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WINDOWS, SKYLIGHTS, AND ATRIA--OCCUPANTS' VISUAL/SUBJECTIVE COMPARISON

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ABSTRACT

Windows, skylights, and glazed atria are all used for admission of daylight into buildings. This paper concentrates on a comparison of subjective occupant attitudes and responses to these design strategies. First, the problem is defined. Then the light directional properties of the various solutions are examined and a comparison made between possible subjective/psychological responses to these solutions. The aspects of the view outside the building, spectral distribution, the variability of daylight, and the effect of the depth of daylight penetration into the built spaces and the resultant light intensities are examined and the subjective responses are compared.

It is acknowledged that there is a need for much more systematic investigation in this field to be able to establish more firm conclusions.

A technical/economical comparison of these design strategies will be dealt with in a later paper.

INTRODUCTION

It is widely accepted nowadays that daylighting and energy-conserving strategies, if properly designed, can yield significant savings in electric power and reduce peak load demands.

The importance of daylight-oriented design was examined in a previous paper (Ne'eman and Selkowitz 1984). In that paper, the same authors emphasized the technical and energy-conserving factors as well as the general subjective response of occupants. However, the way daylight is admitted into the building was not discussed there.

In the present paper, the subjective/psychological aspects of the location of the glazing are examined in detail, while the technical/energy-saving comparison of the various alternatives will be dealt with in a later paper.

It should be noted that 80% to 90% of the overall life-cycle cost of running industrial or commercial buildings is salaries. Thus, it is of utmost importance that we carefully consider aspects of workers' well-being while examining various design alternatives, among them the location of the fenestration and the way daylight is admitted. Bear in mind that buildings should be built to offer people the most satisfying and productive environment in which to live and work. Thus, energy-efficient design strategies should never ignore human needs and preferences.

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THE PROBLEM

Many designers base their choice of fenestration purely on architectural/technical considerations. The accepted attitude is that as long as enough daylight is admitted into a space, it does not matter how or where the light enters. However, the major issue discussed here is whether there is any difference, from the human point of view, in the kind, sizes, and locations of openings through which the daylight "flows" into the built environment. If the answer is positive, what might these differences be and how might they affect architectural and energy-conserving design considerations? (Gershun 1950 (1936]).

THE HYPOTHESIS

Basing our hypothesis on available evidence, we believe that such differences do exist. For example, the subjective response of occupants to daylight coming through vertical glazing at eye height seems to differ from their attitude toward the same amount of daylight coming through skylights or through an atrium-glazed ceiling.

CLASSIFICATION

There are many architectural designs in which the location, geometry, and tilt of the glazing varies. Still, the way daylight is admitted can be grouped into four broad categories:

1. Vertical glazing on external walls (figure 1),
2. Tilted glazing (figure 2),
3. Skylights (figure 3), and
4. Atria (figures 4 and 5).

All design solutions belong to one of these categories or some combination.

DIRECTIONAL PROPERTIES

People are generally unaware of the directional characteristics of the flow of daylight into indoor spaces. It is true that for many conventional activities, the direction from which light is reaching the visual task or the work plane is not critical. On the other hand, in many other cases the "modeling" of objects, which is greatly dependent on the directional properties of the incident light, is of great value. Our subjective appraisal of the lightness of an interior is also greatly dependent on the directional properties of daylight that illuminates horizontal and vertical surfaces.

The direction of light is of utmost importance when the visual task consists of minute details, fine relief, three-dimensional objects such as sculptures, etc.

Some researchers (Gershun 1950 [1936]; Helwig and Krochmann 1958) proposed to use field theory to describe the behavior of the flow of light. When presented as a scalar field, light flow does not necessarily propagate in straight lines (Cuttle et al. 1967; Lynes et al. 1966) as the light rays obviously do (see Figure 6). This description suits the subjective perception and easily explains, for example, how the ceiling and the wall above windows (which cannot receive any direct daylight) are not totally dark. It allows the "flow of light" to bend upwards after getting through the windows, although we know only too well that this happens due to interreflections. Now, after discussing the subjective aspects of the directional characteristics, we can examine how the various fenestration options affect the subjective appraisal and the modeling of objects. Vertical or tilted windows on external walls admit light mainly in a nearly horizontal direction, thus better illuminating vertical surfaces than horizontal ones. This effect greatly helps satisfy occupants about the lightness of the space. On the other hand, dark walls, even if the horizontal surfaces are well-illuminated from above, tend to increase the sensation of gloom and boredom. Consequently, the direction of the flow of light through vertical or tilted openings is subjectively preferable to top lighting. Fully glazed walls (sometimes called curtain walls) behave in a similar way as smaller windows on identical walls.

With skylights, the flow of light is mainly vertical, which enhances the illumination on horizontal surfaces while vertical surfaces are relatively darker. This pattern is rather similar to the direction of light from ceiling mounted electric sources. As a result, the modeling pattern of the light that flows in through skylights is quite similar to the flow of light from electric lighting. Consequently, there is no significant change, in this case, in the directional behavior between the daytime daylighting or integrated lighting and the nighttime electric lighting. However, the change in the pattern of light flow through vertical windows to the nighttime electric top lighting is not considered as a disadvantage. However, a recent change in theory subjectively considers the variability to be beneficial, as will be discussed later.

The comparison is rather more complicated with atria. Almost every design of an atrium is unique and suited to the design of the specific building and its energy system. In most designs, the atrium floor is not used as a working area but is used mainly for circulation, potted plants, and rest areas. Thus, daylight that is admitted through glazed areas at the top level flows into the atrium from above. As a result, work stations at the lower levels of an atrium, even if they are facing the atrium, receive daylight mostly through reflections from the vertical surfaces of the atrium. This light is greatly diffused and its directional properties are less apparent, but they can always be clearly defined. The picture is entirely different when direct sunlight can penetrate the atrium space. The solar radiation is undesirable for efficient energy management during the cooling season while being beneficial during the heating season. Furthermore, the warmth of the sun is greatly appreciated by occupants. From the visual standpoint, if precautions are taken to avoid any specular reflections, sunlight brightens the whole space and subjectively adds to the lightness of the work station as well. Furthermore, direct beam sunlight is highly directional, and even reflected sunlight shows strong directional features.

It is believed that daylight admitted through the atrium and then partly reflected toward the work areas has a tremendous subjective/psychological value, particularly in very large buildings (not high-rise). The flow of light enhances the sense of orientation and helps in relieving the sense of enclosure. However, these aspects need a more systematic investigation to obtain well-defined guidelines for architects and planners.

VIEW OUTSIDE THE BUILDING

The photometric properties and location of the glazed openings greatly affect the direction and content of the perceived outdoor view. For example, diffusing glazing will transmit light but totally or partly obstruct the view. Tinted glazing, on the other hand, will dim the view and in some cases distort its spectral appearance.

The importance of the view out for the well-being of occupants has been discussed elsewhere (Ne´eman and Selkowitz 1984; see also references 2, 3, 4, and 7 in that paper). It has been shown that the subjective attitude toward window size and location is greatly dependent on the "meaningful information" perceived from that view. The more meaningful the information, the more appreciated the view. In this respect, best placement option for windows on external walls is eye level. The glazing can be vertical or tilted. The most preferred view is composed of the landscape with its activity and some view of the sky. Such a view is likely to provide the highest possible information content.

It should be emphasized that even occupants who have the windows at their back, or are remote from them, respond in a way similar to occupants facing the windows. Anyway, workers are not looking at the view a great deal of time. Psychologically, they are satisfied as long as the option exists, and they are certain that with minimal effort they can have the view.

On the other hand, the view content perceived through skylights or through an atrium is, at the best, limited to the weather prevailing outside and a view of the sky. Consequently, skylight daylighting is rather another source of light having superb spectral qualities, which replaces electric lighting to save energy, but lacks most of subjective/psychological benefits of a meaningful, intelligent view.

It is interesting to note that all the attempts made in various studies to provide a man-made substitute to the real natural view were interpreted by occupants as illuminated pictures. Even when the synthetic view was movable, to simulate the variability of daylight, occupants interpreted them as movies or large-screen television transmissions.

In our opinion, the view out is a most valuable feature and an integral requirement with the daylighting option. Consequently, even in architectural solutions where technical and economical considerations show preference to daylight admission without a view out, additional view windows should be added at eye level where possible.

SPECTRAL PROPERTIES

The spectral distribution of daylight depends on whether this light comes from the sky or the direct beam sunlight (see figure 7) (Lynes 1968). Large reflecting external surfaces painted with heavy colors can also affect to some extent the spectral distribution. Although there are slight changes in the spectrum of daylight coming from the north or south half of the sky vault, the major apparent difference is between sky light and direct sunlight.

Subjectively, sky light (particularly from the north sky) is considered cool and neutral. Direct sunlight is associated with warmth and brightness and is much welcomed by occupants as long as selective shading prevents overheating and glare. Even so, direct sunlight is undesirable on work stations because of direct or reflected glare (Ne'eman et al. 1976).

In this context, the subjective preference is more related to the direction of the light-admitting surfaces than to the groups defined earlier. North-facing vertical windows admit the much cooler northern sky light, while south-facing windows, as well as skylights and atria, are exposed to the southern sky light and direct sunshine. In particular, direct sunlight in the atrium, without reaching work areas, brightens and alleviates the whole building, thus contributing to the well-being of its occupants. To avoid any misunderstanding, it should be stated that direct sunshine should be shaded when its thermal contribution overheats the space during the cooling season.

VARIABILITY

As mentioned earlier, the variability of daylight with respect to intensity, direction, and spectral shift during the day was long considered a disadvantage. Stable and constant electric lighting was preferred, particularly in functional arguments. However, there have been recent indications that the variable nature of daylight is physiologically and psychologically beneficial. It is regrettable that the existing knowledge in this field is very limited, and a thorough investigation of the effects of the variable nature of indoor daylight on human beings and their biological timeclocks is badly needed.

The variability of the visual environment is more noticeable when sunlight can be admitted through the openings. Thus, as in the case of spectral considerations, north-facing vertical windows are less favorable than south-facing windows, skylights, or atria.

DEPTH OF LIGHT PENETRATION AND INTENSITY

It is well-known that the location and size of openings greatly affects the depth of light penetration and the light distribution. The location also determines the direction of the flow of light indoors.

There is again a big difference between vertical or tilted windows on the external vertical walls, on the one hand, and skylights on the other. The effective depth of penetration through vertical or tilted openings is limited to three to five times the ceiling height. However, although the daylight levels beyond this limit are inadequate for continuous visual functioning (and if the space is not too deep), we psychologically compensate for the reduced levels and subjectively ignore these differences to a large extent. When the space is deep, as in large modern buildings, side-lighting may produce dark and gloomy areas that need a permanent supplement of electric light (Ne'eman 1983). With skylights, the pattern is entirely different. If the skylights are located evenly over the entire area of the ceiling, the resultant penetration is much more evenly distributed over the whole working area, and light intensities are fairly uniform.

The depth of penetration is more complicated in the case of an atrium. Daylight flows through the atrium glazing and illuminates the interior atrium surfaces. The working areas receive daylight mostly through reflections. Therefore, the depth of light penetration and light intensities are greatly dependent on the geometry of the atrium surfaces and their reflectances. Therefore, it is difficult to define the subjective attitude to the atrium from the penetration point of view.

For large buildings, it seems that evenly distributed daylight from skylights is subjectively preferable to large side-lit spaces. However, if the side-lit deep interior is supplemented with electric lighting, the subjective preference will turn to side-lighting, which provides the desirable view outdoors and gives a better sense of orientation.

CONCLUSION

We have found some noticeable differences in the subjective/psychological attitude of occupants to the various options of daylight flow into the building. The provision of a view out and the possibility of admitting direct sunlight into parts of the interior where it cannot cause glare annoyance are much favored. Also, the directional properties of light admission by the various glazing designs show that side-lighting is subjectively preferable to top-lighting.

The other aspects that were examined, i.e., the spectral composition of the admitted light, the variability of daylight, and the depth of penetration, have some subjective consequences, but they do not strongly depend on the glazing option.

The present comparison is only an initial attempt to understand the differences in subjective responses to the various glazing solutions in a building. We can sum up that our hypothesis is, no doubt, fulfilled. We believe that more research should be done in this field to be able to draw firmer conclusions and to work out clear guidelines for architects and planners.

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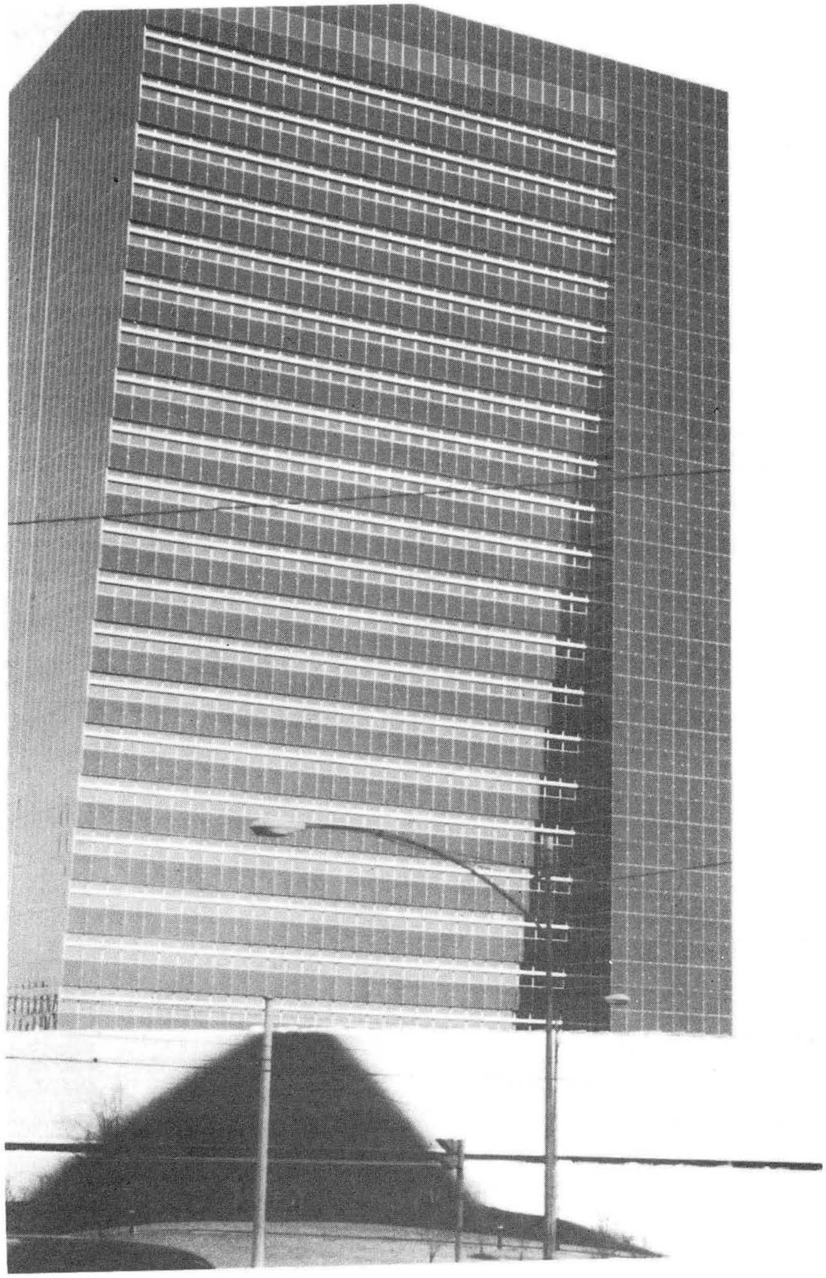

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Fig. 1. Vertical glazing on external walls. Georgia Power Building, Altanta Georgia.

CBB 845-3715

Fig. 2. Tilted glazing, Municipal Hall, Phoenix, Arizona.

CBB 845-3713

Fig. 3. Skylights. Norstar Building, Buffalo, New York.

CBB 845-3711

Fig. 4. Fully glazed atrium. A renovated old Post Office building, now used as a college, Buffalo, New York.

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Fig. 5. Same as Figure 4. View of the glazed roof.

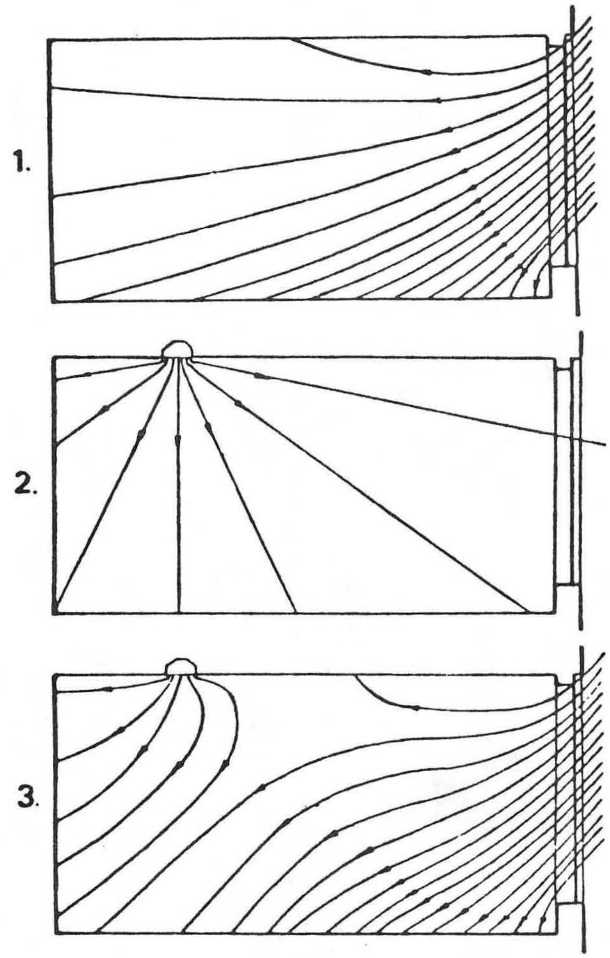

Fig. 6. The flow of light in a room [5].

1. The daylight penetrating through vertical windows.

2. Light from skylight or electric sources.

3. Integration of side-lighting and top-lighting.

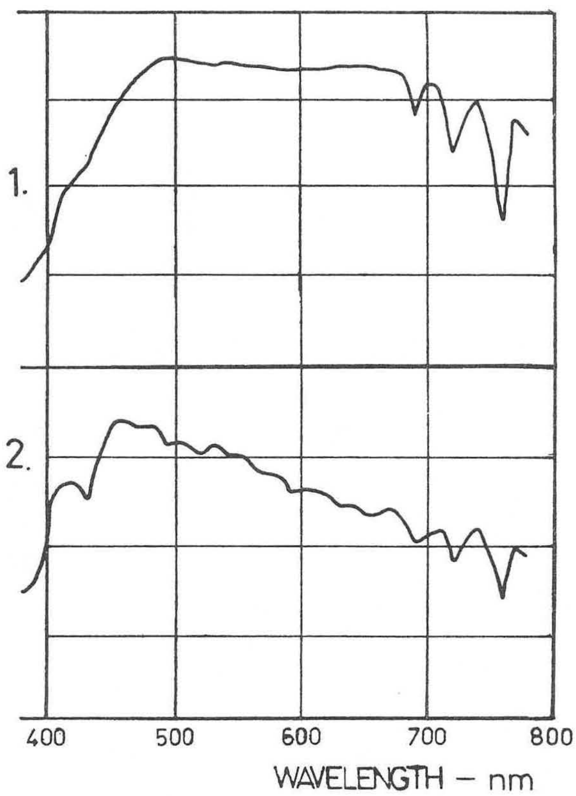

Fig. 7. Relative spectral power distribution.

1. Direct beam sunlight.

2. Total daylight (CIE Illumination D_{6500}).

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