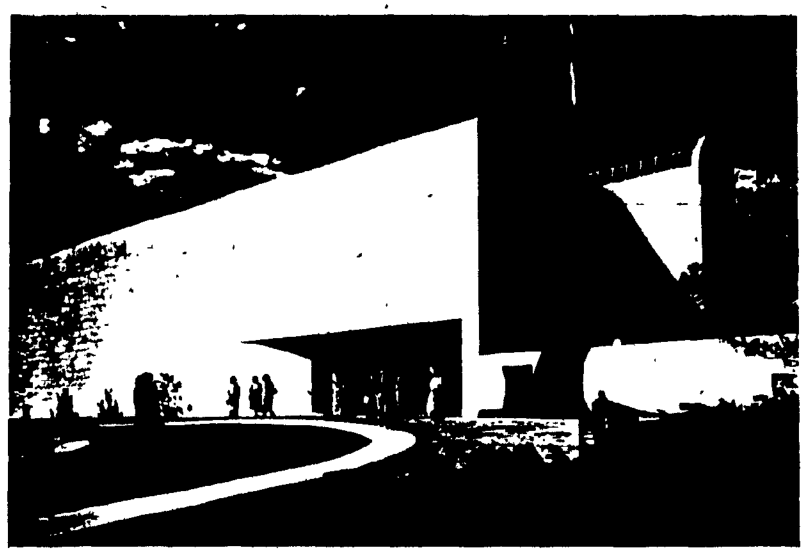

Plate (1.8.b), The Exterior view of the new addition to the Boston Museum [109].

Social and economical factors continued affecting architectural ideas, which naturally were translated into new museum designs. Art Moderne or Art Deco style, making use of classical vocabulary, and responding to modern needs is one of many. The Gray Museum in Springfield, Mass., (Plate 1.9) (1931-33) is designed in Art Deco style, which got its name from the 1925 exhibition of Des Arts Décoratifs in Paris. Then came the international style and the Modern Movement, which was introduced to America through the Museum of Modern Art in New York City. This museum which was completed in 1939 combined new cultural and social activities, and through its building exposed many ideas considered unique to the Modern Movement. "... Formal axes, grand corridors and fixed galleries are abandoned for loft-like floors that can be partitioned to resemble the New York City apartment of typical Museum of Modern Art donors .."(10). "The Museum for a small city" was another production by one of the leaders of modern architecture, Mies Van der Rohe (1886-1969) Plate (1.10). The vocabulary of monuments is changed and expression is only evident from the collage made from one of the galleries. Continuity of space, proportions, grids and geometrical massing were pushed to their extreme. More recent times evoked a new concept in exhibition techniques and lighting design advancement, but flexibility was discussed in length, from one extreme being the Guggenheim (1959) to loft like open spaces such as the Yale Art Gallery.

Differentiation of function took place at an earlier time with respect to activities for different interest groups and the provision

Plate (1.9), Museum of Fine Arts Springfield, Massachusetts. Edward L. Tilton and Alfred Morton Githens, 1931-33. [109].

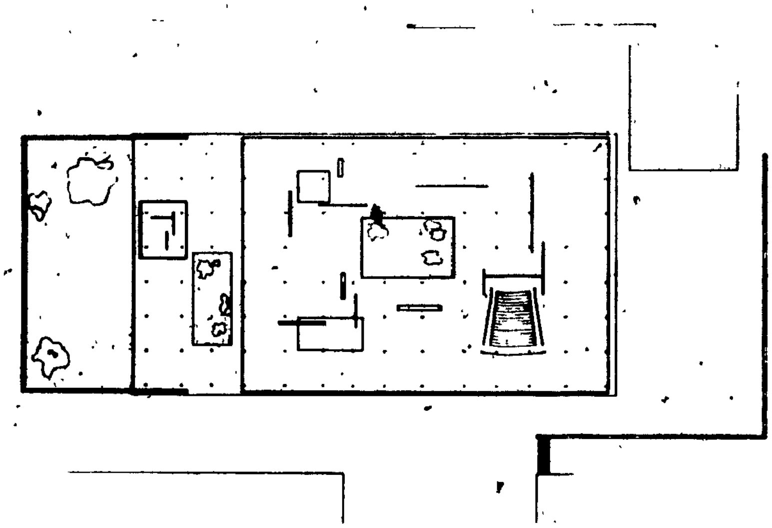

Plate (1.10), Ludwig Mies van der Rohe, "Museum for a Small City", 1942. Plan and interior view. [109].

for a variety of functions, such as libraries, auditoriums, offices and shops. For example the Corcoran Gallery of 1895 provided an art school, studios, a library, an auditorium plus a top-lit atrium for exhibition. In 1927 a museum skyscraper was proposed by Lee Simonson, which funnels people inward as activities become more specialized. Circular circulation was put forward by Clarence Stein in a project called "Museum of Tomorrow" which was intended to address the enormous size of American collections and consequent problems of differentiating between the public's 'museum of inspiration and student's museum of education.."[11]

Activities grew and by 1932, almost all museums tried to incorporate shops, lecture halls, restaurants, book and photo libraries, studios, storage area and conservation laboratories which must be accommodated and lit.

## 1.7 MUSEUM LIGHTING - CURRENT TRENDS

Among other factors affecting museum design, the lighting system is believed to have had the most impact "possibly the greatest technical change to have had an effect on the design of exhibitions, as well as on the presentation of permanent collections was lighting."[12] There are two trends in lighting design; either totally artifical or predominately natural lighting. The Everson Museum in Syracuse*, N.Y. is an example

* These Museums will be studied in future chapters.

of the former and new wings with greenhouse design at the Metropolitan Museum* in N.Y. of the latter Plate (1.11). In most cases each of these systems had to be combined and complimented with the other. General ambient lighting vs. spot lights and directional lighting, control over nature and "reproduction" of natural light led to the use of artifical lighting. In either system the creation of a unique visual environment for the object is the prime goal.

The uniqueness of a museum environment has many dimensions in comparison to other environments. "Museum viewing does not consist of the performance of a single, usually repetitive, task in a static situation but of seeing appreciably different objects in sequence. The problem is therefore not only to achieve visual acuity in relation to the illumination of a single object but to maintain that acuity over a range of objects viewed sequentially."(13) Architects have been struggling with solutions to this problem. L.I. Kahn (1901-1974) was very concerned with lighting and daylight in particular and conducted many studies to explore museum lighting. His final achievement was the Yale Center for British Art, an example of ingenuity in the design process Plate (1.12).

I.M. Pei, in the new addition to the Boston Museum of Fine Arts brings light in, but by different means and for different purposes. The galleria lights public activity areas, shops, restaurants, etc. During

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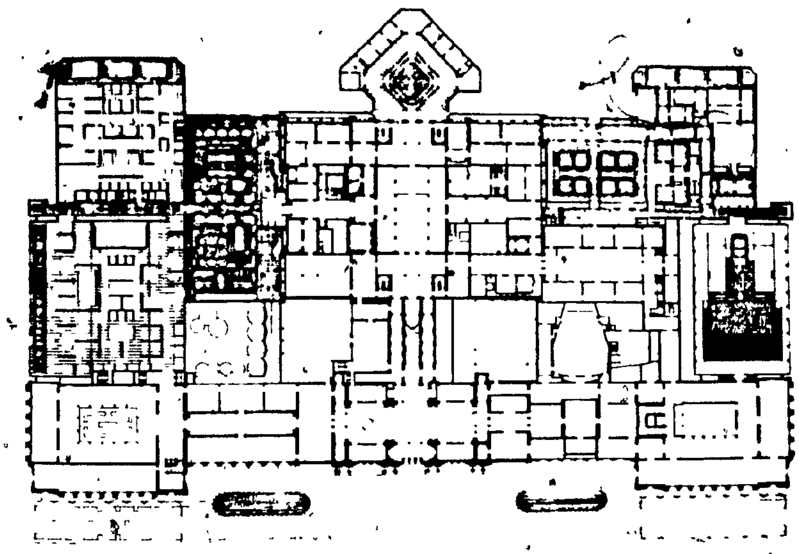
* These museums will be studied in future chapters.



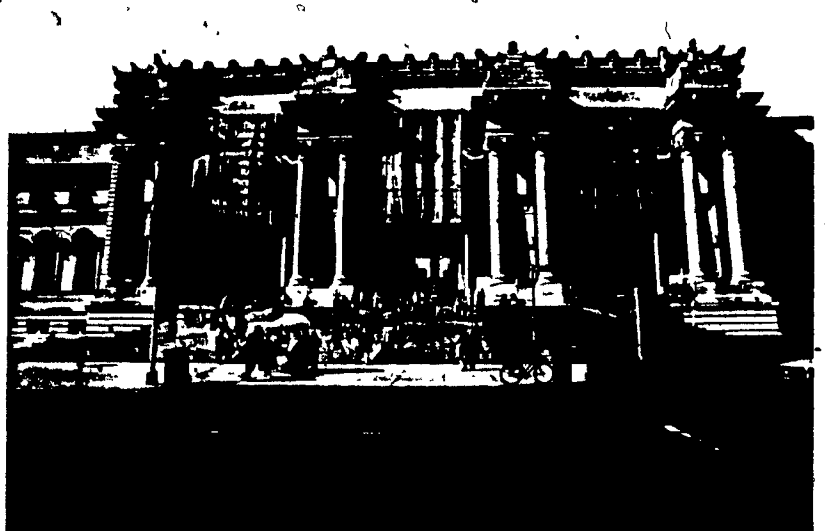
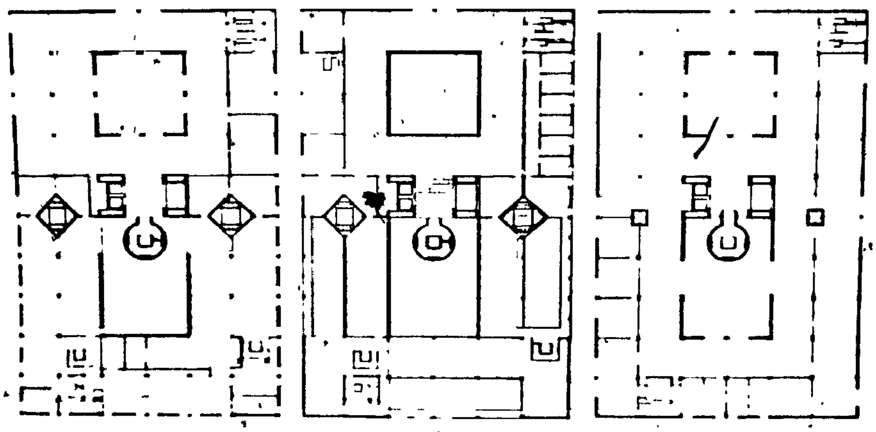


Plate (1.11), The Metropolitan Museum of Art, New York. Master plan showing original buildings and additions by Kevin Roche John Dinkeloo and Associates, 1967-81. [109].



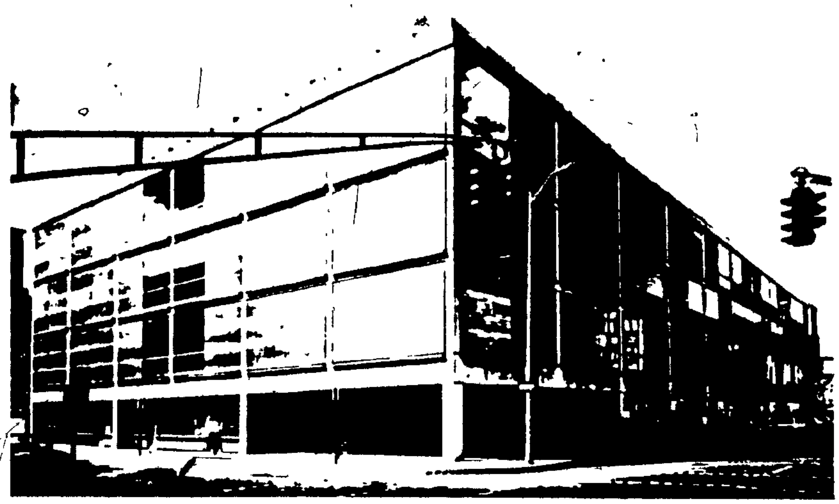


Plate 1.12), Yale Center for British Art, New Haven, Connecticut. Louis I. Kahn, 1969-77. Plan of fourth floor and exterior view. [109].

my discussion with the project architect he stated that modular sky lights for galleries, which were proposed once and rejected by trustees, were added at the later stage of construction at the curator's request.

## 1.8 MUSEUM DESIGN

Architects have been criticized from before the 1850's for not being successful in the distribution of light, or in the amount of space provided for pictures. For example in the Suffolk Street Gallery they put the window at the wrong angle and in the wrong place. The reflection created glare and seeing was difficult.

### 1.8.1 LIGHTING

Methods of lighting became more varied as increasingly sophisticated systems of artifical illumination were employed. While skylights continued to be used, side and clerestory windows were introduced to provide a different quality of natural light.

In general when lighting engineers get to design a lighting system, their design process takes into account:

1. the kind of human activity for which lighting is to be provided
2. the amount of light required
3. the color of the light as it may affect the viewing of particular objects and the environment as a whole

4. the distribution of light within the space to be lit whether indoors or outdoors and the directionality or modeling of the illumination
5. the effect of the lighting system itself on the users including contrast, glare.

Where the 5th criterion is the most important measurement of its success, it is usually lost in the design process. Other criteria when applied to museums have special definitions. People's responses are the most important yardstick. "Paintings are no more than dead surfaces; it is amongst the crowd that are felt the interplay, the explosions, the tremors of light described technically by recognized critics." (14)

The dilemma begins when what is considered desirable for people is in conflict with what is required for works of art. In the lighting design of any other building type this conflict is not so apparent. "For a large proportion of museum exhibits there is a considerable and, it would appear at first, serious divergence between their desirable lighting combinations and those necessary for a person viewing. To try and mediate between these conflicting needs is, it would seem, one of the critical problems of museum design."(15)

**1.8.2 PLANNING**

Architecture, particularly monumental architecture, creates an awareness in people depending on their values and outlooks. In order for this experience to take place, a harmony must exist among the space, element of definition of this space, the objects displayed and the means of seeing and sensing the space. This is where the architect, lighting designer and conservationists should come into harmony. The monument is not the sole purpose of building creation; the painting should not be stored in dark basements and the foot candle is not the solution to a visual environment. The architectural concepts have changed and are still changing, hopefully in relation to social changes. At one time the art museum was supposed to have been a place whereby artistic values took precedence over other matters. Art museums as places of memories have lost their contact with the past, being the object on display. The relationship between the object and its support has not been taken into consideration. Architecture seems to be serving the role of an empty stage, providing a path for any leading actors to play. The curator of the Lehman Gallery was concerned that each collection should be examined thoroughly by the architect and lighting designer before creating its setting. Creation of facades or volumes in relation to a particular content were concerns expressed by curators and conservationists to architects. A choice of classical precedent, regardless of interior function, was practiced. "There was further opportunity for individual interpretation through the choice of models: the Greek temple, Roman basilica, Renaissance Palace, and Beaux-Arts Grand Prix were all deemed appropriate for imitation and metamorphosis." (16).

At the time of competition for the Munich Glyptothek, 1815 Leo Von Klenze offered three designs: one Grecian, one Roman and one Renaissance Plate (1.13). Nevertheless his approach was supported too. "... the art museum is a prestige building, a sparkling cultural jewel in the mundane crown of the commercial landscape and the importance of the symbolic function of the building can sometimes overwhelm a consideration of its more practical uses. Nor is the special meaning of the building lost on architects, no other type of edifice, including the church, seems to have provoked in these years such creative fantasy as art museums."(17) Art museum's architecture has provoked discussions on integration of allied art, architecture and technology, since all play important roles in the creation and function of museums. This integration is of utmost concern in the design of a visual environment.

## 1.10 CONCLUSION

The prime function of museums is the creation of a proper environment for viewers and the works of art. In meeting this requirement, many solutions and designs have been proposed; some were built and some were left as ideas. The need for light, a common factor, creates a continuity among museums throughout time.

As we have seen daylight was the only source for centuries before being replaced to some extent by artificial light. The trend has changed and many new museums are being designed and built with daylight

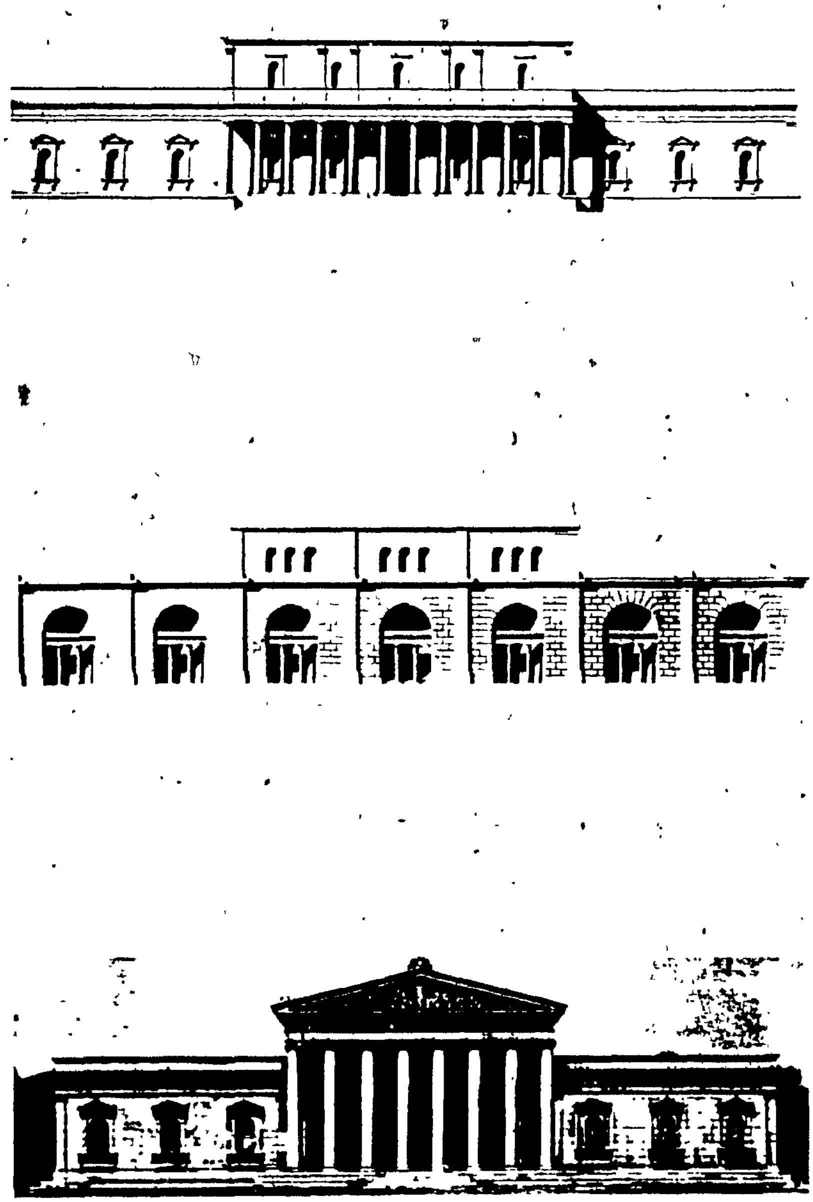


Plate (1.13), The three proposals for Munich, Glyptothek 1815 by Leo von Klenze [114].

as the main source. Examples are the High Museum of Art Atlanta, the National Art Gallery Ottawa, Nochein Museum Frankfurt and the Municipal Museum Mönchengladbach West Germany.

Daylight has been introduced in various ways with varying proportions, densities and qualities. The needs and desires of the viewer have been met to a certain degree. However, conflict between the needs of the viewer and that of the works of art have not been explored. The architectural concepts, with regard to function, planning, urban design and finally the interior reveal that the visual environment has not been explored and the need for a study exists.

1. A survey of early museums showed apparent problems with veiling glare and discomfort glare. Examples are Plates 1.1, 1.2, 1.3, 1.7, 1.8a, 1.9, 1.10, 1.12, 1.13.

2. A few exceptional early museums avoided glare and became prototypes for latter and contemporary museums. Examples are Plates 1.6, 1.11.

3. Methods of display have changed dramatically which affect the viewer to object relationship and visibility.

4. The lighting designs of early museums have been mainly a function of architectural considerations. Technically trained lighting designers have not had a role in daylight design. This trend has changed only recently; however the lack of an integrated technical information resource has handicapped all professionals involved in museum daylighting.

5. It has been shown and expressed by curators that, lighting designs of museums have been usually copied from commercial buildings, since not much practical research exists in this area. Too often those concerned with constructing museums have merely adapted techniques of lighting and display developed for other - usually commercial - purposes without realizing that these techniques were frequently inappropriate to the purpose of a museum.

6. Viewers come to museums to enjoy, to learn, to teach, to communicate, and to take part in many other social, cultural and educational activities that museums are providing. To create such a visual environment, a close cooperation among architects, lighting designers, conservationists and curators is deemed to be inevitable and necessary. All parties must have a proper understanding of the goals and concerns of each other, the museum's needs and the visitor's demands.

## 1.11 FOOTNOTES APPENDIX I

1. S.E. Lee, and J.B. Henning, On Understanding of Art Museums, (Englewood Cliffs, New Jersey: Prentice Hall Inc., 1974), p. 6.

2. Kenneth Hudson, A Social History of Museums, (London: the Macmillan Press Ltd., 1975), p. 25.

3. Helen Searing, New American Art Museums (New York: Whitney Museum of American Art in Assoc. with the Univ. of California Press, Berkley, 1982), p. 35.

4. Hudson, p. 10.

5. Ibid, p. 12.

6. André Malraux, Museum Without Walls, (Translated from French by Stuart Gilbert and Francis Price, Doubleday, New York, 1967), p. 223.

7. Searing, p. 15.

8. Malraux, p. 230.

9. Ibid, p. 231.

10. Searing, p. 50.

11. Lee and Henning, p. 63.

12. Ibid, p. 75.

13. M. Brawne, "Museum Design for Conservation," Paper to IIC Conference in London, 1967, pp. 75-78.

14. Lotus International, Quarterly Review, No. 35, p. 3.

15. Brawne, p. 76.

16. Searing, p. 35.

17. Lee and Henning, p. 52.

# APPENDIX 2

## MEASUREMENT OF COLOR

APPENDIX 2

## A.1 MEASUREMENT OF COLOR

The key to the measurement of color is the spectral power distribution curves of the source and the reflected light from the object. The SPD curves are used to determine chromaticity, color temperature and color rendering of the source, as well as the color of objects and their color change which is important to conservationists.

The CIE chromaticity system is based on the CIE standard colorimetric observer. This is a tabulation of the CIE spectral tristimulus values for colors that could be identified by their wavelength. They are designated by the symbol $\bar{X}$, $\bar{Y}$ and $\bar{Z}$, in which $\bar{Y}$ is basically the CIE standard observer tabulation [115]. The chromaticity coordinates for the pure spectral colors are obtained from:

$$X = \frac{\bar{X}}{\bar{X} + \bar{Y} + \bar{Z}}, \qquad Y = \frac{\bar{Y}}{\bar{X} + \bar{Y} + \bar{Z}}, \qquad Z = \frac{\bar{Z}}{\bar{X} + \bar{Y} + \bar{Z}}$$

where $X + Y + Z = 1$

The spectral locus, Plate (3.9), is plotted by the use of X and Y coordinates for all the pure colors. On this curve the point X = 0.3333, Y = 0.3333 at E corresponds to a hypothetical white radiation or daylight. The purple is indicated by a straight line since it is not a spectral color seen by the eye. The X, Y of any color is located in the area and its location determines its saturation. With regard to the color of objects, a straight line connecting the source on the locus to the point of color and continuing until it intersects with the locus, will result in the corresponding wavelength of the object color [70].

### A.3.2 CORRELATED COLOR TEMPERATURE

If we consider that light as the quantas of energy emitted by a black body at various wavelengths, the mathematical expression by Planck relates the rate of energy emission to the wavelength of radiation and temperature of radiant material. Therefore the temperature of a black body is directly proportional to the energy emitted but inversely related to the wavelength [51]. Graphs of SPD of black body radiators between 2000K and 6000K are plotted [115]. As an example, viewing through the hole in the furnace, illustrates the concept of color temperature. It first radiates heat (red), then it begins to glow and becomes white hot and finally blue. The locus of black body chromaticities on the X-Y diagram is known as the Planckian locus. Therefore any chromaticity represented by a point on this locus may be expressed by a color temperature.

The perceived color of the black body follows the limitations expressed in chapter (3) with regard to the eye, i.e. adaptation. The SPD of all phases of daylight with their corresponding color temperature are plotted [71]. Color temperature is used regularly to identify artificial sources. Plate (A.3.1) is the SPD of two incandescent lamps. If the X and Y of a source are plotted and do not fall on the black body locus but their chromaticity most nearly matches that of the light source, then a correlated color temperature (CCT) is assigned.

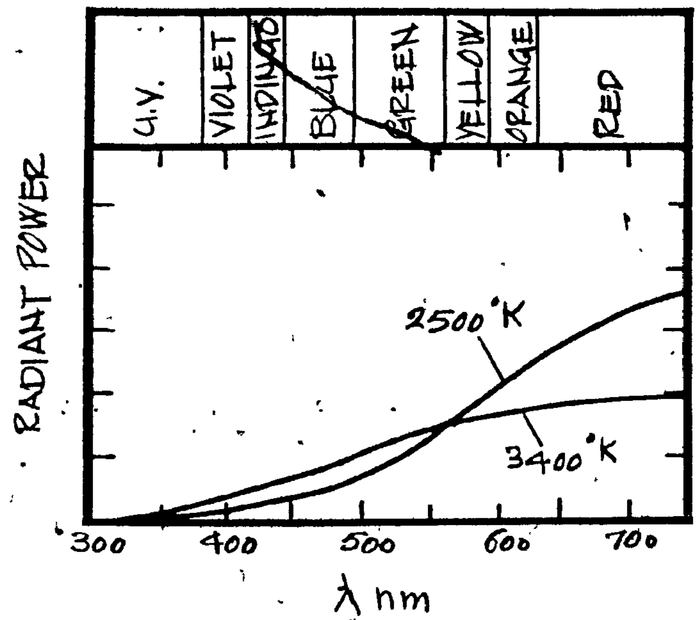



Plate A.3.1. Spectrial power distribution for an Incandescent lamp [116].

| SOURCE | CCT °K |
|---|---|
| Clear blue sky | 15,000 - 30,000 |
| Overcast sky | 6500 |
| Zenith sun (clear day) | 6200 |
| Tungsten halogen lamp | 2300 - 3400 |
| Tungsten lamp | 2700 - 3100 |
| Fluorescent lamp | 2900 - 4500 |

Table A.3.1, correlated color temperature of some museum source [40]

This is the case with fluorescent lamps; the CCT assigned to the lamps correspond to the temperature of a black body that is of closest match to the lamp. The color temperature of various possible museum light sources are tabulated in Table (A.3.1). Color temperature is a very good measure of the color to be expected from a source as it is located analytically through chromaticity calculations.

COLOR RENDERING INDEX

To measure the color characteristics of any light source, to render the color or the appearance of a colored object "correctly", one needs a quantitative value. Therefore CRI is the measure (on a comparative basis) of the accuracy of the object color, illuminated by the light source whose color rendering properties are being studied. Different from the chromaticity process and color temperature evaluation, the CRI cannot be expressed by simple viewing and it requires an analytical approach. The SPD of the source is very important in this process and should be known. The accepted standard is a black body radiator in different C.T.'s. Therefore when there is an expression of CRI we must match the C.T. of the reference source and the unknown source.

The CRI is useless for daylit galleries since sources of different CT are mixed. As well it does not consider relative color perception and the complex psychological process of human perception.

# APPENDIX 3

## TABLES OF DETERIORATION DATA

| | Wave length | Incandescent lamp (2,854° K) | Daylight fluorescent (6500° K) | Warm-white deluxe fluorescent (2,900° K) | Cool-white deluxe fluorescent (4,300° K) | Sun at 30° altitude (Air mass 2, (5,300° K) | Overcast Sky (6,400°K) | Zenith Sky (11,000°K) |
|---|---|---|---|---|---|---|---|---|
| UV | 300 | 0.04 | 0.05 | 3.1 | 4 | 8.4 | 7.1 | 36.6 |
| | 320 | .55 | .5 | 6.7 | 10 | 19.4 | 55.3 | 227.6 |
| | 340 | 1.18 | .1 | 12.0 | 16 | 35.5 | 65.9 | 222.2 |
| | 360 | 2.10 | 6.2 | 17.0 | 22 | 42.2 | 67.0 | 183.5 |
| | 380 | 3.40 | 5.5 | 6.0 | 12 | 49.9 | 69.4 | 162.1 |
| Visible | 400 | 5.09 | 24.0 | 27.0 | 44 | 74.4 | 88.2 | 178.8 |
| | 420 | 7.26 | 21.0 | 6.0 | 30 | 96.3 | 103.8 | 185.4 |
| | 440 | 9.93 | 57.0 | 57.0 | 97 | 113.2 | 108.4 | 173.0 |
| | 460 | 13.10 | 31.5 | 7.0 | 46 | 121.7 | 115.3 | 166.8 |
| | 480 | 16.70 | 31.0 | 7.0 | 46 | 118.3 | 108.5 | 144.7 |
| | 500 | 20.70 | 28.0 | 13.0 | 49 | 121.5 | 106.5 | 130.4 |
| | 520 | 25.00 | 25.0 | 43.0 | 66 | 119.9 | 104.4 | 116.9 |
| | 540 | 29.70 | 34.5 | 79.0 | 100 | 119.8 | 100.7 | 106.2 |
| | 560 | 34.60 | 26.5 | 51.0 | 67 | 118.2 | 98.1 | 98.2 |
| | 580 | 39.50 | 35.0 | 77.0 | 88 | 116.8 | 95.3 | 91.1 |
| | 600 | 44.60 | 28.5 | 97.0 | 97 | 116.7 | 92.1 | 84.8 |
| | 620 | 49.60 | 19.0 | 95.0 | 95 | 116.5 | 88.7 | 78.7 |
| | 640 | 54.50 | 11.0 | 72.0 | 72 | 117.5 | 85.3 | 73.4 |
| | 660 | 59.50 | 6.0 | 45.0 | 47 | 116.6 | 81.9 | 68.5 |
| | 680 | 63.70 | 3.0 | 24.0 | 28 | 114.9 | 78.5 | 64.1 |
| | 700 | 68.50 | 1.4 | 12.0 | 14 | 110.8 | 74.7 | 59.9 |
| | 720 | 72.60 | 1.0 | 9.0 | 10 | 83.2 | 70.1 | 55.9 |
| | 740 | 76.40 | .7 | 6.0 | 7 | 104.1 | 65.1 | 52.1 |
| | 760 | 80.00 | .5 | 4.0 | 5 | 56.6 | 56.1 | 44.4 |

Table (A-4.1), Spectral distribution of irradiance, $H_\lambda$, from the seven light sources studied. (Figures in parentheses are approximate color temperatures in degrees Kelvin.) [1].

| Wave length | $\bar{y}_\lambda$ | $D_\lambda$ |
|---|---|---|
| 300 | 0.0000 | 7.75 |
| 320 | .0000 | 4.50 |
| 340 | .0000 | 2.63 |
| 360 | .0000 | 1.45 |
| 380 | .0000 | 1.07 |
| 400 | .0004 | .66 |
| 420 | .004 | .37 |
| 440 | .023 | .20 |
| 460 | .060 | .12 |
| 480 | .139 | .065 |
| 500 | .323 | .037 |
| 520 | .710 | .021 |
| 540 | .954 | .012 |
| 560 | 0.995 | 0.007 |
| 580 | .870 | .004 |
| 600 | .631 | .002 |
| 620 | .381 | .001 |
| 640 | .175 | .0005 |
| 660 | .061 | .0000 |
| 680 | .017 | .0000 |
| 700 | .0041 | .0000 |
| 720 | .0010 | .0000 |
| 740 | .0003 | .0000 |
| 760 | .0001 | .0000 |
| 780 | .0000 | .0000 |

Table (A-4.2), Probable relative damage. $D_\lambda$, caused by unit irradiance as a function of wavelength compared to the luminous efficiency, $\bar{y}_\lambda$, of radiant energy for the average normal eye (CIE standard observer).

| | Wave Length mu mm | Kingsport water-white glass | Ordinary window glass | Corning Greenish Nultra Glass | Corning Noviol O | Plexiglas LPC-518K | Pittsburgh Laminated X-Ray Lead |
|---|---|---|---|---|---|---|---|
| UV | 300 | 0.048 | 0.000 | 0.00 | 0.000 | 0.000 | 0.000 |
| | 320 | .557 | .000 | .00 | .000 | .000 | .000 |
| | 340 | .933 | .380 | .00 | .000 | .000 | .000 |
| | 360 | .986 | .783 | .06 | .000 | .001 | .000 |
| | 380 | 1.000 | .902 | .34 | .084 | .028 | .000 |
| Visible | 400 | 1.000 | .946 | .74 | .44 | .635 | .031 |
| | 420 | 1.000 | .967 | .87 | .69 | .962 | .218 |
| | 440 | 1.000 | .978 | .93 | .81 | .989 | .478 |
| | 460 | 1.000 | .978 | .96 | .90 | .992 | .675 |
| | 480 | 1.000 | .978 | .97 | .93 | .995 | .798 |
| | 500 | 1.000 | .989 | .98 | .96 | .997 | .870 |
| | 520 | 1.000 | .989 | .99 | .98 | .998 | .903 |
| | 540 | 1.000 | .989 | 1.00 | .99 | .999 | .915 |
| | 560 | 1.000 | .989 | 1.00 | 1.00 | 1.000 | .922 |
| | 580 | 1.000 | .978 | 1.00 | 1.00 | 1.000 | .923 |
| | 600 | 1.000 | .978 | 1.00 | 1.00 | 1.000 | .922 |
| | 620 | 1.000 | .967 | 1.00 | 1.00 | 1.000 | .907 |
| | 640 | 1.000 | .957 | 1.00 | 1.00 | 1.000 | .895 |
| | 660 | 1.000 | .946 | 1.00 | 1.00 | 1.000 | .890 |
| | 680 | 1.000 | .940 | 1.00 | 1.00 | 1.000 | .884 |
| | 700 | 1.000 | .935 | 1.00 | 1.00 | 1.000 | .875 |
| | 720 | 1.000 | .924 | 1.00 | 1.00 | 1.000 | .869 |
| | 740 | 1.000 | .913 | 1.00 | 1.00 | 1.000 | .856 |
| | 760 | 1.000 | .891 | 1.00 | 1.00 | 1.000 | .843 |

Note: If both Kingsport Water White Glass and Plexiglas LPC-518K are used together in a fluorescent fixture the combined transmittance will be the same as for the Plexiglas filter above.

Table (A-4.3), Spectral internal transmittance of six filters [1].

| Wave length | From Table A-4.2 | | From Table A-4.1 | Products | | From Table A-4.3 Noviol O | Products | |
|---|---|---|---|---|---|---|---|---|
| 300 | .0000 | 7.75 | 36.6 | 0.0 | 284 | 0.000 | 0.0 | 0.0 |
| 320 | .0000 | 4.50 | 227.6 | 0.0 | 1024 | .000 | 0.0 | 0.0 |
| 340 | .0000 | 2.63 | 222.2 | 0.0 | 584 | .000 | 0.0 | 0.0 |
| 360 | .0000 | 1.45 | 183.5 | 0.0 | 266 | .000 | 0.0 | 0.0 |
| 380 | .0000 | 1.07 | 162.1 | 0.0 | 173 | .084 | 0.0 | 14.5 |
| 400 | .0004 | .66 | 178.8 | 0.1 | 118 | .44 | 0.0 | 51.9 |
| 420 | .004 | .37 | 185.4 | 0.7 | 69 | .69 | 0.5 | 47.6 |
| 440 | .023 | .20 | 173.0 | 4.0 | 35 | .81 | 3.2 | 28.4 |
| 460 | .060 | .12 | 166.8 | 10.0 | 20 | .90 | 9.0 | 18.0 |
| 480 | .139 | .065 | 144.7 | 20.1 | 9 | .93 | 18.7 | 8.4 |
| 500 | .323 | .037 | 130.4 | 42.1 | 5 | .96 | 40.4 | 4.8 |
| 520 | .710 | .021 | 116.9 | 83.0 | 2 | .98 | 81.3 | 2.0 |
| 540 | .954 | .012 | 106.2 | 101.3 | 1 | .99 | 100.3 | 1.0 |
| 560 | .995 | .007 | 98.2 | 97.7 | 1 | 1.00 | 97.7 | 1.0 |
| 580 | .870 | .004 | 91.1 | 79.3 | 0 | 1.00 | 79.3 | 0.0 |
| 600 | .631 | .002 | 84.8 | 53.5 | 0 | 1.00 | 53.5 | 0.0 |
| 620 | .381 | .001 | 78.7 | 30.0 | 0 | 1.00 | 30.0 | 0.0 |
| 640 | .175 | .0005 | 73.4 | 12.8 | 0 | 1.00 | 12.8 | 0.0 |
| 660 | .061 | .0000 | 68.5 | 4.2 | 0 | 1.00 | 4.2 | 0.0 |
| 680 | .017 | .0000 | 64.1 | 1.1 | 0 | 1.00 | 1.1 | 0.0 |
| 700 | .0041 | .0000 | 59.9 | 0.2 | 0 | 1.00 | 0.2 | 0.0 |
| 720 | .0010 | .0000 | 55.9 | 0.1 | 0 | 1.00 | 0.1 | 0.0 |
| 740 | .0003 | .0000 | 52.1 | 0.0 | 0 | 1.00 | 0.0 | 0.0 |
| 760 | .0001 | .0000 | 44.4 | 0.0 | 0 | 1.00 | 0.0 | 0.0 |
| | | | Sums | 540.2 | 2591 | | 532.3 | 177.6 |
| | | | Ratios | 2591/540.2 = 4.80 | | | 177.6/532.3=0.334 | |

Table (A-4.4) Details of the computation of probable rate of damage per footcandle for Zenith skylight and for Zenith skylight filtered Corning Noviol O glass. [1].

| Condition and Location | fc. | IX . |
|---|---|---|
| Standard clear sky and sun | 8000. | 100. |
| N.Y. City clear air and sun | 6450. | 95.5 |
| N.Y. City overcast | 1160. | 16.5 |
| 1. DAYLIGHT IN GALLERIES*: | | |
| (a) Floor exhibits - without sun louvers | 498 | 3.02 |
| (b) Wall exhibits - without sun louvers | 174 | 1.06 |
| (c) Floor exhibits - with sun louvers** | 169 | 1.03 |
| (d) Wall exhibits - with sun louvers** | 59 | 0.36 |

2. ARTIFICIAL LIGHT IN GALLERIES:

| LOCATION & SPECIAL FILTER, IF ANY | INCANDESCENT (2854° K) | | FLUORESCENT Daylight (6500° K) | | Warm Delx. (2900° K) | | Cool Delx. (4300° K) | |
|---|---|---|---|---|---|---|---|---|
| | fc | IX | fc | IX | fc | IX | fc | IX |
| Floor Exhibits: | | | | | | | | |
| Bare | 30 | 0.04 | 30 | 0.11 | 30 | 0.12 | 30 | 0.15 |
| Water White Glass | 30 | 0.04 | 30 | 0.11 | 30 | 0.09 | 30 | 0.13 |
| Corning Noviol 0 | 30 | 0.01 | - | - | - | - | - | - |
| Plexiglas LPC-518K | - | - | 30 | 0.07 | 30 | 0.02 | 30 | 0.03 |
| Wall Exhibits: | | | | | | | | |
| Bare | 12 | 0.02 | 12 | 0.04 | 12 | 0.05 | 12 | 0.06 |
| Water White Glass | 12 | 0.01 | 12 | 0.05 | 12 | 0.04 | 12 | 0.05 |
| Corning Noviol 0 | 12 | 0.00 | - | - | - | - | - | - |
| Plexiglas LPC-518K | - | - | 12 | 0.03 | 12 | 0.01 | 12 | 0.01 |
| Emphasis Spots*** | | | | | | | | |
| Bare | 60 | 0.08 | - | - | - | - | - | - |
| Water White Glass | 60 | 0.08 | - | - | - | - | - | - |
| Corning Noviol 0 | 60 | 0.02 | - | - | - | - | - | - |
| Case Lighting | | | | | | | | |
| Bare | 60 | 0.08 | 60 | 0.22 | 60 | 0.24 | 60 | 0.30 |
| Window Glass | 60 | 0.06 | 60 | 0.20 | 60 | 0.12 | 60 | 0.16 |
| Water White Glass | 60 | 0.08 | 60 | 0.22 | 60 | 0.18 | 60 | 0.26 |
| Plexiglas LPC-518K | - | - | 60 | 0.14 | 60 | 0.04 | 60 | 0.06 |

* Based on probable rate of damage per footcandle (D/fc), adjusted for transmittance through roof and ceiling glass, Clear Sky - 1.56, Sun - 0.421, Overcast Sky - 0.672, in proportions as given.
** When properly operated.
*** These values, both in fc and IX, should be added to those for general illumination whichever source is used for either floor or wall exhibits.

Table (A-4.5), Probable degree of damage hazard (annual) from light sources in the Metropolitan Museum of Art. (Showing an average illumination from sources, fc and index of Exposure, IX).

# SAMPLE OF MUSEUM LIGHTING

# SURVEY HANDBOOK

# MUSEUM LIGHTING

# SURVEY HANDBOOK

MUSEUM:
LOCATION:
DATE:
BY:

MUSEUM LIGHTING SURVEY

A. GENERAL INFORMATION

MUSEUM: NAME: ______________________________

LOCATION: ______________________________

AREA SURVEYED: ______________________ FLOOR: __________

DIMENSIONS: L = ____ W = ____ H = ____ OTHER = __________

ADJACENT AREA: ______________________________

TABLE I. GENERAL CONDITIONS

| INTERIOR SURFACE | | MATERIAL | TEXTURE | COLOR | L1 | L2 | REFLECTANCE | CONDITION |
|---|---|---|---|---|---|---|---|---|
| CEILING | | | | | | | | |
| SKYLIGHT | | | | | | | | |
| WALL / WINDOWS | (S) | | | | | | | |
| | (N) | | | | | | | |
| | (W) | | | | | | | |
| | (E) | | | | | | | |
| FLOOR | | | | | | | | |
| SHADES OR BLINDS | | | | | | | | |
| OBJECT SURFACES | | | | | | | | |
| 1. | | | | | | | | |
| 2. | | | | | | | | |
| 3. | | | | | | | | |
| 4. | | | | | | | | |

Texture: Gloss, Semigloss, Matte, Rough, Soft.

Colour: pink, red, orange, brown, tan, olive, green, blue, purple, white, gray, black (light, medium, dark).

L1. Illuminance of standard gray card with known reflectance.

L2. Illuminance of plane

$$\text{reflectance } \rho_2 = \frac{L_1 \times \rho_1}{L_2}$$

Notes on general information:

## B. DESCRIPTION OF GENERAL LIGHTING SYSTEM

1. DAYLIGHT: WINDOWS ______________ SKYLIGHTS ______________

2. TABLE 2. LUMINAIRES

| Quantity | Wattage | Light Source | Distribution | Description | Spacing | Mounting | M.H. or susp. | Condition |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |

NOTES:

Light sources: incandescent filament, flourescent, mercury.

Distribution: direct, semi-direct, general diffuse, semi-indirect, indirect.

Type of mounting: recessed, semi-recessed, surface, suspended

Description: straight incandescent, daylight incandescent, tinted incandescent, cool white, warm white, daylight, delux.

Notes on lighting system:

## C. DRAWINGS

1. Draw required sketches for the survey:

   Show 1. Center line of space

   2. Door and window openings

   3. Skylight

   4. Picture location

   5. Switch location

   6. Section cuts

## D. DATA

### I OUTSIDE

1. Calibration: - Turn on the instrument, stabilize for 15M.

2. Set up the chart recorderer and solar cells one in shade, one in sun.

3. Weather condition: start: ______________ finish: ______________

4. Exact time to start the chart recorderer: ______________

5. U.V. reading out side: shade: ______________ sun: ______________

   NOTES: ______________________________

   ______________________________

   ______________________________

### II INSIDE

6. Indicate the route on the plan, no. the points.

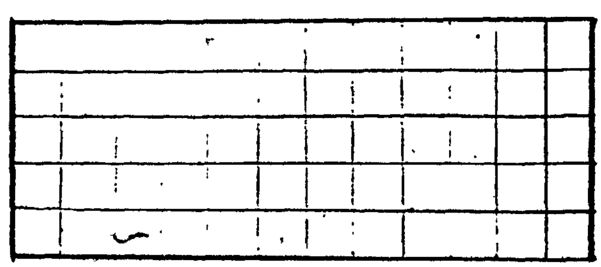
7. Starting time: ______________________________

8. Tape data in this order: point no., time, lower lux, upper lux, U.V., U.V./lum, colour temperature.

9. Data taken from one painting.

   - Indicate points

   - Read each point number, time, lux, U.V., colour temperature at the centre.



## III BRIGHTNESS MEASUREMENTS

1. Indicate points on the plan as standing in the centre of this space dall point no. and reading with meter.

F. TEST PANELE BRIGHTNESS

1. Take brightness readings before photography recording and after.

2. TABLE 4: BRIGHTNESS

| POINT | BRIGHTNESS BEFORE | BRIGHTNESS AFTER |
|---|---|---|
| CARDS 1. white | | |
| 2. off white | | |
| 3. light grey | | |
| 4. grey | | |
| 5. dark grey | | |
| 6. black | | |
| DARKEST | | |
| BRIGHTEST | | |

NOTES:

## E. VISUAL RECORDING

1. Colour Slide:
   - To show the general areas
   - To show the glare source (use polarizer)
   - Use colour sample strips

2. Equipment:

Lense ______________ Film type ______________

Camera ______________ Film ASA ______________

Filter ______________ Emulsion No. ______________

3. TABLE 3: COLOUR SLIDES

| VIEW | F-STOP | T-SHUTTER SPEED |
|---|---|---|
| N. 1. | | |
| W. 2. | | |
| S. 3. | | |
| E. 4. | | |
| OTHER 5. | | |
| 6. | | |
| 7. | | |
| 8. | | |
| 9. | | |
| 10. | | |

NOTES:

Locate camera position and arrows of views.

## G. PHOTOGRAPHIC RECORDING

1. Equipment:

   Camera: ____________ Film type: ____________

   Lense: ____________ Film ASA: ____________

   Filter: ____________ Emulsion No.: ____________

2. Grey and colour strips in view.

3. TABLE 5: $T_1$ = ________ $F_1$ ________

| VIEW | $F_1/\frac{1}{8}T_1$ | $F_1/\frac{1}{4}T_1$ | $F_1/\frac{1}{2}T_1$ | $F_2/T_1$ | $F_1/T_1$ | $F_3/T_1$ | $F_1/2T_1$ | $F_1/4T_1$ | $F_1/8T_1$ |
|---|---|---|---|---|---|---|---|---|---|
| N. | | | | | | | | | |
| W. | | | | | | | | | |
| S. | | | | | | | | | |
| E. | | | | | | | | | |
| Ceiling | | | | | | | | | |

4. Record brightness at (F) stage.

NOTES: $F_1$, $T_1$ CORRECT EXPOSURE
$F_2$ $F_1$ + 1/2F 1/2 step up
$F_3$ $F_1$ - 1/2F 1/2 step down

## H. GENERAL OBSERVATIONS

1. Are viewers subject to undue glare conditions from general lighting system? ____________________

   ____________________

   - supplementary lighting? ____________________

   ____________________

   - daylighting? ____________________

   ____________________

2. Are viewers subject to undue reflected glare conditions from general lighting system? ____________________

   ____________________

   - supplementary lighting? ____________________

   ____________________

   - daylighting? ____________________

   ____________________

3. What daylighting control means are used and how effective? ____________________

   ____________________

   ____________________

   ____________________

4. Are viewers subjected to troublesome shadows? Diagram the problem.

   ____________________

   ____________________

   ____________________

5. Are U.V. control means used? If yes, what kind? When? ____________________

   ____________________

   ____________________

   ____________________

   ____________________

6. What is your opinion of the general lighting system? ______________

____________________________________________

____________________________________________

gloom? ______________________________________

____________________________________________

7. What is your opinion of general visual comfort? ______________

____________________________________________

____________________________________________

____________________________________________

____________________________________________

____________________________________________

8. How effective is the lighting scheme with regard to the viewing of works of art? ______________________________

____________________________________________

____________________________________________

____________________________________________

____________________________________________

9. General comments: ______________________________

____________________________________________

____________________________________________

____________________________________________

____________________________________________

____________________________________________