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ABSTRACT

The American Institute of Architects National Committee on Architecture for Education presents this guide which addresses methods of energy conservation in school buildings with simple design, construction, and equipment-control technology so that trained and creative people can take over functions normally done by machinery and automated controls. A general discussion first covers energy consumption problem areas in educational facilities, followed by interior space utilization needs and use of manual climate control. Various ways of reducing energy load are examined, including building and classroom orientation to the sun and in differing climates, shielding barriers for the sun and wind, proper insulation and ventilation in roofs as well as interior spaces, and the type of heating system used. Other energy efficiency considerations involving food processing, boiler systems, and building operations involving load distribution and off-peak loading conclude the report. (GR)

LOW-TECH ENERGY CONSERVATION FOR SCHOOLS

by Benjamin Stein, AIA

The Committee on Architecture for Education

Enclosure to Proceedings
CAE/M32
June 15-17, 1989
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GENERAL PARAMETERS

In the course of improving the environment, we find there is still much to learn about conserving energy resources. Examples of early uses of architectural solutions such as sighting and shielding provide us with relatively primitive but very useful information. The following report addresses methods of energy conservation in school buildings with simple design, construction, and equipment-control technology. It should be understood that, as a corollary, to fully benefit from these methods, education and training may be necessary for the building management, maintenance, and operational staff to execute the conservation strategies.

Active and passive solar techniques are excluded from this paper except for generalized energy pick-up, a "low-tech" system. While simple solar techniques may be easy to install, maintain, and operate, internal climatic parameters dictated by regulatory standards for public buildings often demand more sophisticated installations than those implied by the term low-tech.

Samples of application opportunities existing in educational buildings include alteration, retrofit, facility renovation, and on-going maintenance and operations. Also, applications for new education facilities and support structures should be considered when planning construction, maintenance and operation methods.

ENERGY CONSUMPTION

In designing a school to reduce heat (energy) loss, the entire building enclosure (envelope), including the foundations, floors, walls, windows, and ceiling-roof assemblies, must be considered. Avoiding excessive heat gain through the building envelope is a consideration not only in warmer regions but in just about any climate, especially as year-round use of buildings increases.

In the mid-west and the north, energy consumed in heating and cooling fresh air for ventilation can exceed the energy necessary to offset heat loss or gain through today's more efficient building envelope. Air conditioning costs have increased as building envelopes have been tightened to offset higher energy costs.

In southern climate zones and regions where education facilities are scheduled for year-round use, air conditioning may be the major energy consumer. While the design and operation of an air conditioning system may be defined as "high-tech," the consumption of energy may be reduced by low-tech methods.

Artificial lighting may also consume a large proportion of the energy requirements of a building. Heat generated by lighting equipment can add stress to costly cooling loads. Efforts to reduce consumption in this area must remain consistent with regulatory standards, but efforts to expand methodology and reduce lighting level requirements to meet realistic user needs may be desirable.

Many other sources of energy loss may be considered in a discussion of energy consumption; for example, monitoring the use of food service hot water to eventually reduce cost.

OPERATIONAL FACTORS

Operational factors in the use of space take many forms including room population densities, occupancy scheduling (such as full-time or part-time use), and the increasing trend toward evening occupancy.

Individual comfort may vary depending on level controls of heating or cooling, humidity, ventilation, and lighting. The limits necessary to maintain comfort and preserve adequate learning environments may vary but must be consistent with regulatory standards.

One possible method of improving operational standards is to compliment the use of automatic controls with manual override capability. Manual control of environmental systems may provide reductions in energy consumption when operated by trained personnel following strict guidelines and schedules, but may not be consistent with regulatory standards. Unfortunately, relying on the human factor can be very wasteful if not properly monitored.

Another way to reduce energy consumption may be to introduce low-consumption electric and plumbing fixtures. In order to continue low energy consumption, it is important that all systems be properly maintained.

OTHER FACTORS

Careful examination of regulatory requirements with relation to operating parameters can lead to the reduction of major energy loads. In many cases regulatory requirements may be unrealistic and steps should be taken to obtain waivers or

to revise requirements to levels consistent with contemporary practices, standards, and limits.
A helpful first step for analyzing existing buildings is a thorough energy audit. Qualified experts can develop a list of energy shortcomings and give general recommendations for corrective procedures, many of which may be of little or no cost and simple to initiate.

REDUCTION OF ENERGY LOADS

ORIENTATION

Solar aspects:
The optimum site orientation of new solar building design can have a substantial impact on heating/cooling requirements and artificial lighting needs. The use of solar heat has a long history in the design of school buildings, a history often forgotten with the advances in building technology and the low cost of fuel over the last 50 years.

Classrooms facing south will pick up heat from the sun, but may experience difficulties with excess light and heat. On the contrary, northern orientation cannot take advantage of the sun as a heat source, but it can reduce the load on air-conditioning and ventilating systems in warm and tropical climates. Eastward alignment can contribute heat gain in the morning but may often mean additional heat loss in the afternoon. Western orientation perhaps has the least to offer in solar gain since schoolrooms are heated adequately by mechanical means before the sun is available. Solar gain late in the day may only add an undesirable load to the ventilation or cooling systems.

The advantages of solar orientation and large window areas are often offset in northern climates by the additional heat loss encountered during shaded or cloudy periods and night time. Energy accumulated may be saved by the use of insulation or high-R value glass and multiple glazing with a passive storage means. Correct solar orientation has much to offer but a strict balance should be maintained between solar advantages and the value of properly insulated walls.

Non-solar aspects:
The orientation of a building should be considered with other environmental aspects in mind. For example, the relationship of the building to the prevailing wind is of substantial importance. Wind can offer natural cooling and

ventilation: an advantage and energy cost savings in southern climates, yet a disadvantage in northern regions. Variations in the average direction throughout the entire year and at different times of day should be taken into consideration. Among other factors, orientation of a school building in relation to external sources of distraction, both visual and audible, may combine with solar and wind orientation to affect energy consumption.

SHIELDING

Just as orientation may affect energy demand at different times of the day, natural and man-made features may reduce energy needs by use of physical features for solar and wind screening. In northern regions, early morning sun is most desirable for solar gain, but mid-day or afternoon sun may be excessive or distracting. The location of a building in relation to nearby hills, other buildings, or man-made shields or devices can protect a building from the sun at appropriate times. Similarly, these objects may be located to shield a building from chilling winter air currents.

The proper use of planting can offer diverse opportunities for protection from the elements, other natural features, or man-made objects. Coniferous screens offer year-round protection from sun and wind while deciduous trees offer seasonal shielding. Where screening from sun during the warmer months is more important than wind shielding in the winter, the fact that deciduous trees hold their leaves can be a positive factor. Additionally trees with a high crown or open leaf pattern placed close to the building will allow the low winter sun and cool summer breezes to reach a building while still shielding it from the high sloped rays of the summer sun.

Placement of shielding barriers in relation to a building should be very carefully considered. Where cooling is of prime importance, placement of a barrier device at an appropriate distance can still offer shielding from low sun while allowing wind to swoop over and down to help in building ventilation.

The options afforded by use of planting for energy conservation are many and varied. Erosion control, reducing lawn maintenance energy use, control of snow drifting, and placement of drifts to accomplish solar reflection in designated locations are only a few of the more esoteric functions offered.

BUILDING ENVELOPE

Windows and storm windows:
The interrelationships of natural light, artificial lighting, solar orientation, heat loss/gain, and climate zones should be carefully examined before deciding on the number of windows and their location. While many windows may offer solar gain and reduce demand for artificial lighting, this advantage is often offset by direct heat loss and a need to reduce glare and control excessive heating.

Manually operated windows should be considered a "must" to preserve the opportunity for natural ventilation in schools. If, however, the building is air conditioned, the users must be made aware of the necessity to keep windows closed during air conditioning or ventilation cycles to keep mechanical systems operation at peak efficiency. In severe climates the use of wood, thermal break metal windows or storm windows should be given strong consideration.

A detailed analysis of the options and savings offered by double glazing, triple glazing, high-R value, and reflective glass border on "high-tech" solutions, yet a few general rules can offer some guidance. All these methods of glazing offer potential benefits in energy savings but a close analysis is necessary to determine a realistic payback period.

In all but the warmest climate zones, double glazing is typical. In severe climates triple glazing is often a reasonable option, but on south (and occasionally east) exposures the reduction in solar gain, due to additional reflection and refraction, will more than offset the reduction in convection heat loss. The reduced manufacturing cost of high-R value glass in recent years allows a realistic cost payback period. Window manufacturers will often provide a detailed analysis of solar energy performance of specific applications of their products.

Avoiding a complex study of sun angles and shading patterns, a well-trained architect can determine where windows may be adequately shaded by exterior louvers, latticework, or roof overhangs. This type of exterior protection may admit early morning sun while shielding late day overheating.

Interior shading by vertical or horizontal blinds can admit sufficient daylight while reducing heat gain or glare. Window quilts will help retain heat picked up by solar gain but often require additional artificial lighting.

WALLS

The simplest and most cost-effective method of controlling heat loss through a wall is by proper installation of adequate insulation. The use of blanket, foam, board, blown-in, or reflective insulation must be tailored to the climate, orientation and the construction methods and materials of the building. If future problems are to be avoided, a vapor barrier must be included. Care must be taken to properly install a vapor barrier because when a building alternates between the heating and air-conditioning cycles, the "warm side" will change from the inside to the outside of the structures.

Due to the continuing trend toward higher levels of insulation, a concern for moisture penetration and problems with vapor and air-infiltration barriers become more critical. The location of a vapor barrier in a "super-insulated" structure can be complicated and could render this type of design most difficult for public buildings due to the potential for misapplication. While the installation may not be considered high-tech, the design will call for well- engineered methods of construction. As the building envelope becomes tighter against uncontrolled air infiltration, a greater need to assure efficient means of artificial ventilation will be necessary and low-tech insulation may require a high-tech ventilation system.

Exterior finishes should be carefully selected for their absorbing, reflecting, or insulating characteristics. In cool climates dark colors can offer an energy gain and, conversely, light colors or metallic finishes can well serve to reflect unwanted heat from air-conditioned buildings. Poor insulation qualities of masonry can be at least partially offset by bricks as a "heat sink" and temperature modulator. A building owner should, however, be cautious that overlaying existing structures with insulation panels can often lead to moisture problems, decay, and the possibility of loss of insulation value if not correctly designed.

Note: A great deal of work is being done on simple modifications to existing or new masonry structures (or wood structures with masonry in-fill) to make them solar effective by turning them into heat-collecting "Trombe" walls. These options are available but require attention on the part of the users to keep environmental conditions within acceptable levels. Regulatory requirements by government agencies often make simple methods impractical for public building applications. The need for precise manual control can result in low-tech solutions being upgraded to high-tech solutions.

ROOF STRUCTURE

Insulation, vapor barriers, ventilation:
Whatever has been said about insulation in walls applies to roof structures as well, but "in spades." The cautions become even more obligatory since the potential for moisture problems in un-vented spaces is very great. As the levels of insulation increases, problems with roof membranes multiply. Snow loading, moisture penetration, temperature differential, expansion-contraction characteristics, and other factors must be carefully considered.

Attic spaces:
Shielding and ventilation is a must. So is preserving the integrity of the insulation layer, particularly when the attic is properly vented and openings in the insulation layer become funnels that drain the heat away at amazing speed. As those who live in older buildings are aware, the attic can be an effective shield for the interior of a building. The advantage of dropping temperatures between interior and exterior in several steps, as with an attic space in older buildings, is irrelevant after installation of modern insulation. Shielding the building with a double roof, a "low-tech," yet expensive method of countering problems with sun, rain, snow and ice, has long been successful both in primitive mountain and tropical structures as in the use of "flies" on tents.

VENTILATION

Regulatory requirements:
The reduction of energy requirements in the area of school ventilation offers great potential but whatever is done must be accomplished within the regulatory requirements of the jurisdictions involved.

Regulatory standards for school ventilation were re-examined in the early 1970's with the first "energy crunch," and, in many cases, were reduced to dangerously hazardous levels. The pressure on regulatory agencies to keep energy consumption down by requiring ventilation levels in buildings justified only on health and life-sustaining criteria resulted in levels inadequate for a learning environment.
The resultant poor level of performance has called for a re-examination of ventilation levels by both the regulatory agencies and the designers. Requirements for fresh air are

better understood and are now set at more realistic levels, somewhere between the excessive earlier standards and the unacceptably low requirements.

Natural ventilation:
The common method of ventilation in school buildings in years past was to open windows for air supply and exhaust by gravity "chimney like" vent shafts. While effective in moderate climates, this method wasted heat, sending much of the heated air "up the chimney." In winter months, tightly closed dampers, closed windows, or storm windows often entirely negated the ventilation.

Natural ventilation at appropriated times of the year can provide a major energy savings. Open windows, with appropriate draft deflectors, coupled with cross ventilation or gravity exhaust systems are effective. Such systems must be properly sealed during extreme weather conditions, requiring sophisticated custodial control.

The manual operation or manual over-ride of automated ventilation systems can offer substantial energy control and savings when permitted by regulatory agencies and where carefully monitored. Reducing ventilation levels for partially occupied spaces, deleting ventilation during heating cycles, cutting off ventilation in unoccupied rooms, and effectively utilizing natural ventilation and similar strategies, will provide major reductions in energy demand. As always, care must be exerted to design and maintain ventilation to acceptable levels. These approaches may involve large blocks of custodial and management time, requiring careful and thorough training of personnel.

Automatic control cycles and alternative settings:
Most of the measures mentioned above for manual control of ventilation systems can also be accomplished with careful design and use of automated control systems and timers. It will, however, require a "high-tech" control system and knowledgeable personnel as well as extensive monitoring and re-setting of timer cycles. Levels of ventilation can often be reduced without a great deal of trouble if the control manufacturer is consulted. Energy efficient designed equipment such as "face-and-bypass" ventilation units may be considered "high-tech," but the resetting of controls to alter ventilation (based on need) can be simply accomplished.

Low-tech energy reclamation:
The principles involved in air-to-air heat exchanger and similar equipment used to reclaim formerly wasted heat from air exhaust are very simple, but the equipment and installation can be quite complex. The very simple units being manufactured for residential installation have often proved unsatisfactory for institutional use. The need to keep the units frost-free, drain condensate, deliver satisfactory air flow, and reduce maintenance to a minimum has resulted in a new "high-tech" peripheral industry. Nevertheless, the growing demand for such technology will surely result in simpler and more reliable heat reclamation installations in the near future.

Other forms of energy reclamation can be simpler to install and operate. Fans used to help circulate air in large spaces can make the best use of available heat. Heat transferred from warmer areas of the building to cooler ones (i.e., moving heat from the south to the north side of a building) can save energy. Code constraints in relation to fire barriers must be taken into account and though methods may be simple, fire dampers and other necessary precautions should not be ignored.

HEATING SYSTEMS

Unit ventilators:
While unit ventilators are controlled by sophisticated methods, they are simple to control for localized heat distribution because they act independently. It should be mentioned that, with some types of units, the savings in energy may not be directly related to the decrease in room temperatures or ventilation parameters.

Central ventilation-heating systems:
This type of system is the most difficult to reduce energy consumption by low-tech methodology except in maintenance or control of cycles. A central system usually is totally dependent on sophisticated control systems.

Combined system:
Perimeter radiation can become responsive to localize demand with simple thermostatic valves or residential type local controls. Centralized ventilation systems have the same parameters as for central ventilation-heating systems.

Controls and control cycles:
In many cases control locations, cycles, and adjustments can produce reasonable reductions in energy consumption. Where

possible, controls can be responsive to occupancy cycles with timer settings to activate ventilation systems only when needed. Pre-heating schools and then dropping heat requirements after occupancy can not only reduce the cost of heating but also will lower the ventilation load requirements.

Manual override:
Human intervention can be very effective but depends on competency, system knowledge, and training of operating staff, careful monitoring, and regulatory permission.

MAINTENANCE

System maintenance:
Continued efficient system operation depends on regular periodic maintenance. Preventive maintenance on heating, air conditioning, and ventilation systems is a must. Don't wait until problems occur.

Maintenance procedures and operations:
Normal building and grounds maintenance in itself is a consumer of energy. Careful scheduling of operations and care of maintenance equipment will reduce energy consumption in ways not always evident on the balance sheet.

LIGHTING

Regulatory requirements:
When considering the control of energy use in lighting of school rooms, minimum regulatory requirements must be considered. While regulations are often based on foot-candle levels from artificial light at desk level, codes may be interpreted to allow such lighting to be maintained (if not so designed) by a combination of artificial and natural light sources. Because daylighting may replace artificial lighting demand, the switching of light fixtures to allow rows, if not individual lights, to be turned off will be most useful.

A simple procedure such as training staff when to turn off lights can provide substantial savings, not only in the consumption of energy for lighting, but also in reduced loads on ventilation and air conditioning systems. The use of area and task lighting for small occupied zones, individual instruction, and small groups could be considered where desirable as allowed under regulatory standards.

There are several areas in regulatory codes that could use re-study and may encourage energy savings. Among these are:

o Lighting levels based on combined natural and artificial lighting.
o Separate requirements for designed and maintained levels of lighting.
o Reduction of required lighting levels.
o Other methods of measurement (i.e., equivalent sphere illumination) conducive to innovative design.
o Allowance for task lighting.

In designing schools, we depended on daylighting for years, but it has limitations. As low ceilings have become common, the distance of penetration of daylight into a room has been decreased. With the trend toward more facilities being used for long hours in the winter and during the evening, it is obvious that schools must be designed to accomplish the design intent with artificial light alone. However, we should not lose sight of the place that daylight can take in the overall picture.

Care should be given to new building design so that daylight is used to its fullest advantage. Blinds can often be an advantageous substitute or adjunct to shades that will permit daylight to enter the room without the concurrent heat load. Similar gains can be made by building in exterior shading and/or reflective surfaces to introduce reflected light while cutting out the direct rays.

Room decor and lighting levels:
Light color schemes can make the most effective use of both natural and artificial lighting. While high gloss finishes may be easier for maintenance, they induce glare that can offset the advantages of proper levels of illumination. Permission to design illumination on other than a foot-candle basis encourages various methods of indirect lighting that will have a strong influence on classroom decor.

Heat transfer:
Light fixtures produce heat to the advantage of energy conservation. In large buildings, salvaging heat from lighting sources may make a contribution to warming the building but the technology for this becomes rather sophisticated. Basically, the heating advantage and cooling load generated by artificial illumination should be addressed with similar methods as those of low-tech energy reclamation discussed earlier.

OTHER LOADS

Cycling off peak loading:
Relatively little study has been done on energy demands methods of cooking, (with the exception of microwave cooking) which does not often consume much less energy than other electrical appliances. There is concern whether possible negative side effects of microwaves (either real or imagined) and the possible energy savings should have been adequately addressed. Cooking consumes large amounts of energy and further study would be most desirable.

Energy related to food processing becomes evident in heat developed in kitchen areas. Heat recovery ventilation units offer major savings but the design and installation of such units certainly falls beyond the parameters of "low-tech," as do the various approaches to dishwashing, refrigeration, and other perimeter activities. Where permissible, chemical sanitizing in dishwashing, either manual or automatic, can reduce energy consumption over high temperature water sanitizing, but the process is often labor intensive with manpower costs offsetting energy savings.

Domestic hot water:
A number of alternatives present themselves in the generation and distribution of domestic hot water that may offer generous energy savings. The technologies of boiler-supplied central hot water, central-direct fired hot water heaters, terminal units, and tempered water systems are not in themselves complex. However, to come up with the most efficient system, a detailed analysis of individual buildings (size, heating system demand, distances involved, construction and climate) may be necessary.

Boiler supplied, independent hot water heaters, and terminal units each have their advantages and disadvantages, not all related to energy consumption. Where distances are great and localized demand is small, terminal units may save energy. Terminal units are often considered an easy and convenient solution to difficult problems rather than for their possible energy savings. The old "side arm" heater may still be a viable option in severe climates where heating systems are in operation for much of the school year. Where heating units are not in demand for long periods of time, energy can be best utilized by separate, centralized domestic hot water generators. Certainly the advantages of modern insulated units should be utilized where possible.

Tempered water systems for hand washing and/or showers are not usually a consideration in evaluations of energy savings, but in that of safety. Students often use excessive amounts of heated water (offset by large amounts of cold water) when using traditional systems, and maintenance factors in thermostatic mixing valves often tender them ineffective. A continuously circulating pre-mixed tempered water system may therefore often economy along with safety.

Terminal units as a system add-on:
Where additional, localized domestic hot-water demand occurs in existing buildings, either for pre-heating or dishwashing, and the hot water supply is either non-existent or inadequate, terminal units offer the least difficult, simplest, and most economical solution to the problem of energy conservation.

OPERATION

Load distribution, occupancy phasing:
Automatic load distribution can offer substantial savings, but the technology is complicated. A simple form of natural load distribution is to phase the occupancy of a building to best utilize the space, staff, and energy potential of the structure. While this doesn't take a lot of technological expertise, it does require careful scheduling, cooperation, and skill on the part of the staff, administration, and possibly the community as a whole.

Off-peak loading:
This will not save energy. In fact, with possible storage units involved it may take more energy, but it may reduce costs by relieving energy demand on the supplying utility company. Careful scheduling of high energy consumption activities, including ventilation start-up, cooking, etc., for off-peak time periods, like load distribution, takes time, care, and knowledge.

The effects of finishes and furnishings on comfort as a means of reducing heating/cooling requirements: This is more psychological than physical. The use of warm colors, soft finishes, carpet, warm lighting, cushioning, etc., can produce a climate conducive to lower-heating requirements. Conversely, hard, cool surfaces, and gentle breezes can reduce the demand for air conditioning. Comfort is often a matter of perception, as those of use who can still remember our mothers rolling up the winter carpet and spreading the woven rush mats can well testify. Needless to say, such an approach will only be possible if regulatory requirements allow for it and staff, students, and management are receptive.

Manual control and cycles:
Operational opportunities and strategies are closely related to the design parameters suggested earlier.

SUMMARY

The opportunities for low-tech energy savings are many and varied. Basically "low-tech" allows flexible, responsive, and creative people to take over functions normally done by machinery and automated controls. The horizons are very broad, but if people are to regain direct control over our environment, they will have to develop extensive knowledge, careful training, creativity, patience, and cooperation on the part of teachers, administrators, parents and other members of the community.

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