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ABSTRACT

Recent research indicates there are a great many nonvisual effects of light on people. The control of rickets and the suntan effect are well understood. Less well known effects include synchronization of a number of physiological rhythms and prevention and control of infantile jaundice. Physiological and psychological effects also vary with the type of artificial light, whether it is from incandescent or cool-white or full-spectrum (daylight) fluorescent lamps. Student behavior appears to be favorably affected by full-spectrum lamps. Color also has an effect on people and their behavior. Research suggests that blues and greens tend to foster relaxation while shades of red or orange tend to induce activity. In discussions of windows versus windowless space, building occupants seem to favor the ability to view the outside world. If the effects reported in the studies that have been undertaken to date can be replicated, educators and school facility designers should be able to design classrooms capable of producing desirable and predictable student behaviors. (MLF)

Lights, Windows, Color: Elements of the School Environment

at

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by

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Abstract

The activities of primitive man were conducted under sunlight and surrounded by blue skies, green hills and meadows, and the greys, browns and blacks of the soil. That was his environment. Modern man spends almost all of his time in controlled environments where artificial lights replace the sun and a rainbow of colors puntuate the visual panorama.

Recent research indicates that there are a great many non-visual effects of light on people. Of these effects the suntan effect and the control of rickets are two that are well understood. Other important (but perhaps less well known) effects include synchronization of a number of physiological rhythms, and prevention or control of infantile jaundice. Still other research indicates that variations in the quality of light can influence student achievement and behavior.

Closely related to light is color and there are studies which indicate that color too can produce measureable effects in the classroom.

Indeed, the reported research is sufficiently conclusive to allow the suggestion that light and color have predictable effects on students and that learning environments can be designed to foster these predictable effects. This paper is devoted to a discussion of the effects on people of lights, windows and color.

Lights, Windows, Color: Elements of The School Environment

Sunlight is by far the most common type of natural light. Other types include lightning, the auroras, and bioluminescence. Sunlight may be received as direct light or as skylight (diffused light). For most people, some part of each day is spent under the influence of sunlight. However, as society becomes more urbanized, the amount of time spent daily under the influence of sunlight is decreasing. More and more people are spending more and more of their time under the influence of artificial light.

Of direct concern to this paper is the school environment--the lighting and colors used in classrooms where students are studying. Three major light sources are examined: natural lighting, incandescent lighting, and fluorescent lighting (cool-white and full spectrum). Other light sources including mercury vapor, metal halide, and high pressure sodium have poor color rendition characteristics and are generally unsuited for classroom use. For that reason they are not discussed in this paper. It is also important to differentiate between discussions about light sources and discussions about well designed lighting systems. Because the latter is a well documented science it will not be discussed here but full attention will be given to light sources. Because of its close relationship to light, color and its effects on people will also be examined in this paper.

Natural Light and Related Studies

Sunlight is the form of natural lighting which nurtures most living things. Photosynthesis (the ability of plants to use sunlight in manufacturing food) and phototropism (the tendency of plants to grow towards light) are two light-related processes that are well understood. The effects of natural light on people are less well understood. Some of the known or suspected effects of light on people are discussed in later sections of this paper but before such a discussion takes place, it is useful to discuss the nature of sunlight.

When sunlight passes through a raindrop, a rainbow is formed. Sunlight passing through a prism produces the same effect. While sunlight appears to be "white" light, the rainbows produced by raindrops or prisms suggests that sunlight contains many colors. The range and intensity of these colors is referred to as the spectrum of sunlight. From Figure 1 it can be seen that the sunlight reaching the earth's surface consists of energy in wavelengths ranging from 290 nanometers (nm) to 900 nanometers (Thorington, Parascandola & Cunningham, 1971:34). For the most part vision is a response to light energy reflected from objects in wavelengths ranging from 320 nm to 770 nm. Wavelengths shorter than 320 nm fall into the ultraviolet range while wavelengths longer than 770 nm are more readily sensed as heat (infrared). Between 320 nm and 770 nm the energy intensity is uniformly distributed.

Because sunlight contains all colors in relatively uniform amounts, all colors are equally visible when viewed under sunlight. Natural light serves as the reference for comparing the color rendition characteristics of other light sources with natural light having the maximum or reference color rendition index (CRI) of 100.

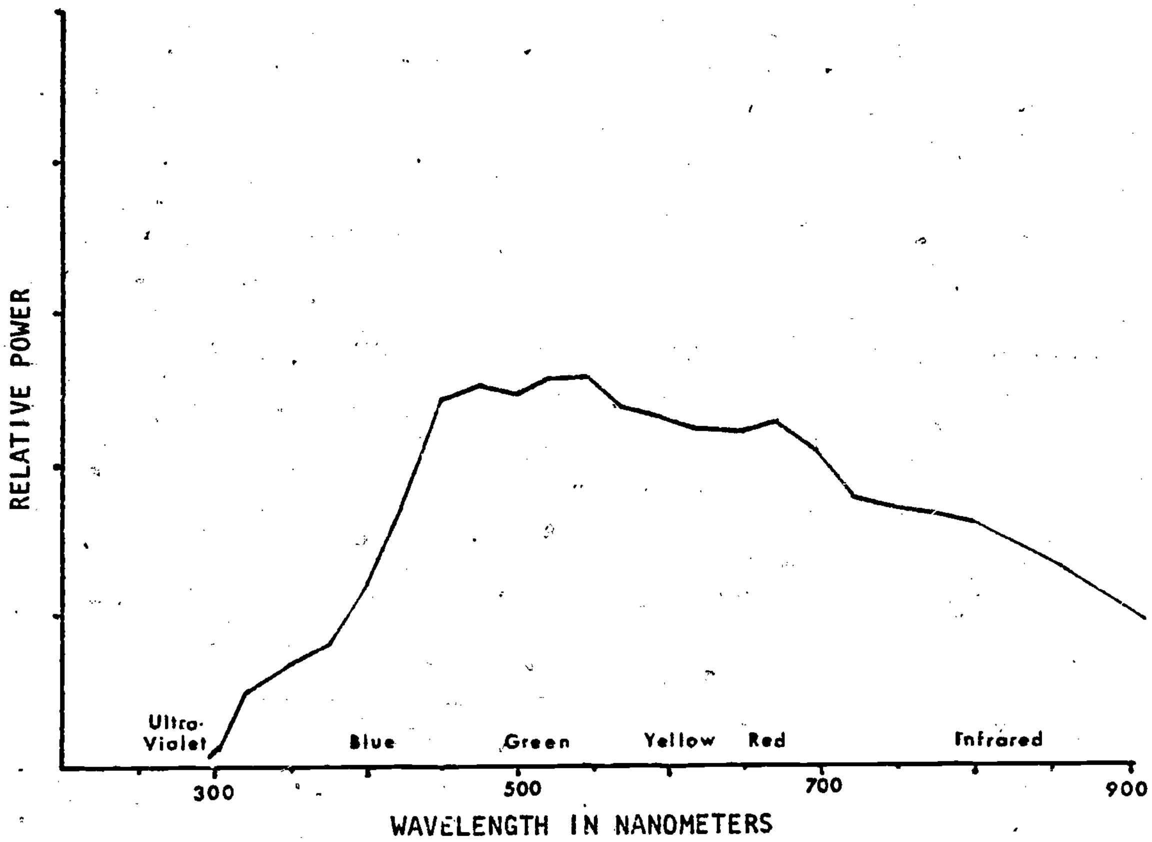

Figure 1. Spectrum of natural light--color temperature 5500k

Aside from enabling vision, natural light has some interesting effects on animals and people. Some of these effects are physiological and some are psychological. The scope of these effects are highlighted by Dantsig, Lazarev, and Sokolov (1967:225) who say:

> If the human skin is not exposed to solar radiation (direct or scattered) for long periods of time, disturbances will occur in the physiological equilibrium of the human system. The result will be functional disorders of the nervous system and a Vitamin D deficiency, a weakening of the body's defenses and an aggravation of chronic diseases.

Wurtman and Neer (1970) declare that:

> The indirect effect of light about which most information is available is, of course, vision. Retinal responses to environmental lighting also mediate an expanding list of neuroendocrine [hormonal] effects. These include control of pubescence, ovulation, and a large number of daily rhythms.

An article in the CEFP Journal (1979:16) quotes Faber Birren as stating:

> The action of ultraviolet radiation intensifies enzymatic processes of metabolism, increases the activity of the endocrine [hormone] system, promotes the immunobiological responsiveness of the body and improves the tone of the central nervous and muscular system.

A number of the light-related physiological and psychological processes which have been identified are discussed below.

Vitamin D Synthesis

Rickets was first described in England in 1650--about the time of the introduction of the use of soft coal. The use of soft coal (and its related smog) spread quickly through Europe and with a concurrent increase in the incidence of rickets. In 1909 Schmorl did post-mortems on 386 children that had died with rickets (Loomis, 1970). He noted that deaths declined in the spring and increased in the fall. Healings of rickets at the same time increased in the spring and declined in the fall. By 1919 researchers had reached the conclusion that sunlight was the key to the cure of rickets. Kurt Huldschinsky, a pediatrician in Berlin in 1919, discovered that artificial light was effective in curing rickets (Loomis, 1970). Currently it is accepted that ultraviolet irradiation or regular doses of Vitamin D can prevent or cure rickets.

Robert Neer (1975:409-416) describes the relationship between ultraviolet irradiation (at wavelengths shorter than 310 nm) and the synthesis of Vitamin D. The process he describes involves synthesis of a precursor of Vitamin D in the skin of humans when irradiated by ultraviolet light and he further notes that:

> The amount of 7-dehydrocholestrol present in three

> square inches of human skin would supply the daily requirements of Vitamin D_3 if completely converted.

He also notes that:

> Childhood rickets is readily cured by 2.5 - 7.5 micrograms of Vitamin D daily [equivalent to approximately 2 to 4 glasses of fortified milk], prolonged exposure to winter sunlight, or five minutes exposure to artificial ultraviolet radiation equivalent to summer sunlight at 36° latitude [i.e., the southern United States].

Calcium Absorption

Neer, et al (1970) describe a study involving male residents at the Chelsea Massachusetts Soldiers' Home in which full-spectrum fluorescent lighting was used. The full-spectrum fluorescent lights delivered about 5 percent of their total radiant energy in the ultraviolet range (290 nm - 380 nm). The conclusion of the study was that:

> ... Relatively small amounts of ultraviolet light can stimulate calcium absorption among elderly men who have no exposure to sunlight and eat a diet containing few foods fortified with Vitamin D.

Neer (1975:413) further asserts that:

> The winter decrease in adult calcium absorption is prevented or reversed by daily exposure to artificial sunlight in doses equivalent to 15 minutes' strong natural summer sun at 36° N.

Synchronization of Internal Clocks

A great deal of research has been undertaken into the effect of environmental lighting on the biological function of animals and people.

Richard Wurtman (1968) summarized an impressive amount of research and declared:

> One fact seems certain: light has biologic effects, and they may be very important to the health of the individual. Data have been available for some time showing that environmental lighting influences 'well-being', performance, and other biologic phenomena which are difficult to measure. Recently evidence has begun to accumulate that light exerts specific biologic effects, which are easily measured and reproduced in the experimental laboratory. These effects are of two kinds: (1) those which modify the individuals endocrine [hormone] and metabolic state, and which are mediated through the retinas; and (2) those which result from a

> direct action of light on the skin (e.g., stimulation of Vitamin D production, skin tanning, photolytic dissociation of bilirubin).

After further research, Dr. Wurtman (1969) reported that on:

> Reviewing the entire equation, we see that light input (or its absence) controls pineal synthesis and secretion of the hormone melatonin. This hormone influences the functional activity of a number of glands, probably by direct action on brain centers that control the anterior pituitary.

He (Wurtman, 1969) continues by noting that:

> One aspect of biologic responses to light that seems to deserve immediate study concerns the identification of that portion of the energy spectrum capable of influencing neuroendocrine functions in humans.

Wurtman and Weisel (1969) studied the effects of cool-white and Vita-Lite (full-spectrum) light on a group of rats.

> By the time the animals attained the age of 50 days, there were considerable differences in the weights of several organs.... The testes and ovaries of rats born and maintained under Vita-Lites were significantly larger than those of animals exposed to the cool-white source, while the spleens of both males and females were significantly smaller for both sexes. Female rats housed under Vita-Lites had larger hearts and pineals than females exposed to the cool-white source, while males housed under Vita-Lites had larger adrenals than animals of the same sex kept under the cool-white fluorescent source.
>
> These data provide clear evidence that at least some neuroendocrine effects of environmental lighting display an action spectrum, i.e., the effects of a particular light source on gonadal growth depends upon its spectral characteristics.... The photo receptive units which mediate the neuroendocrine control of the ovary either must be sensitive to differences in the proportions of, for example, blue to yellow light, or must have the capacity to respond to long-wave ultraviolet irradiations as well as to visible light.

Hyperbilirubinemia

Bilirubin is formed by the breakdown of hemoglobin and is normally excreted after undergoing a chemical change in the liver. In newborn infants (and especially premature infants) the bilirubin excreting process may not be fully functional. A rise in the level of bilirubin can lead to jaundice. If untreated the excessive bilirubin can effect the brain and permanent neurological damage can result.

Thorington, et al (1970), Hodr (1971) and Lucey (1972) cite numerous studies involving the use of phototherapy in treating hyperbilirubinemia. As an alternative to exchange transfusions, irradiation with light (especially blue light in the 440 nm to 470 nm range) has proven effective and is considered standard treatment in many hospitals.

Psychological Effects of Sunlight

Relatively few studies have been undertaken into the psychological effects of sunlight. One study conducted in England by Longmore and Ne'Eman (1974) provides some interesting insights. For example:

> ... Of the people interviewed in working places such as schools, offices and hospitals, two-thirds (64 percent) considered sunshine inside buildings to be a pleasure and one-third (31 percent) as a nuisance.

As a rule, those who liked sunlight in buildings did so because they felt it provided pleasant light, improved the appearance of interiors, provided warmth, and provided therapeutic effects. Those who disliked it did so because sunlight caused fading and because it provided thermal and visual discomfort (high contrast and glare).

Sunshine in buildings is most appreciated by those occupants who can protect themselves against the unpleasant effects of sunshine either by shading or by simply moving away from the sun. In schools or offices we find much more confined activities. The occupants of these buildings spend a great deal of time in fixed sitting positions, with a limited range of directions of view. Thermal, or, even more often, visual discomfort may be caused by exposure to direct sunlight.

The study authors (Longmore and Ne'Eman 1974) conclude by stating:

> The main design implications of these findings are that buildings should be designed to admit as much sunshine as possible. On the other hand they should be provided with adequate and flexible shading facilities. This will provide occupants with full control of the penetration of sunshine to meet climatic and human demands.

Adverse Effects of Sunlight

Excessive exposure to the ultraviolet component of sunlight can have adverse effects. The more common effects are sunburns, skin aging, and skin cancer. Prolonged exposure to ultraviolet light can also cause damage to the lens of the eyes. Bickfor (1981:19-3) says:

> ... Some investigators are coming to believe that all wavelengths below 400 nanometers the ultraviolet region of the spectrum should be excluded, where possible, from the eye, especially since these wavelengths can be easily

> eliminated by inexpensive sunglasses and contribute nothing to visual perception.

He (Bickford, 1981:19-5) continues by noting:

> The only known benefit of ultraviolet radiation of skin is the production of Vitamin D from precursor chemicals which are formed in the skin.

Artificial Light and Related Studies

While natural light may be used for lighting the interior of buildings, various factors, including the seasonal variations in natural light intensity and duration, make it mandatory that some form of artificial lighting be used to augment natural lighting. The most common forms of artificial lighting are incandescent and fluorescent.

Incandescent light is produced by heating a tungsten wire in an inert gas. The radiant energy from incandescent lamps in similar to that of candlelight or firelight and tends to fall in the red end of the visible spectrum (Figure 2). The color rendition index (CRI) while very low--about 40--tends to be very flattering to skin tones.

Fluorescent light is produced by bombarding with electons a phosphor coating on the interior of the light tube. These electrons are released when other electrons emitted from cathodes bombard mercury vapor. To some extent the color characteristics of fluorescent lights can be controlled through the mixing of phosphors. Cool-white light, often referred to as the standard fluorescent light has a spectrum as shown in Figure 3 and a CRI of 68. The spectrum of full-spectrum lights, with a CRI of 91, is shown in Figure 4. As can be seen in Figure 4, full-spectrum lights also contain significant amounts of energy in the ultraviolet range.

Zamkova and Krivitskaya (1966) augmented regular fluorescent light with ultraviolet suntan lamps in a controlled experiment involving school children. They reported several findings. Among them were: increased levels of working ability and resistance to fatigue, improved academic performance, improved stability of clear vision, and increased weight and growth in the experimentally irradiated group over the control group.

Volkova (1967) studied the effects of ultraviolet supplements to general lighting in a factory. As compared to a control group, the experimental group demonstated decreased permeability of skin capillaries, increased white cell activity, and reduced catarrhal infections and colds.

Laszlo (1969) reported that certain snakes and lizards that had been notoriously difficult to keep alive in captivity responded favorably when the lights they were exposed to were changed to full-spectrum lights (Vita-Lites).

Himmelfarb, Scott and Thayer (1970) reported that light from Vita-Lite (full-spectrum) bulbs was significantly more effective in killing bacteria than light from standard cool-white bulbs.

Sharon, Feller and Burney (1970) reported that:

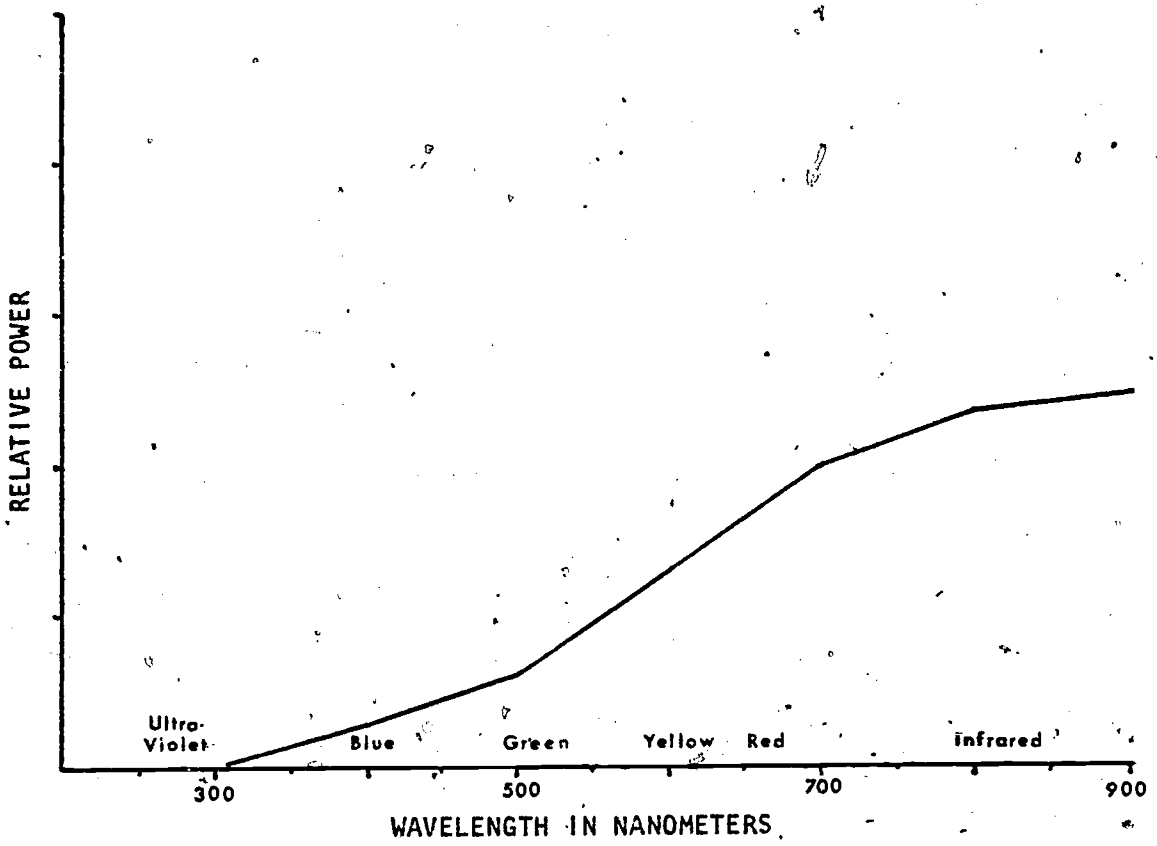

Figure 2. Spectrum of incandescent lamps.

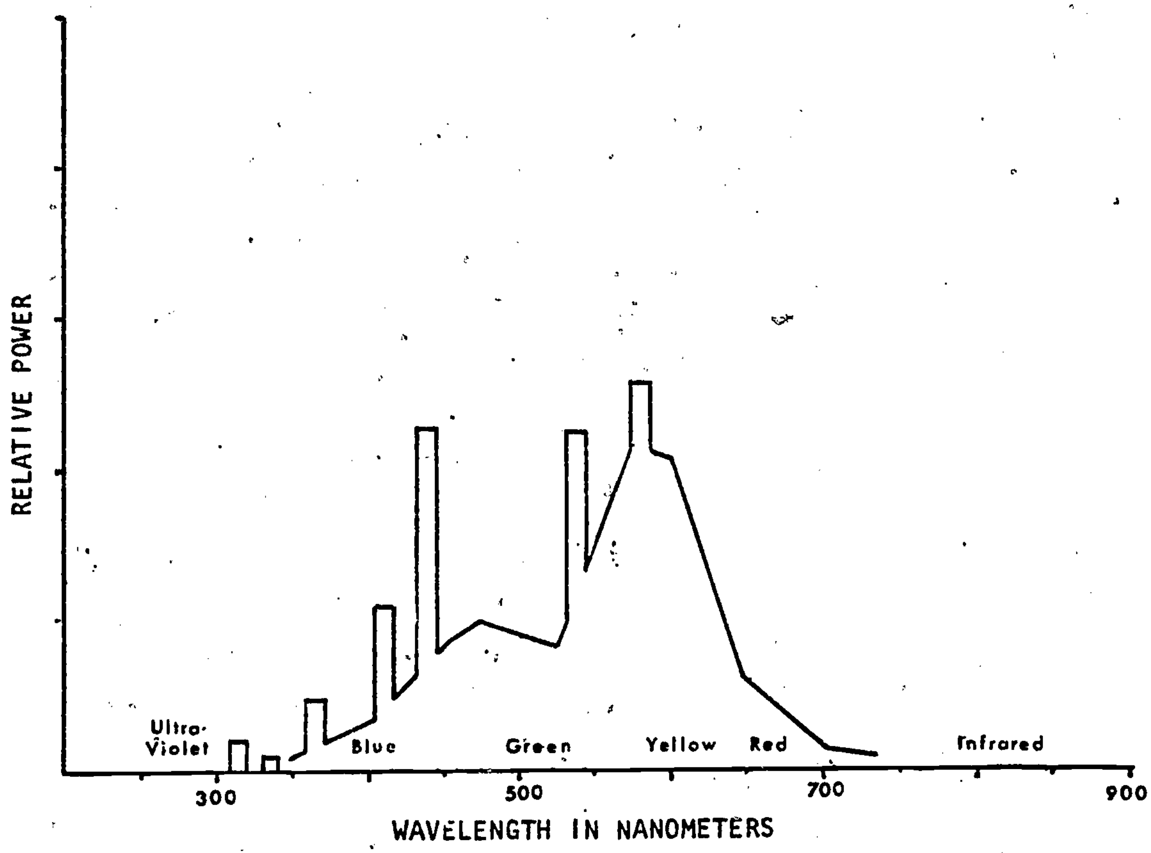

Figure 3. Spectrum of cool-white fluorescent lamps.

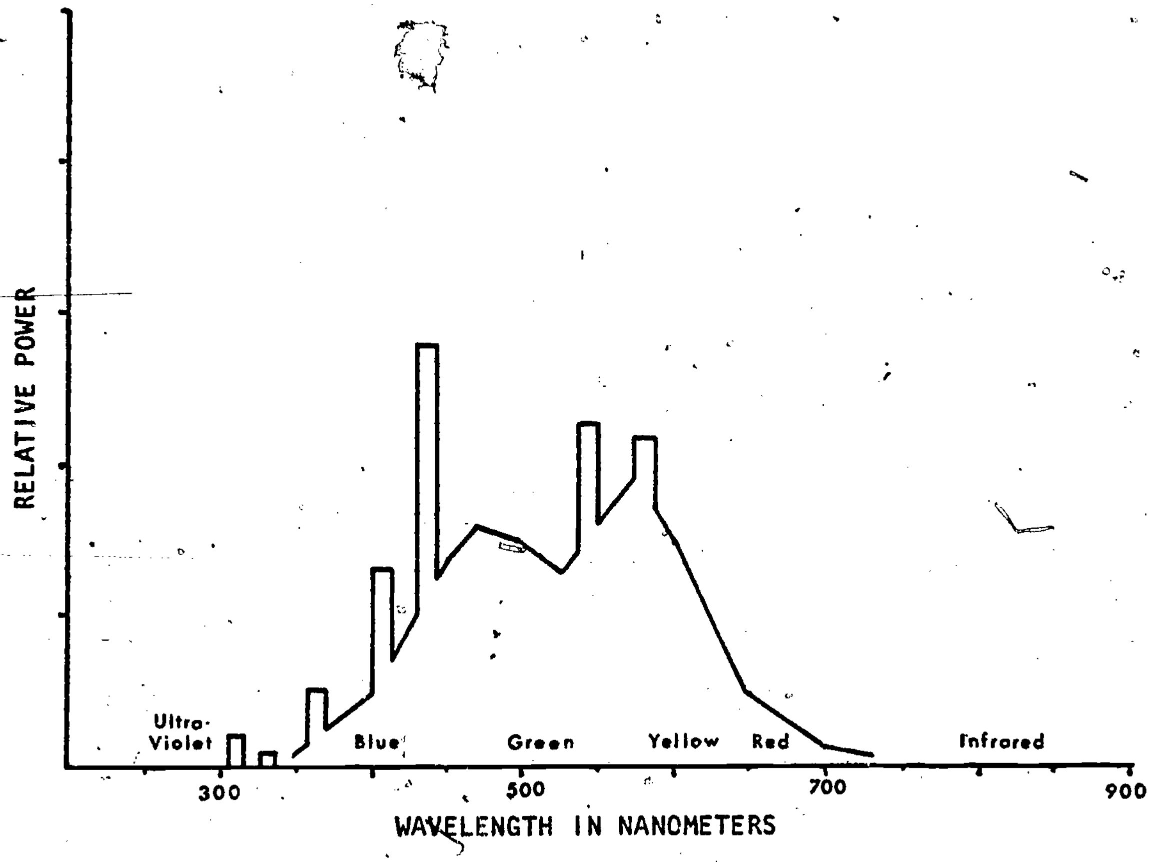

Figure 4. Spectrum of full-spectrum (daylight) fluorescent lamps.

> Golden hamsters, exposed to fluorescent light which simulated both the visible and ultraviolet spectrum of natural outdoor light, had one-fifth as many caries [tooth cavities] as animals exposed to conventional fluorescent light. Total body weight, gonad and submandibular gland weights were greater for the animals raised under the simulated natural light.

MIT Report on Research (1970) carried an article describing a study of elderly people under cool-white and simulated natural light conditions. The article stated:

> The group of 10 living under the simulated sunlight absorbed twice as much calcium into their systems as did the 10 exposed to fluorescent light cool-white. The amount of ultraviolet light needed to produce this effect was much below the amount needed to cause even a trace of sunburn. It was equivalent to the exposure one might obtain by taking a 15-minute lunchtime walk in Boston or Washington in the early spring.

Maas, Jayson and Kleiber (1974) report a study comparing the effects of full-spectrum to cool-white light on a group of students at Cornell University. The findings of the study indicated that students studying under full-spectrum lights had a decrease in critical flicker fusion (the frequency of intermittent stimulations of the eye at which flicker disappears) and an increase in visual acuity. Students studying under cool-white illumination "became less lively or more lethargic after four hours under the cool-white light".

Mayron, Ott, Nations and Mayron (1974) found the:

> . . . Use of full spectrum fluorescent lighting and radiation shielding [lead foil shields to shield against stray soft x-rays emanating from the fluorescent light cathode] decreased the hyperactive behavior of students in two first-grade rooms as compared to the students in two control rooms with standard cool-white fluorescent lighting.

In a later study, Mayron and Kaplan (1976) used bean seeds as a check for radiation outside the normal light spectrums emanating from fluorescent lights.

> Using an assay system based upon the germination time of bean seeds, growth of root, stem and leaves, and negative tropism of bean seedlings and plants, influence other than visible light was demonstrated to be emitted from fluorescent lamps and fixtures, most noteably at the electrode ends of the lamps and from the ballast. These biological effects appear to be blocked by grounded aluminum screening used as shielding, suggesting the electromagnetic nature of the influence.

Painter (1977) describes a small-scale study that compared the effects of incandescent and fluorescent lighting. When exposed to incandescent lighting in the classroom the hyperactivity behavior of a class of nine children, variously described as autistic or emotionally disturbed, decreased. When standard fluorescent lights were replaced, hyperactive behavior returned to normal levels.

Coleman, Frankel, Ritvo and Freeman (1976) also reported a study in which it was concluded that:

> . . . The fluorescent background illumination increased the amount of repetitive behaviors in six autistic children.

Using time-lapse photography, Ott (1976) studied the effects of full-spectrum fluorescent lights as compared to standard cool-white lights. The full-spectrum lights had lead shields over the cathodes to stop the radiation of suspected soft x-rays. He concluded that:

> Under improved lighting conditions, using full-spectrum fluorescent tubes with lead foil shields over the cathode ends to stop soft x-rays, childrens' behavior in the classroom showed dramatic improvement.

Color and Related Studies

As with light, there are studies which indicate that color has a marked effect on people and their behavior.

Hanlon (1979:89) makes reference to several studies of the effects of color.

> Color and touch (including temperature and humidity) are two components in the classroom climate that usually are overlooked or ignored unless they cause discomfort.
>
> A number of experiments have shown that people feel warmer in some rooms than in others although the physical temperature is exactly the same. The feeling of warmth can be added to a room through the use of red, yellow, orange, and rich brown colors in furniture, bulletin boards, and carpets. Low ceilings, about ten feet or less, with incandescent lighting or soft, warm table lights in small, individual work areas, increase the feeling of "warmth". Generally, also pleasant is a well-filled room of comfortable furniture organized by function. If filing cabinets or metal bookshelves must be in the classroom, they can be grouped together visually, as well as functionally, as a resource-storage unit. If their surface is blemished or unsightly, they can be spray painted or used for vertical display of posters or pictures. The rest of the room can be arranged into individual, small-group or large-group areas.
>
> By contrast, if your problem is one of heat rather than

> cold, you can "cool" your room, again by color--blue, green, pale neutrals, and white--with bare floors and high ceilings. The lights should be fluorescent and the room quiet with optimum ventilation and sparse furnishings. The "cool" effect can be achieved by a careful stress on simple lines and a minimum of visual-aural chaos. The "modern" school furnishings can be the most helpful, as the lines and shapes of the equipment are straight and plain with basic, low-contrast, smooth-textured surfaces. Graphic, bold designs, so popular now with teenagers and young adults, can be painted on one or two light walls by the students to add visual movement and rhythm without sacrificing the desired "cool" atmosphere.

The "Research Review" section of a recent CEFP Journal (1979) includes summaries of several color-related research projects.

In one of the cited studies by Garnsey:

> . . . Two adjacent committee work rooms were compared, each equivalent in size but different in color. The committee in the gray-salmon colored room accomplished more work, finished sooner, and estimated that the time passed more quickly than the committee in the gray-blue-green room. As another example, this may be best illustrated by a practical application in an actual situation. One particular bank was so enclosed by other structures that it was impossible to air condition the building. The interior of the bank was originally painted "institutional tan." The people commented on how hot it was in the bank. Simply by changing the color of the interior to a light blue-gray-green and by painting the interior columns white, the heat problem was reduced. The people in the bank perceived the temperature as being cooler.

The reviewer found sufficient evidence to support the conclusion that:

> It is also possible to use color to facilitate classroom management, based on the rationale that cool colors promote a feeling of tranquility, whereas warm colors promote increased stimulation. From this psychological standpoint, hospitals, business and industries have taken advantage of proper color selection more than educational institutions have.

The reviewer also contends that:

> Another psychological dimension of color can be found by its receding or advancing effects. Applying this to school facilities, long halls may be made to appear shorter by painting a warm color at either end. Small rooms (seminar rooms) may appear not so confining by the use of cool colors on some walls.

Another interesting application of color theory was also cited in the review.

> Knute Rockne also must have understood how color affects moods of people. In a novel attempt to psychologically affect the opposing teams, he had the home team locker rooms painted a brilliant red (high-energy color) while the visiting team's locker rooms were painted blue, causing a restfull feeling. Coach Rockne attributed a part of his success to his use of colors in the locker rooms.

Philip Hughes (in press) makes references to several studies which focused on the role of color. Plack and Shick in 1974, for example, found the effects of color to include:

> ... Changes in mood and emotional state, psychomotor performance, muscular activity, rate of breathing, pulse rate, and blood pressure.

A study conducted in 1958 by Gerard investigated the effects of colored lights on psychophysiological functions.

> Blue, red and white lights of equal brightness were each projected for ten minutes on a screen in front of 24 normal adult males. The autonomic nervous system and visual cortex were found to be significantly less aroused during blue than during red or white illumination. The colors also elicited significantly different feelings, with blue being associated with increased relaxation, less anxiety and hostility and red illumination being associated with increased tension and excitement. Manifest anxiety level was significantly correlated with increased physiological activities and subjective disturbance during red stimulation. He found responses in the opposite direction of quiesence and relief during blue illumination.

According to Hughes (in press) the work of Aaronson in 1971 reported much the same effect of colors on activities and arousal.

Day (1980:5) in discussing the physical environment of a school provides some comments on the use of color.

> Color affects and influences humans of all ages. Some colors tend to stimulate, some soothe and relax, and others create fatigue, depression and irritation. For any given color there is an association that goes with it in the subconscious mind. Thus, various colors may serve definite functions in planning the school room....Dark colors often produce a feeling of gloom in individuals. Color may cause emotional reactions and create feelings of coolness, warmth size, dimension, weight and distance.
>
> Educational leaders and others responsible for school

> planning have often virtually ignored the value of color in the learning environment. Planners should be concerned with using proper color to influence the visual environment. Industry uses color to speed production and reduce accidents, hospitals use various shades of color to enhance the effectiveness of the surgeon and to promote faster healing for the patient. Color that is properly used certainly will contribute to an improved environment for learning.

H. Wohlfarth and K. Sam (1981) have just completed a study of the effects of color and light variables on a small group of severaly handicapped children and their teachers in Edmonton. The findings indicate that during a three-week exposure to full spectrum lighting in a classroom painted in relaxing shades of blue, several measures changed significantly. For example: the systoltic blood pressure of the students (both blind and sighted) dropped approximately 20 points (from 120 to 100); aggressive behaviors dropped to 56 percent of their normal levels; non-attentive behaviors dropped to approximately 23 percent of previous levels; and, teachers reported that they found the environment much more relaxing and that they were abie to get more work completed by the students.

Windows and Related Studies

Primitive men probably first took shelter from the elements by occupying caves. Later they must have learned to fashion crude shelters from materials at hand. As their building technology developed doors were provided as a means of easy access and as a means of barring intruders. Window-like openings probably were used to permit the entry of light, to provide fresh air, to permit a view of the external world, and in some cases perhaps to serve as emergency exits.

Windows still serve these basic roles. To varying degrees they are used to light building interiors, to provide a form of air-conditioning, to provide a view of the world outside, and to serve as a means of emergency escape from or emergency entrance into buildings.

Recently technology has eliminated the need for windows to provide interior lighting and air-conditioning. The question that arises is whether or not these technological alternatives to windows are adequate. There is an impressive amount of research into windowed and windowless space.

As early as 1965, Larson (1965:53-55) reported the findings of a case study as follows:

> The removal of windows in Hoover School has obviously had some effect, even though indirect, on the behavior of youngsters. The variance in absence records of the kindergarten children as distinguished from those for children in the three older grades suggests a relationship to fenestration that should be further investigated. Some concern for an outside view is also evident in the pupil responses to changes in environmental factors. In the main, however, the testschool children have shown very

> little personal interest in whether their classrooms had windows or not.... The one positive finding that does emerge from the Hoover School experiment is the remarkable shift in attitude by teachers. There is no question as to their preference for windowless classrooms, once they have had the experience of teaching in such an environment, and they are unanimous in their reasons for not wanting the windows: the children are no longer distracted by outside happenings when classrooms become windowless, and besides, the extra wall space can be put to good instructional use.

With a view towards possible energy savings as a result of modified use of windows, Collins (1975) conducted a rather comprehensive review of relevant literature. What she found was a need for further research into the functions served by windows (Collins, 1975:79):

> It seems clear that there is no single solution, such as windowless buildings or minimal windows, because human requirements cannot as yet be fully specified. It is evident, however, that windows do perform desireable functions for people in buildings that should not be overlooked in the design of energy efficient buildings.

Romney (1975) conducted a study into the effects of windowless classrooms on the cognitive and affective behavior of elementary school students. He (Romney, 1975:vi) concluded:

> . . . That it was not possible to pass a definite judgement that windowless classrooms are detrimental to student cognition and learning. Students were significantly affected by their environment, but no clear relationships could be drawn due to the influence of unidentified variables.

Schulz (1977) provides an overview of lighting and its relationship to the learning space. Poor lighting, according to Schulz (1977:2) includes glare, uneven distribution, and too low or too high an intensity and forces the eyes to strain in an attempt to see better. On the other hand, Schulz (1977:4) suggests that there are:

> . . . Several advantages, physically and educationally, of quality classroom light: (1) greater comfort and contentment, (2) a more cheerful environment which is more conducive to mental health, (3) more concentration and a greater desire to work, (4) less fatigue and therefore fewer side effects such as laziness, bad posture, nervousness, and lack of interest, and (5) greater accuracy and neatness.

Schulz (1977:12-15) also concludes that:

> According to most sources no common type of illumination has yet been proven better than any other for

tasks such as reading and writing. Recommendations for schools usually specify fluorescent lights or a combination of fluorescent and incandescent.... No type of artificial lighting is superior to natural well-diffused daylight. The human eye responds more favorably to daylight in speed of vision, accuracy, and sustained acuity.

Schulz (1977) continues in her treatise by discussing light variables such as measurement, brightness or intensity, reflection and glare, distribution, and flexibility and control as being relevant to any consideration of holistic lighting.

Discussion

The findings of the cited studies clearly define the effects of light in establishing and maintaining physiological functions and balances. As Dr. H. Neubold (1978:234) has concluded: "Light is nourishing".

The relationship of light to the physical well-being of people is not surprising inasmuch as a naturally-lit environment was the normal environment of our ancestors. Nor are the effects of color surprising. Blues of the sky, the greens of vegetation, and earth tones were also part of man's natural environment. It is reasonable to assume that people will be most comfortable and relaxed in environments that most closely simulate these conditions.

As primitive man became more sophisticated and began to use caves and crude structures as shelter from the elements, he still spent most of the daylight hours outdoors and in pursuit of his livelihood. Only in the very recent past has man begun to spend most of his waking hours in artificial environments within the confines of buildings and under the influence of artificial lights.

The photobiologic action spectra of importance to mankind are shown graphically in Figures 5 to 8 (from Thorington, etal, 1971). Natural light provides the spectral distribution of energy necessary for the biological functions identified in these figures. Full spectrum fluorescent illumination also provides substantially all of the spectral energy requirements. The spectrum of incandescent and cool-white flourescent sources fails to cover the entire photobiologic action spectra of importance to man.

For people who are outdoors for a significant part of each day, the quality of indoor lighting to which they may be exposed may have little effect. Their needs for natural light stimulation are adequately met.

For people who spend virtually all of their day indoors, and with outdoor exposure limited to morning and evening natural light, there may be a need for artificial lighting that is supplemented with light stimulation in the spectrum areas of energy deficiency--especially ultraviolet. Moreover, there may be a need for a visual environment rich in blues, greens, and the earth tones of nature.

The use of windows to obtain the required light supplements is of little effect because ultraviolet light, which is the most significant missing component in artificial light, is effectively filtered out by ordinary window glass.

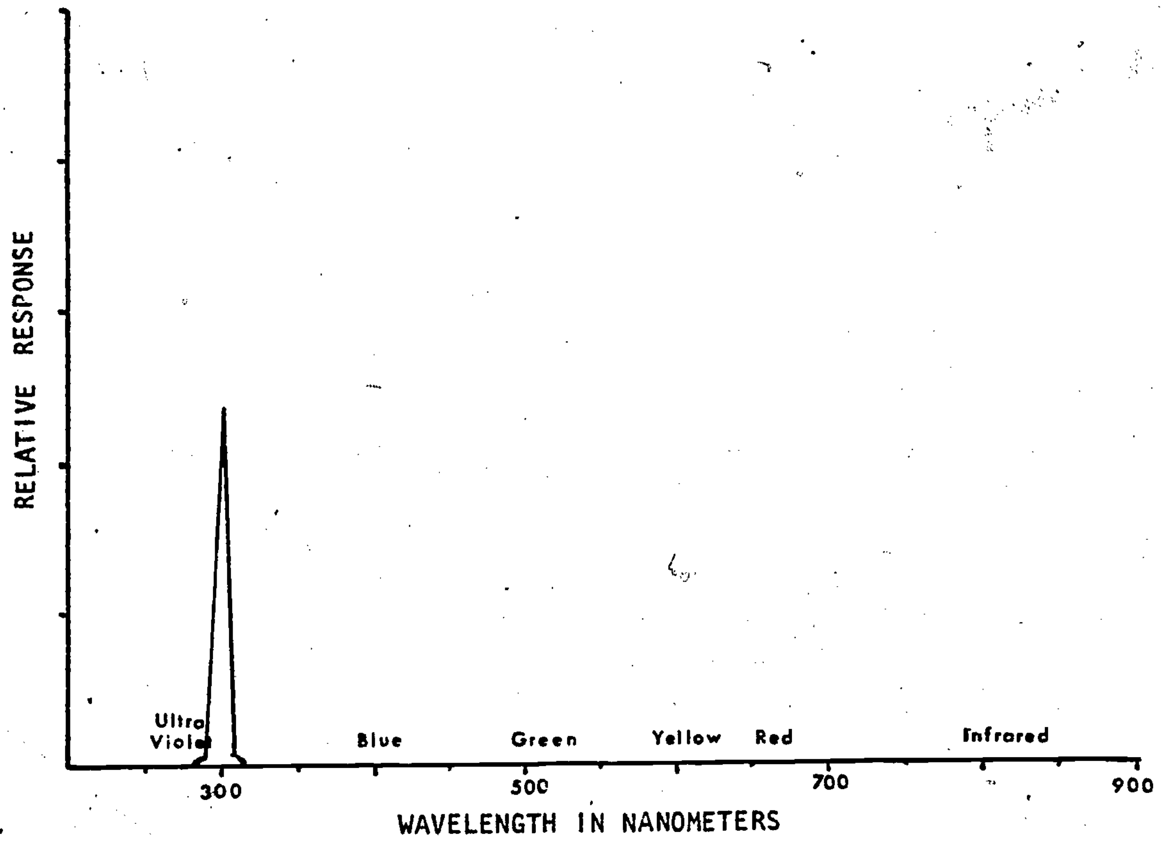

Figure 5. Action spectrum of skin reddening and Vitamin D synthesis.

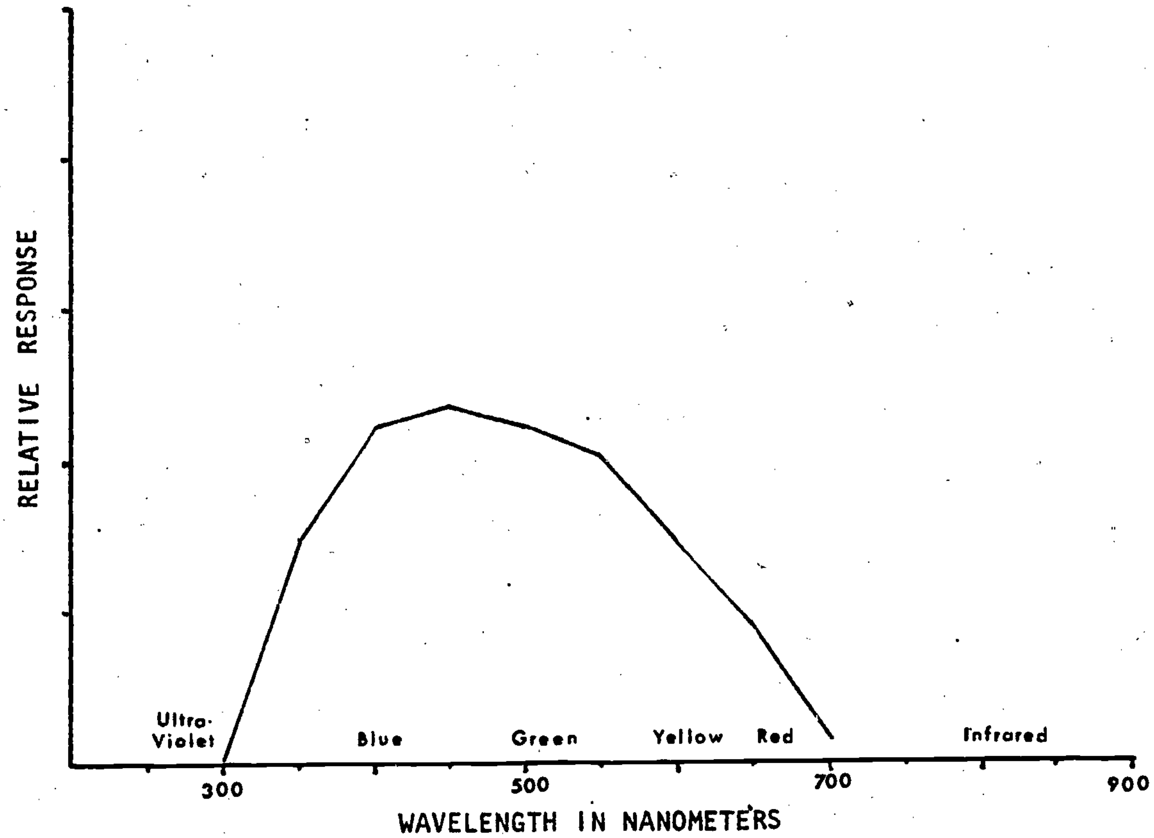

Figure 6. Action spectrum of skin pigmentation (suntan).

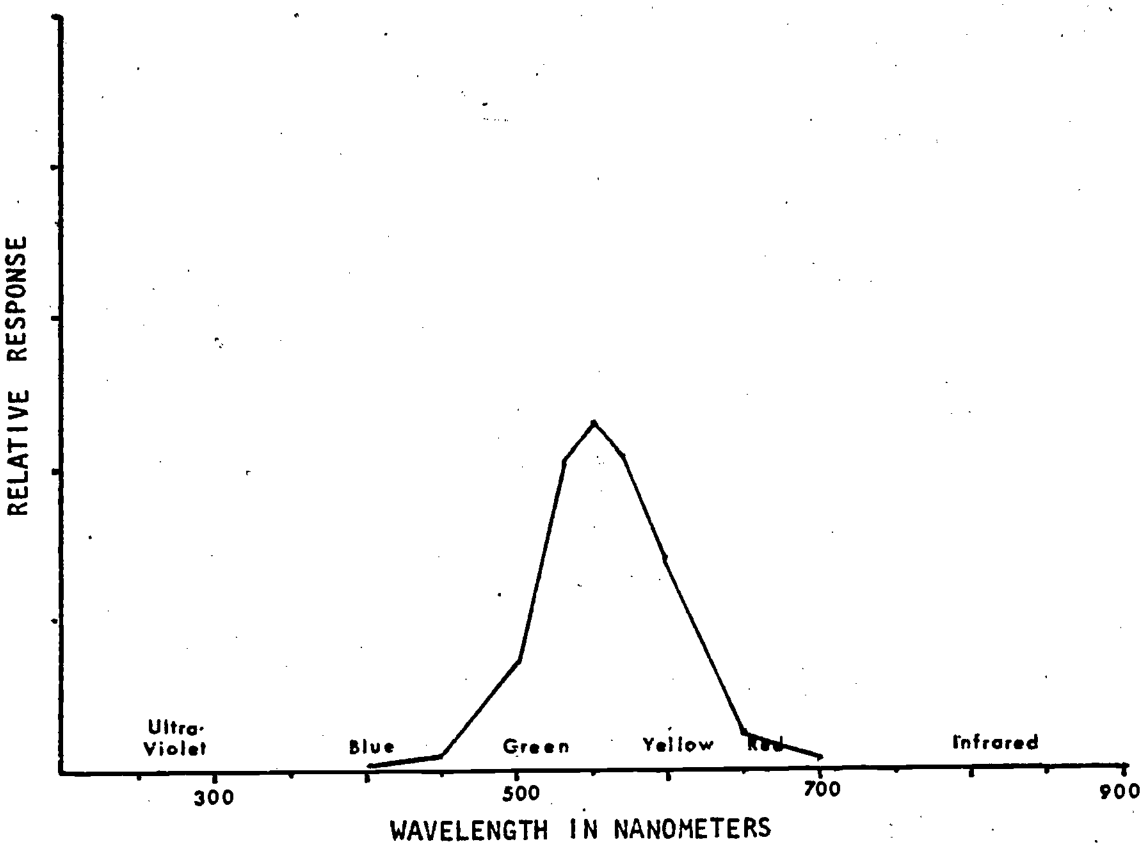

Figure 7. Action spectrum of vision.

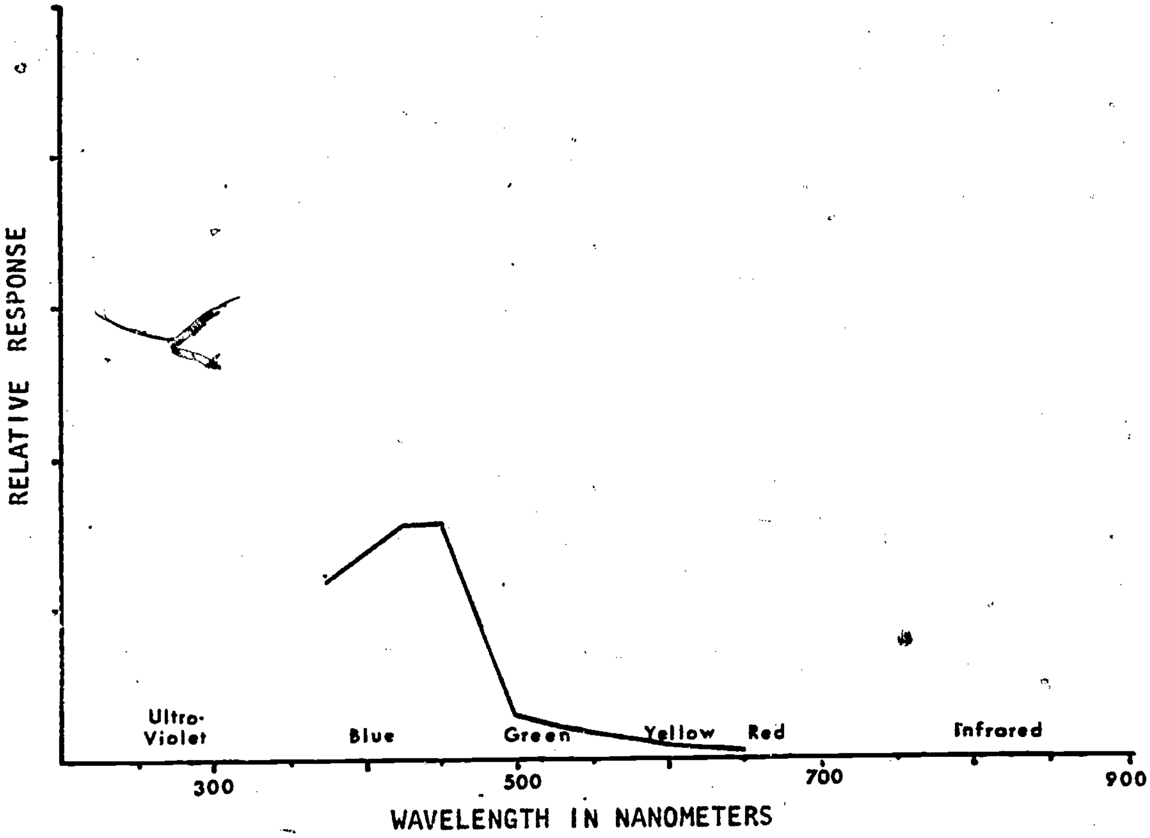

Figure 8. Action spectrum of bilirubin degradation (jaundice therapy).

The necessary supplementary ultraviolet light could, however, be provided in several other ways. One way would be to provide banks of sunlamps in some rooms or areas frequented by all building occupants--lounges, cafeterias, showers, washrooms, and gyms. A second way would be to replace existing lights with full-spectrum lights which contain significant amounts of energy in the ultraviolet rays. A third way would be to provide some outdoor activity between approximately 10:00 A.M. and 2:00 P.M. A fourth way would be to supplement diets with appropriate doses of Vitamin D, for example, by drinking two to four glasses of fortified milk daily.

When it comes to a discussion of windowed versus windowless space, view becomes the critical issue. Building occupants seem to favor the ability to relate to the outside world while confined indoors.

Windows are less useful as a means of illuminating interor space. Aside from the fact that the glass filters out the ultraviolet portion of the spectrum, windows provide difficult light to manage. It is difficult to manage because of the potential reflections, glare, and sharp contrasts. The most favorable attribute of natural, or window, lighting is improved color rendition--in this respect it is the ideal.

Windows may be used as a means of collecting solar heat. In these cases orientation is dictated by solar effect with minimum attention to view or other considerations.

Conclusion and Recommendations

The light-admitting and air-conditioning functions originally served by windows can be handled more effectively and efficiently in other ways. Windows in comtemporary buildings may be confined to providing views of the external world and in rare cases to serving as emergency passageways.

The type of lighting that is provided in interior spaces should be designed to serve the needs of the users. If the users regularly have exposure to adquate daily amounts of sunshine, the selection of artificial light sources is relatively uncomplicated. If, on the other hand, the users are deprived of adequate daily exposures to sunlight, then artificial light sources should be supplemented with some form of ultraviolet radiation or Vitamin D supplements. Stated another way, if users are not receiving adequate daily doses of sunlight or Vitamin D, an alternative to special lighting arrangements would be to schedule some outdoor activities when the sun is at its highest elevation. This is especially the case in schools.

Where high color rendition is of major concern, natural light or full spectrum light may be used.

Color should be selected carefully for school environments. Research suggests that blues and greens tend to foster relaxation while shades of red or orange tend to induce activity.

Finally, because few studies have adequately examined the variables of light, windows and color in the educational environment, further studies of these variables should be encouraged. If the effects reported in the studies that have been undertaken to date can be replicated, educators and school facility designers should be able to design classrooms capable of producing desireable and predicable student behaviors.

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