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ABSTRACT

In recent years one of the most prevalent requests directed to design architects by teachers and administrative personnel is to include in the architectural program for their new school provisions for admitting more daylight into their classrooms. This guide by the American Institute of Architects National Committee on Architecture for Education explores the dilemma of lighting standards in schools; natural lighting and energy consumption; the inclusion of daylighting in the design process; and the tools needed in the pre-design and design phases. Also discussed are various daylighting techniques and strategies and the design principles that have evolved based on the lessons learned from recent studies. Final comments explore the opportunities for upgrading an existing school's ability to conserve energy beyond designers' expectation for daylight entry. (GR)

Daylighting Update

A Brief Guide To The Process Of Designing Energy Conserving Schools Through The Use of Daylighting

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The Committee on Architecture for Education

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LOOKING AHEAD FROM A VIEW OF THE PAST

Educators throughout the country, in their quest for improving education, have spent many hours during the past several years evaluating the learning process. They have attempted to qualify important elements in teaching skills, instructional aids, curriculum, and the upgrading of student self-esteem, all in the effort toward maximizing student learning. Included in this evaluation is the attempt to define those physical characteristics of the school environment which relate to the enhancement of the learning process. Noted among other important facets of the design of this environment is the use of color, artificial light, and daylight, and the manner in which they should interface to lend harmony to the ultimate design solution. This appears to be a relatively new (or perhaps a revived) concern, indicating a greater sensitivity to the psychological value of one's physical surroundings.

In the early 1970s a trend toward the building of windowless schools developed, undoubtedly springing from the designer's desire to achieve greater control over the thermal and lighting ambience. The unfortunate result was that this trend not only denied the building's occupants the opportunity for visual extension of their environment, but also added a feeling of confinement, and to some degree dampened their inherent circadian rhythms. Yet, many architects, engineers and educators embraced this movement, although some tended to alleviate its deficiencies by accepting the "open classroom" concept which gave greater visual extension within the building (although with some possible disruption of student concentration), and by installing a few windows at critical locations, provided a modicum of exterior relationship.

In recent years, however, one of the most prevalent requests directed to design architects by teachers and administrative personnel, is to include in the architectural program for their new school the provision for admitting more daylight into their classrooms. This indicates a greater recognition of the value of natural daylight, and the need to relate more directly to the outdoors.

THE DILEMMA OF LIGHTING STANDARDS

Started in 1979, a one and one-half year research study on school lighting was undertaken by the AIA Committee on Architecture for Education, with input from the Illuminating Engineering Society (IES) and the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE). The study was concluded with a position paper on lighting quality, lighting levels, and the related problem of energy conservation in our schools. The paper, titled School Lighting Revisited, was directed to the Board of Directors of The American Institute of Architects (AIA). That Board subsequently adopted the position that the architectural profession should not take the responsibility for establishing lighting levels but should concern itself with quality of light in the structures it designs, leaving the quantitative aspects to those who study lighting as a science and who are prepared to accept any liability resulting from their recommendations. Later research papers authored by psychologists, medical doctors, and other technical people have asserted that there is not necessarily a correlation between overall lighting levels and learning achievement, which to many minds now leaves lighting level guidelines somewhere in the "twilight zone."

Lighting levels in the past have been recommended by the Illuminating Engineering

Society and by the U.S. Bureau of Standards for various categories of use, and architects and lighting designers have followed these guidelines in general. Most government agencies having jurisdiction over the design and construction field have, however, in accepting these guidelines, translated them into firm regulations leaving the architect and engineer with little leeway in interpreting them for specific needs.

An example of this inflexibility can be seen in the conflict of terms in regulations issued by various agencies. While the State (local) Department of Health may dictate a lighting level of 50 footcandles for a classroom, a state Energy Agency may restrict electrical consumption to a specific number of watts per square foot for the building. This has caused the design professions to seek other more appropriate options in providing good lighting solutions that do not stretch the boundaries of energy codes.

THE ENERGY FACTOR, TASK AND NATURAL LIGHTING

The energy crisis of the late 1970s had already influenced the involved professions to view lighting from the perspective of delivering adequate lighting for task requirements. The new IES Guidelines now recognize that overall lighting can be optimized by addressing task-oriented lighting, including the possible use of daylighting, in what may be the initial attempt to accomplish with finesse what had formerly been done by "brute force." This gives the architect and lighting designer the opportunity to enhance ambient artificial light with the introduction of natural daylight, adding the bright possibility of conserving energy in the process.

There are, to be sure, certain special areas in schools where the lighting may not be improved through daylighting. Computer rooms which require an even footcandle level of glare-free illumination is an example, but where daylighting can be utilized to augment artificial lighting or reduce its requirements, it can not only be an enhancement of the school environment but an energy saver as well.

A ROLE FOR DAYLIGHTING IN CONSERVING ENERGY

Daylighting can be introduced into interior spaces by properly designed apertures in the sidewalls and/or roofs of buildings. Glare can usually be controlled by well- designed screening devices placed to deflect direct beam light and thus soften the admitted light. Obviously, it is appropriate to incorporate proper controls on light fixtures to increase or reduce output and prevent large swings in illumination levels due to changing cloud conditions which vary the amount of daylight entering the apertures provided. Artificial lighting for night use of the building must be accommodated also.

Used creatively, daylighting can be an effective means of reducing overall energy consumption. It is a renewable resource available at all times during the daytime hours.

A recently concluded study program of the U.S. Department of Energy has shown that certain non-residential buildings, designed to be responsive to climate, used about 47 percent less energy than their conventional counterparts, a rather startling achievement. The single most important factor in their energy efficiency was that daylighting was utilized in all of these buildings and was relied upon heavily as a design strategy in over half of them. What procedures, then, should be followed by school districts to design and build climate-responsive buildings comparable to those surveyed in this study? First, the program should begin with the assembling of a creative and knowledgeable design team, a team that views the design process in a broad context. This process, by its very nature, is a problem-solving activity. It addresses such factors as user requirements, spatial relationships, utilities integration, building code requirements, and structural considerations, to name but a few. In this era of diminishing fuel supplies, energy use must be addressed if the design is to be truly successful.

DAYLIGHTING AND THE DESIGN PROCESS

Design creativity has been considered by many in the architectural profession to be an intuitive process. A renowned architect has described intuition as "informed experience." Good energy-conscious design, however, requires more than the designer's intuition; indeed, the designer's informed experience in assessing a building's energy requirements is usually inadequate when tested by proven energy analysis techniques. Thus the design team should also include a "solar designer" having the dual capability of developing both an energy program (in addition to the architectural program) and the carrying out of energy analyses of conceptual design alternatives. These required capabilities may, of course, be possessed by one of the regular members of the team, such as the architect or mechanical engineer.

The design process cannot be "quick and dirty." As indicated above, every successful building design begins with a well-defined program as part of the pre-design phase. Expect from the start that the process will take extra time and require extra effort, in that additional analyses will be required over and above the usual "intuitive" approach. The design team should set energy design goals and objectives, and plan the techniques to be used in achieving the most energy-efficient building possible. It should be kept in mind that approximately 90 percent of all energy and daylight design decisions are made in the first 10 percent of the design process.

TOOLS FOR THE PRE-DESIGN AND DESIGN PHASES

The Architectural/Engineering (A/E) team must clearly establish the nature, timing, and quantity of the building's energy requirements. For example, how does the timing of those requirements coincide with the availability of solar or other environmental resources?

One of the pre-design tools frequently used to answer the above question is the establishment of a "base case building." Analyzing a conventional non-solar building helps determine the building's energy problems, and is useful in evaluating design alternatives. This can be accomplished in several ways: by the computer modeling of a hypothetical building without solar features; the comparison of building energy performance standards (BEPS) to the building type and location; the examination of energy use records of similar buildings in the area; and the assessment of the last building developed by the same owner.

Regardless of which option is chosen, the objective is to identify the conventional building characteristics that the owner otherwise would have selected and built. The base case can then be used to quantify the magnitude and timing of energy requirements. Internal heat generators such as people, computers, and light fixtures, as well as unusual ventilation requirements as found in a natatorium or gymnasium, are some of the factors to be assessed.

In the development of the design, there are three important criteria:

1. Consider energy conscious design alternatives as early as possible in the process. (Set energy goals and objectives/techniques before starting plan concepts.)

2. Support all design decisions with thorough analyses.

3. Affirm that solar design is an architectural, mechanical, and electrical integration issue, not an alternate or add-on exercise.

The choosing of other appropriate design tools for the analysis of the project is an early decision of the design team. Design tools can be defined as "any device which assists in the formulation and/or evaluation of energy-efficient strategies for new or existing buildings." These include workbooks, nomographs, calculator routines, physical models, microcomputer software, and mainframe computer programs.

In assessing the quantity and quality of daylight, a physical model of the building is the best design tool.

Light performs in models exactly as it does in full-sized environments provided the architectural surfaces and details are accurately replicated. These details include the scale and geometry of spatial elements, window openings, texture, reflectivity, transparency, and opacity of key finishes. Color is important where reflective properties are concerned. Transmission properties of glazing can be simulated or described by numerical factors if openings in the model are left uncovered.

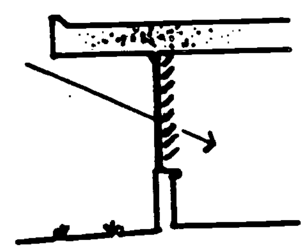
By using physical models and other appropriate tools early in the design phase, the necessary design changes can be identified while they can still be easily incorporated; discovered later, they may be much more difficult to incorporate.

As the final scheme is developed, actual light levels can be measured in the scale model and translated into seasonal performance, thus yielding auxiliary energy requirements and cost projections for lighting.

A PALETTE OF TECHNIQUES AND A VOCABULARY OF STRATEGIES

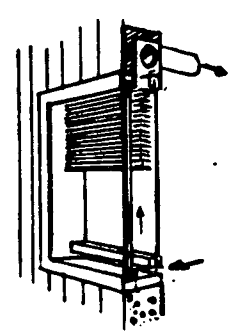
A good daylighting solution demands that the designer have access to a palette of techniques, a vocabulary of daylighting strategies whose elements can be refined and combined with other architectural elements. In that palette of techniques are the following daylighting apertures:

- Conventional windows in the vertical exterior walls: Usually fitted with glare control devices, roof overhangs, or exterior integral, or interior shades and blinds. Shades and blinds allow occupants to adjust daylight for comfort.



CONVENTIONAL WINDOWS

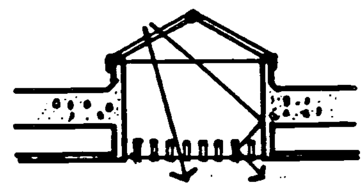
- Integral blinds within window units can help the windows become effective solar collectors, yet reflect daylight to the interior (air-curtain



AIR CURTAIN WINDOWS

windows). The occupants, however, may disregard the goal of energy conservation by pulling the interior blinds and turning on the lights, even when daylight would be adequate and comfortable.

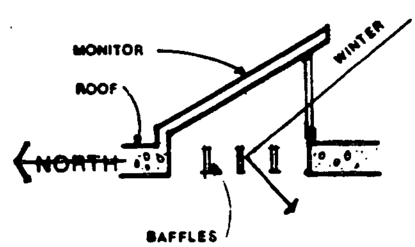
- Skylights or roof windows set parallel to the roof plane: Commonly used as a source of natural light, they admit about four times the amount of light as a vertical window with the same glazing. Skylights with adequate diffusing baffles can produce a uniform daylight level but also can contribute to excessive solar gain from high summer sun.



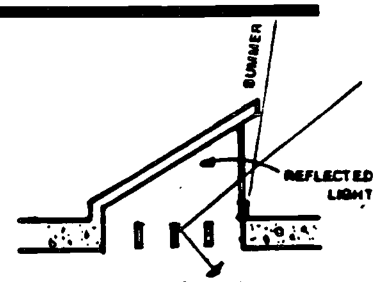
SKYLIGHTS

Using skylights properly may require a separate energy analysis to consider the degree to which its glazing protects the interior space from unwanted solar gain (shading coefficient) in relation to the amount of daylight it transmits (visible transmittance) and its thermal efficiency (U-value). This will allow evaluation of the glazing options available such as clear, reflective or tinted glass, or plastics. To be considered also are code restrictions which may require glass to be either wired or laminated, a possible hinderance in achieving the desired result.

- Roof monitors: Raised sections of a roof with vertical windows, admit light high into a space. These devices seem to benefit larger non-residential



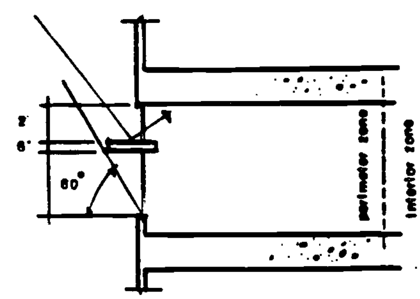
buildings, such as schools; buildings that have large roofs covering various activity areas that normally do not receive daylight.



ROOF MONITORS

- South-facing roof monitors should be designed to let in natural light to reflect off vertical baffles, spaced to maximize sun angles of the locale. Since natural light produces less heat than artificial light, the rear slope of the roof monitor is designed to protect against direct summer sun, while direct rays from the lower winter sun are allowed to enter the monitors freely. Thus, reflected light can provide controlled even illumination into the interior space.

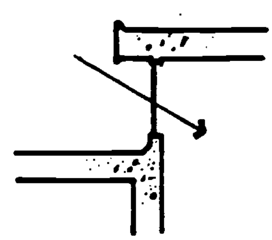
- Light shelves: Horizontal, fixed, reflective surfaces, near or within a window structure, reflect and disperse sunlight onto ceilings and walls.



LIGHT SHELVES

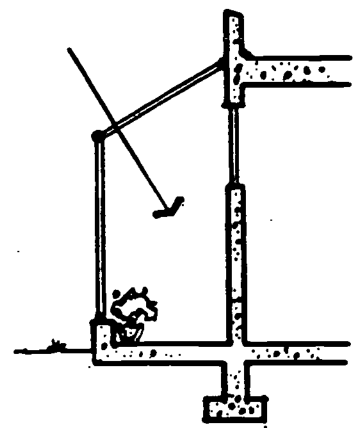
- Clerestories: Upper zones of a vertical wall or sloped roof, are pierced by glazing to admit light.

- Atria: Used as circulation spaces, can also provide natural light for adjacent interior spaces.



CLERESTORIES

- Sunspaces: Add usable space during some seasons and provide natural light all year for adjacent interior spaces.



SUNSPACES

Based on the above and on lessons from recent studies, several design principles can be qualified:

- Vertical glazing is usually superior to sloped glazing and definitely superior to horizontal glazing (skylights) in internal load-dominated buildings.

- Glazing sloped toward the sun is difficult to shade with overhangs, admitting too much direct beam light.

- Skylights admit even more heat gain from high summer sun.

- Except for dramatic light desired in special areas, diffused light is best, with diffusion provided by walls, ceilings, or special diffusing grids.

- Providing light to interior or core areas is best achieved using roof monitors with distribution devices to reduce brightness contrast.

- Roof monitors can face south where there is even a modest heating load.

- Light shelves are expensive and do not demonstrate greater energy savings than overhead daylighting systems.

OPPORTUNITIES IN EXISTING SCHOOLS

Although the range of options is limited in the use of daylighting to conserve energy in existing schools, the opportunity for conservation still remains.

Retaining the integrity of a well-designed building--while upgrading its energy efficiency--is a goal worthy of achievement. Unfortunately, the most common solution for renovating energy-wasteful school buildings is to remove the existing windows and replace them with insulated panels and small view glazing. Since the advent of Exterior Insulation Finishing Systems (EIFS), this insulated panel method has become even more popular, the result being that these buildings often appear to be boarded up. An alternative solution is to replace existing glazing with a higher quality window system, using daylight to reduce the use of artificial lighting. This alternative saves costly electricity, while maintaining the original aesthetic quality of the building. An energy analysis performed in Pennsylvania schools compared these options and shows that although the daylighting option does use more fuel, it saves more electricity than the insulated panel system, thus lowering the total energy bill.

Important guidelines established by this and other studies are:

1. Minimize the peak connected lighting demand. This can be done by designing for limited watts per square foot in both classrooms and ancillary areas, by computerized or manual switching, or by optimizing daylighting systems to keep electric lights off on both clear and overcast days.

2. Decrease lighting consumption by minimizing both the load and hours of use of electric lights. Low watts square feet help here, as

well as daylighting with effective automatic controls.

3. Minimize first cost (embodied energy) by selecting the minimum number of lighting fixtures and system components required to light the building. Careful selection and design of electric lights appears to be a way to finance better lighting control systems.

The increasing prominence of daylighting as a design solution to improve energy efficiency is a response to high electricity costs in non-residential buildings. Measured in BTUs, lighting energy may be less than energy required for heating and cooling, but the cost of delivering light is often two or three times greater than the cost of delivering heated or cooled air; and lighting in a school, for example, is a major end use.

THE DAYLIGHTING REPORT CARD

Successful daylighting solutions, both in new and rehabbed structures have a number of characteristics in common, but the most important contribution to success is proper light distribution. If daylight is well distributed, a visually comfortable and largely glare-free learning environment is achieved.

In the U.S. Department of Energy program, the most successful daylighting solutions had the following characteristics:

- Controlled glare and contrast.
- Screening of direct beam lighting from the occupied space.
- No visibility of light source.
- Admission of light high on wall or at ceiling level.
- Use of several smaller roof apertures, not just a few large openings.

- South facing of roof monitors or clerestories.

Satisfaction with lighting was consistently high. Users spontaneously mentioned delight with daylighting in the buildings using a wide variety of natural lighting solutions. Artificial lighting and daylighting were well integrated providing acceptable lighting conditions almost all the time. Fewer than 5 percent of the users complained of "too dim" or "too bright" conditions, regardless of time of year, time of day, or building location. Glare problems reported in several buildings were usually associated with perimeter rather than overhead light sources. Careful, broad distribution of indirect daylight emerged as most successful.

In most cases, lighting energy use was lower than predicted, regardless of whether lighting controls were automated or manual. Daylighting alone sometimes provided 100 percent of the illumination needs.

The electrical lighting systems were usually manually controlled by the occupants in response to their own perceptions of illumination requirements. The basic level of performance evaluation indicated that the daylighting systems were extremely effective in reducing artificial lighting requirements, surpassing even the designers' expectations.

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